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WC2A 2JR

United Kingdom

Apollo Tutesigensi

Association of Researchers in Construction Management (ARCOM)

7 Bell Yard,

London

WC2A 2JR

United Kingdom

Email: conference@arcom.ac.uk

ARCOM Declaration:

The papers in these proceedings were double-blind refereed by members of the scientific committee in a process that involved, detailed reading of the papers, reporting of comments to authors, modifications of papers by authors and re-evaluation of re-submitted papers to ensure quality of content.

Foreword

Welcome from the Chair - 39th Annual ARCOM Conference

Dr Apollo Tutesigensi, University of Leeds

It was a great privilege for me to edit the Proceedings of the 39th Annual ARCOM Conference. The Conference Organising Committee, Conference Secretary and I hope that our 39th Annual ARCOM Conference provides opportunity for improving and increasing knowledge and research and, altogether, contributing towards shaping construction management practice and research journeys.

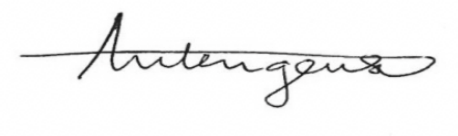
In the process of organising the 39th Annual ARCOM Conference, we received abstracts and papers from a broad range of authors from a broad range of countries reporting research conducted over the last few years on a broad range of topics. The long-standing topics of sustainability; health, safety, and wellbeing; performance; digitalisation; design and technology; and infrastructure development account for over 50% of the papers. The rest of papers are accounted for by the topics of contract management; disaster management and resilience; equality, diversity, and inclusion; human resources management; offsite construction; pedagogic research and procurement. This list shows continued variety of interest and embracing of new developments in the social and technological dimensions. May this continue to encourage us to seek to create knew knowledge wherever it may be required.

The conference theme of ‘constructing for the future’ was conceived out of continued realisation of the need to accelerate our responses to, and readiness for, global issues such as net zero, sustainable construction and 4th industrial revolution. It was aimed at signposting the need to be reflective practitioners and challenge the often ‘taken-for-granted’ ideas in our quest to contributing towards innovations required to enhance the construction industry’s contribution to addressing the global issues. Papers in these Proceedings of the 39th Annual ARCOM Conference have reflected on this theme in direct and subtle ways. Yet, this theme is not for the 39th Annual ARCOM Conference only. It is a theme on which we should continue to reflect as we read the papers, critique the papers, and build on the papers in our future research, publications, or practice.

The Proceedings of the 39th Annual ARCOM Conference came together because of the work of many people. My co-editor, Dr Chris Neilson organised, liaised, copy-edited, and sometimes nudged. Cath O’Connell dealt with all IT matters ever so promptly. The Organising Committee reviewed all the 307 abstracts received and joined the Scientific Committee to review papers at both initial and final review. The ninety-seven members of the Scientific Committee reviewed several papers at both initial and final review stage. Of course, we could not have papers or proceedings without authors. The authors were determined to go through the multi-stage review process and reflect on critical-friends’ comments, questions, and suggestions – many of which were really challenging! We are indebted to all these people, thank you, you are wonderful people!

A measure of our authors’ resilience is in the fact that from three hundred and seven abstracts, we received one hundred and eighty-four papers. Following the review process, we accepted one hundred and twenty papers: thirty-eight working, and eighty indexed, papers. In these Proceedings of the 39th Annual ARCOM Conference, you will find the eighty indexed papers in full.

I wish everyone enjoyable reading!



Dr Apollo Tutesigensi
Chair – 39th Annual ARCOM Conference

ARCOM Committee for 2022/2023

Scientific Committee 2022/2023

The success of the Annual ARCOM Conference depends on the voluntary efforts of the members of both the ARCOM Committee and our international Scientific Committee. We are indebted to the members of both commitees who together provided rigour and constructive feedback in the peer-review process.

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CONTRACT MANAGEMENT

CONSTRUCTING FOR THE FUTURE: CAN THE DUTY OF GOOD FAITH IMPROVE PAYMENT IN THE UK CONSTRUCTION INDUSTRY?

Abiola Aderibigbe[1], Nnedinma Umeokafor[2] and Tariq Umar[3]

[1] *School of Engineering and Built Environment, Liverpool John Moores, Liverpool, L69 7ZX, UK*

[2] *School of Engineering and Built Environment, University of Greenwich, London, SE10 9NN, UK*

[3] *School of Architecture and Built Environment, University of West England, Coldhabour Lane, Stoke Gifford, Bristol, BS16 1QY, UK*

Adversarialism within the UK construction industry fosters poor payment practices. Thus, stakeholders down the supply chain consistently suffer cashflow issues which can cause insolvencies. This study consisted of a critical review of literature and found that while the UK government proffered solutions to combat poor payment practices, these have had minimal impact. Hence, poor payment practices persist. It also found that lack of adequate progress in battling payment problems suggest further research is needed to determine sufficient solutions. Furthermore, it explored if creation of a (statutory) duty of good faith (via legislation) applied to construction contracts could lead to a reduction in adversarialism, thereby causing improved payment practices. This led to recommendations of empirical investigations including whether legislation has an influence on good faith towards reducing poor payment practices by wholly tackling adversarialism through implementing statutory-backed good faith legislation. This research addresses the gap in knowledge of the possible and plausible impact good faith could have on adversarialism and by extension adversarial payment practices within the UK construction industry.

Keywords: Adversarialism; contract; good-faith; insolvency; payment

INTRODUCTION

The construction industry is deplored as highly fragmented (O'Connor, 2009; Naoum *et al.,* 2010; Riazi *et al.,* 2020). Conflict and adversarialism within the industry is well-documented in literature for example see Latham, (1994), Bishop *et al.,* (2009), Arcadis (2021) and Arcadis (2022). This has resulted in the continued devastating effect on productivity, cost, performance, client satisfaction and company liquidity (Latham, 1994; Bishop *et al.,* 2009). A major feature of the adversarialism within the construction industry, is the industry's approach and practices towards payment (Constructing Excellence, 2016; Confederation of British Industry ("CBI"), 2020). Despite the UK government's recognition of the need to address and improve payment practices within the industry, (for example by introducing the Prompt Payment Code and other legislation around reporting payment practices), poor payment practices

[1] abioladeola@live.co.uk

Aderibigbe, A, Umeokafor, N and Umar, T (2023) Constructing for the Future: Can the Duty of Good Faith Improve Payment in the UK Construction Industry? *In:* Tutesigensi, A and Neilson, C J (Eds) *Proceedings of the 39th Annual ARCOM Conference,* 4-6 September 2023, University of Leeds, Leeds, UK, Association of Researchers in Construction Management, 14 -23.

continue to persist. These poor payment practices put organisations within the industry at risk as high rates of late payments have been an established cause of insolvencies (CBI, 2020). This is further worsened by the industry's approach towards risk allocation and the utilisation of adversarial 'traditional' construction contracts (Bishop *et al.,* 2009; O'Connor, 2009; CBI 2020). These adversarial contracts rigidly delineate responsibilities with much elaboration on the consequences of failure, thus reinforcing self-protective behaviour and instilling mistrust among contracting parties (Bishop *et al.,* 2009; O'Connor, 2009; National Building Specification (NBS) 2018). The current payment climate necessitates actions beyond the steps the UK government has taken to improve payment practices within the industry. Thus, in addition to critically reviewing and analysing the current payment climate, this research also aims to explore the premise that the creation of a (statutory) duty of good faith (via legislation) applied to construction contracts could lead to a reduction in adversarialism within the industry, thereby causing an improvement to payment practices. This research addresses the gap in knowledge of the possible and plausible impact a statutory duty of good faith could have on adversarialism (and adversarial payment practices) within the industry.

METHOD

The literature research methodology (Lin, 2009) was used in producing this research. This entailed reading through, analysing and sorting relevant literatures to identify the essential facts for the research. In the first instance, a bibliometric table was produced using the previously mentioned keywords as search parameters within the Web of Science platform to identify an initial 50 articles, journals and books that were relevant to the research topic. Then, a qualitative approach was utilised to extract relevant, and applicable literature from the bibliometric table to attain an accurate and clear picture of the state of adversarialism and adversarial payment practices within the construction industry. In addition to the bibliometric table, a wide body of sources produced between 1934 to 2022 were also examined. These included reports, writs and sources issued by government bodies and departments (e.g., Department for Business, Energy, and Industrial Strategy ("BEIS")), non-profit organisations (e.g., CBI), membership organisations (e.g., Constructing Excellence), UK legislation, regulations, codes (e.g., Construction Act 2011), and various academic journals cited in the literature review and outlined in the references. These gave further context to both the history and present situation of adversarialism and adversarial payment practices as well the solutions which were created to combat them. Finally, the industry's consideration of good faith was examined by the review of sources as well as relevant positions from experts practicing within the UK judicial system.

LITERATURE REVIEW

In the UK, over the last 80 years, reports have raised concerns over the construction industry's performance branding it 'under-performing' (Latham, 1993; Latham, 1994; Egan, 1998; Murray and Langford, 2003; Wolstenholme 2009;). A significant part of this is regarding payment practices as the industry has a history of delayed payment and late payment practices (Constructing Excellence, 2016; CBI, 2020). Since 2004, 19 separate payment initiatives (charters, codes, regulations etc.) have collectively failed to resolve the problem of poor payment practices (Constructing Excellence, 2016). The introduction of the Reporting on Payment Practices and Performance Regulations 2017, brought about the requirement that businesses within the industry report on how quickly they pay all invoices on average, set out their standard payment terms and provide a figure on how many invoices are paid late (CBI, 2020). In addition, the government introduced the Prompt Payment Code in 2008 and issued reforms of the voluntary code in 2021 (Foreign Commonwealth and Development Office, 2021). Despite these measures, the construction industry continues to rank poorly for payment practices.

Small businesses (which dominate the industry) bear the worst brunt. Almost half of SMEs within the sector (approximately 45%) report that late payments are a major obstacle to their success (BEIS, 2019) CBI, 2020). Considering that the average for SME late payments across all other sectors in the UK stand at 33% (CBI 2020), 45 % is high and indicative/reflective of the severity of the problem within the industry. In addition, small businesses in construction spend on average 130 hours each year, at an average cost of £1,500 per business, chasing payments, while incurring an aggregated sum of £180 million in debt interest charges (Constructing Excellence, 2016). According to the Asset Based Finance Association ("ABFA"), the construction industry is particularly adversely affected by long waits for payment; with waits for payment having increased by 22% between 2008 to 2015 from 88 days to 107 days (ABFA, 2015). The ABFA also found that construction firms were having to wait an average over 15 weeks to receive payment (ABFA, 2015; Construction Excellence 2016). These dismal payment practices lead to insolvencies (Myers Clark, 2015). According to R3 (insolvency specialists), one-in-five UK corporate insolvencies are caused by late payments (ibid) these insolvencies are heavily suffered within the construction industry as the construction sector continues to routinely suffer more insolvencies than any other sector (CBI, 2020).

To further elaborate, average margins at the industry's largest construction firms are in the red (CBI, 2020). Thus, in terms of cashflow, prompt payment could make a huge difference to an organisation. The most prominent example of this was the high-profile collapse of Carillion in January 2018, at the time Carillion was the second largest UK construction contractor by turnover (CBI, 2020). The troubling fact is that Carillion's demise was the latest in a series of high-profile construction failures over the last decade (2010s - 2020s). These failures include ROK in 2010, Mouchel in 2012, and Longcross in 2015, while Interseve was placed into pre-pack administration in 2019 despite group revenues of almost £3 billion (ibid). In addition, Brymor Construction Group, one of the biggest regional contractors operating around the south coast of England, employing around 150 staff with £80 million revenue entered administration in June 2022 (Construction Enquirer, 2022). In the 12 months to Q2 2019, the UK construction industry suffered 3,100 insolvencies (The Insolvency Service, 2019). The CBI's Construction Council attributes these failures to adversarialism within the industry (i.e., poor payment practices, poor risk allocation and prevailing industry structures and cultures) (CBI, 2020).

Possible Solutions to Poor Payment

To combat and improve poor payment practices within the construction industry the UK government did the following:

- Through the Construction Act (2011) (as amended) legislated against the notion of 'pay-when-paid' practices (Chartered Institute of Architectural Technologies, 2011)
- Established the Small Business Commissioner in 2017
- Introduced the Payment Practices and Performance Reporting requirement for large businesses in 2017.

- Strengthened the voluntary Prompt Payment Code's compliance board powers in 2018.
- Published new policy guidance for public sector procurement teams on accounting for payment performance in September 2019
- Implemented much needed reforms to the Prompt Payment Code (effective July 2021)

Although these actions by the UK government connotes that the government rightly recognises the need for payment practices to be addressed, changing the 'traditional' construction business model, where risk gets unequally transferred to contractors/sub-contractors down the supply chain would stimulate major improvements in the industry (Bishop *et al.,* 2009; O'Connor, 2009; CBI, 2020). Such a step involves taking a holistic approach towards tackling adversarialism within the industry i.e., not just focusing on adversarial behaviour towards payment.

Consequently, industry experts and academics like Latham and Egan have advocated for collaborative working as a solution to combat adversarialism (Latham, 1994; Egan 1998; Wolstenholme, 2009; Farmers, 2016). However, collaborative working has had minimal impact (Ng *et al.,* 2002) due to reasons such as lukewarm attitudes towards the practice within the industry (Ng *et al.,* 2002; Bishop *et al.,* 2009; NBS 2018). It was also proposed by experts that the use of "good-faith-like" wording within industry-standard form contracts could be a potential solution to combat adversarialism. Latham suggested (in his 1994 report) that a statement should be written into industry standard agreements (as core clause 1) that both the employer and contractor affirm to establish a reasonable agreement, and deal with each other in a spirit of mutual trust and co-operation (Latham, 1994). These types of wording are most prevalent in the New Engineering Contract ("NEC") and to an extent the Joint Contracts Tribunal ("JCT") forms. Despite their use over the last 20 years (Christie, 2019), adversarialism continues to worsen. The continuous worsening position of adversarialism suggests that, trying to insert collaborative/good-faith-like wording into standard form contracts (which are by their nature already adversarial) will not solve the issue.

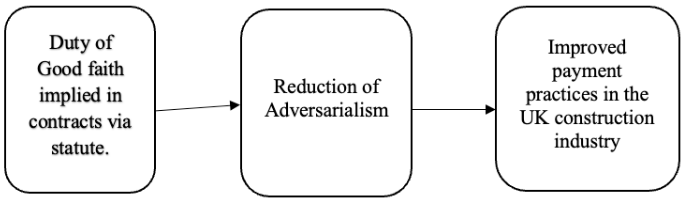
Other experts have also proposed the use of Integrated Project Delivery (IPD) to reduce adversarialism within the industry. IPD is a method of delivery which fully integrates collaborative working amongst all contracting counterparties (O'Connor, 2009; Ashcraft, 2010; Reaves, 2012). Its principles are: (i) mutual respect and trust, (ii) mutual benefit and reward, (iii) collaborative innovation and decision making, (iv) early involvement of key participants, (v) early goal definition, (vi) intensified planning, (vii) open communication, (viii) appropriate technology; and (ix) organisation and leadership (AIA California Council, 2007; Ashcraft, 2010). IPD goes beyond the implementation of good-faith-like wording (in standard construction contracts), partnering techniques and early involvement of construction managers in the design phase. Rather, it's a process that reinforces collaboration from the beginning of the design (including FEED - front end engineering design) to the end of construction and gives every party to the project a stake in the outcome of the project (Reaves, 2012).

However, the use of IPD also has barriers and limitations (Ghassemi and Becerik-Gerber, 2011; Viana *et al.,* 2020). Studies on its use revealed that IPD suffers from persistent barriers in line with cultural challenges, risk allocation, joint control, and financial transparency and that a further step beyond adopting IPD philosophy and principles is required to change behaviours and attitudes towards reducing adversarialism (Ghassemi and Becerik -Gerber, 2011, Simonsen *et al.,* 2019).

The introduction of laws and regulation (via the use of legislation) is already established as an effective way to change practices, attitudes, and behaviours (Bilz and Nadler 2014). For example, a change in law i.e., the Smoking Ban was paramount to stopping people smoking indoors (Bilz and Nadler 2014). As a result, smoking outdoors has now become a cultural norm. This effect is also demonstrable in the construction industry. For example, in the UK the introduction of the Environmental Permitting (England and Wales) Regulations 2007, (S.I. 3538 of 2007), and 2010 (S.I.675 of 2010) (replaced by the Environmental Permitting (England and Wales) Regulations 2016 (S.I. 1154 of 2016)) (collectively "the Environmental Regulations") compelled the built environment to change its attitude towards environmental awareness (Constructing Excellence, 2007; Willmott Dixon 2010).

Compliance with the Environmental Regulations brought about initiatives such as the Code of Sustainable Homes, the UK Government's zero carbon homes by 2016 target, the UK net zero by 2050 target and the UK net zero emissions law (BEIS, 2019). The Environmental Regulations further compel industry stakeholders to utilise products which comply with them (Bishop *et al.,* 2009). This use of legislation may be applied to adversarialism and extended to payment, where adherence and compliance is mandatory as opposed to voluntary (like the Prompt Payment Code). Therefore, it is proposed that the introduction of a relevant new law or regulation (via legislation) underpinned by good faith as a legal duty could potentially mitigate adversarialism causing an improvement in the industry's payment practices. The theoretical framework is summarised in Figure 1:

Figure 1: Theoretical framework of research



Good faith at its core is about mutual trust, honesty, transparency, and fair dealing between contracting parties (Mante, 2018) and it embraces the precepts and principles of collaborative working (including IPD) as shown in Table 1.

Table 1: Corresponding principles of collaborative working and good faith

Collaborative Working Principle	Corresponding Good Faith Principle
Open (& Honest) Communication	Honesty
Knowledge Sharing	Transparency
Joint problem resolution	Fair dealing

Considering that the legal concept of good faith possesses corresponding principles to the method of collaborative working (and IPD), it could be argued that the creation of a statutory legal duty of good faith may achieve the same outcome the method of collaborative working and IPD was designed to achieve, thus fostering an atmosphere of improved payment practices across the UK construction industry.

Limitations of Legislation and Good Faith

Using legislation has limits (Xanthaki, 2005). Legislation can be difficult to interpret if goal based, and there is a general user's aversion towards it (Office of the Parliamentary Counsel, 2013). Also, it does not guarantee regulatory success because it relies on the user's intent and interpreters to comply with it (Xanthaki, 2005). While the use of guideline and prescriptive legislation has proved to help address this, there are limitations such as limiting innovation (Umeokafor *et al.,* 2020). Nevertheless, the positive outcomes of the use of legislation (ibid), necessitates the exploration of the introduction of a relevant new law or regulation (via legislation) underpinned by good faith as a legal duty. This could potentially reduce adversarialism (and by extension promote good payment practices). It is poorly understood if and how this will occur. The industry's understanding of construction contract-context challenges relating to the creation of a statutory duty of good faith to reduce adversarialism is poor. The same is applicable to type of legislation (goal-based or prescriptive) which can be used.

In addition, good faith duties in contracts also have limitations. While legal scholars and practitioners in common and civil law jurisdictions have a general understanding of its meaning and application (Leggatt, 2016), its broad and nebulous nature causes difficulties in defining it, meaning its application is sometimes subjective (Santier, 2017). This is exacerbated in the UK because under English law, good faith still only has shallow roots (Leggatt, 2016), and the courts in England and Wales have a negative attitude towards it. They have taken and continue to take a traditionalist approach, reiterating in strong terms their antipathy towards good faith; consistently holding the position that an overriding notion of good faith contradicts established and fundamental principles of English law like certainty and party autonomy (Santier, 2017). Nevertheless, there is a consensus on its meaning and application (Leggatt, 2016). Moreover, in the UK, statutory law supersedes the common law, so the creation of a statutory duty of good faith would leave UK judges with no option but to apply and enforce it. Specific questions such as how and if to objectively define good faith need to be addressed in the context of making it a statutory requirement in contracts.

CONCLUSIONS

This research establishes the need for an empirical study to determine if a statutory duty of good faith will help reduce adversarialism in the construction industry, thereby improving payment practices. Despite the associated challenges (such as the broad and nebulous nature of laws and applicable legal concepts which causes difficulties in defining them), this research has demonstrated that there is potential that a statutory-backed duty of good faith could be used as a tool for reducing adversarialism in the industry which will have positive implications for payment, and the performance of the industry as a whole including its economic contributions to the country. The findings of such an empirical study will further bridge the gap in knowledge regarding adversarialism and poor payment practices in the UK construction and engineering industry.

Drawing on the points covered so far in this research, the following propositions and hypotheses need empirical investigation:

- Legislation has an influence on good faith towards reducing adversarialism.

- Goal-based rules underpinned by good faith as a legal duty are more likely to contribute to reducing adversarialism than prescriptive rules underpinned by good faith.
- Objectively defined, good faith duties in standard forms of contracts have no influence on collaboration.
- Collaboration in construction projects is likely to increase if statutory-backed good faith duties are inserted into standard contracts in construction.
- Payment in construction is likely to improve if "good faith" like and statutory-backed good faith obligations are inserted in construction contracts.
- Adversarial, hostile, and lukewarm attitudes towards payment, collaborative working is likely to change if statutory-backed good faith duties become the norm and industry standard.

The next phase is an empirical study investigating these propositions and hypotheses and using qualitative research to advance the understanding.

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FACILITATING AGREEMENT IN DISRUPTION CLAIMS THROUGH DISRUPTION ANALYSIS METHODS

Babar Ali[1], Ajibade A Aibinu and Vidal Paton-Cole

Faculty of Architecture, Building and Planning, The University of Melbourne, Melbourne, 3010, Australia

Disruption in construction projects is one of the major causes of claims. The extent of each contracting party's responsibility for disruptions in a project is a frequently asked question in such claims. Over the years, various disruption analysis methods have been developed to address this question, but the consensus among experts and contracting parties on this matter is still sparse. Such lack of agreement on a uniform disruption analysis method often results in disputes between contracting parties. An investigation of the recommended disruption analysis methods is conducted in this research by interviewing 22 disruption claims experts in Australia. Results revealed that most experts preferred using the baseline productivity method (23%) followed by the measured mile method (18%) because they promote objectivity in the assessment. Results from this study suggest that the objectivity in analysis methods along with information availability can enable agreement between contracting parties for their application in disruption claims. This study identifies the need for an established information management system to facilitate resolution of disruption claims.

Keywords: contracting; dispute resolution; information management; productivity

INTRODUCTION

Disruption claims also known as inefficiency claims or loss of productivity claims arise in construction projects because of the occurrence of triggers of disruptions. Disruption in construction projects is defined as “a disturbance, hindrance or interruption to a contractor’s normal working methods, resulting in lower efficiency” (SCL 2017). These are actions or events which prevent the contractors from proceeding with their work or some planned activities. Changes in design, rework, excessive overtime, bad weather, unforeseen site conditions, out-of-sequence work, the lack of materials or equipment, conflicts with other contractors, a delay in responding to information requests, poor coordination, and poor supervision are factors or events that can trigger disruptions (Davison and Mullen 2009; SCL 2017). Disruptions are detrimental to the performance of contractors and could lead to time overruns in construction projects (Klanac and Nelson 2004). Further, it increases the contractor’s cost of work due to changes in the contractor’s anticipated working conditions, planned resources or manner to perform work (Schwartzkopf 1995). Contractors can use disruption claims to get compensated for the loss if the catalysts

[1] babar.ali@student.unimelb.edu.au

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for disruption are outside their control, entitled in the contract and proven to be factual (Klanac and Nelson 2004).

However, disruption claims often result in disagreements leading to disputes between contracting parties (Davison and Mullen 2009). Such disputes may grow and eventually be litigated, which is a very expensive and lengthy experience for the parties involved (Cheung *et al.,* 2004). Arcadis (2022) published a report on the global disputes in construction projects including infrastructure, buildings, and roads, and estimated the average annual dispute cost to be $52.6 million with an average resolution time of 15.4 months.

One of the major problems in disruption claims' resolution leading to disputes is the lack of uniformity and consistency in the techniques for analysing and assessing disruptions in construction projects (Aibinu 2009). The contractor may quantify or substantiate its productivity and financial loss arising out of disruption events using a variety of methods, and the owner or its representative (claim's certifier) may also then evaluate the submitted claim based on one or more of the available methodologies. Using different approaches for the same disruption event will yield different results and lead to disputes as demonstrated by Kumaraswamy and Yogeswaran (2003).

Some of the key methods for analysing disruption claims include (1) measured mile method; (2) baseline productivity method; (3) earned value analysis; (4) program analysis; (5) work trade sampling; (6) system dynamic modelling; (7) project comparison studies; (8) industry studies; and (9) cost-based method. The measured mile method compares productivity in areas or periods of the works impacted by identified disruption events to productivity in areas or periods of the works not impacted by those identified disruption events (Zink 1986). Baseline productivity method is a modification to the measured mile method and is based on intermittent unimpacted periods period (Robert 2017). Earned value analysis calculates the planned man-hours for performing specific construction activities and compares it to the actual man-hours spent (Schwartzkopf 1995).

In program analysis, specialist programming software assists in determining periodic percentage completion for impacted activities (SCL 2017). In work trade sampling, contemporaneous records of direct observations (time ad output) from workers are used to determine productivity (SCL 2017). System dynamic modelling is a computer simulation strategy that creates a model of the disrupted project using specialised software (Williams *et al.,* 2017). In project comparison studies, the productivity of a disrupted project is compared to a similar project or activities on un-disrupted projects (SCL 2017). In industry studies, industrywide research is used to estimate the productivity-loss, provided such studies are relevant to the disrupted project's characteristics (SCL 2017). In cost-based method, the difference in unit cost is calculated for the impacted and unimpacted periods after deducting the non-labour costs (Robert 2017).

The results obtained from different analysis methods to determine the contractor's entitlements for the inefficient hours due to disruption events often varies. This has also been established by Robert (2017) through a case study project. These differences in the outcomes often lead to disagreements and disputes between contracting parties (Aibinu 2009). Similarly, due to the availability of multiple disruption analysis methods, disruption claims involve a high degree of "cognitive conflict" (Aibinu 2006). Cognitive conflict results when people understand data pertaining to factual concerns differently. Different perspectives on what is significant, as well as disparities in the methods and processes used to evaluate claims and disputes, can lead to cognitive conflicts (Moore 2014).

Thus, it is vital to establish an agreement on the use of a common disruption analysis method for analysing disruption claims. This could be beneficial in the following ways: (1) improving consistency in the claims' analysis and assessment, (2) ensuring that the parties share a consistent understanding and expectations of how claims will be evaluated, and (3) increasing the transparency in the evaluation and substantiation of claims to foster trust between the parties.

Research Gap and Aim

Owing to its significance, this area of disruption claims has always been of great interest to researchers. The key research in this area can be classified as improving the existing and developing new disruption analysis methods (Ibbs and Liu 2005), guidelines and recommendations for the selection of appropriate disrupting analysis methods for analysing disruption claims (Nguyen and Ibbs 2010), and utilisation of computer-based tools and technology to improve disruption analysis (Al Malah *et al.,* 2013). However, despite the volume of research work on disruption claims, limited focus has been made on improving the agreement between contracting parties on a uniform method for analysing and assessing disruption claims for construction projects. To minimise the potential for conflict, it is important to develop a consensus among contracting parties on an acceptable and effective method to be used for analysing disruption claims when they arise.

To develop a consensus and enable agreement between contracting parties on a suitable disruption analysis method, it is important to recognise the preferred methods for analysing disruption claims by the experts in this area. This information will enable contracting parties to agree and select the most viable method for analysing disruptions in construction projects. Accordingly, the aim of this study is "to explore the methods of disruption analysis that can enable agreement between contracting parties when analysing and assessing disruption claims". The specific objective of this research is to investigate the experts' recommended disruption analysis methods and determine the reasons for their preference.

Theoretical Background

One way of improving the process of disruption claims and minimising the disagreements and disputes between contracting parties is through pre-contract negotiation and agreement on the disruption analysis method. Aibinu (2009) empirically proved that the higher the extent of pre-contract negotiation and agreement between the contracting parties on the methods for analysing and quantifying the disruptions, the lower will be the chances and intensity of disputes in construction projects. The theoretical underpinnings can be found in social psychology literature (concept of control), which suggests that the participation of the parties involved in any conflict resolution process could reduce the conflict's intensity and raise the likelihood that the outcome of the decision-making process would be respected by the parties (Thibaut and Walker 1978). To achieve the early participation of contracting parties, agreements on rules for quantifying and assessing the impact of anticipated disruption should be widely promoted (Aibinu 2006).

The agreement on the adoption of a uniform disruption claims analysis (by contractor) and assessment (by owner) method can have both instrumental (quality of decision-making) and non-instrumental (social-psychological) effects. Through improvement in quality of decision-making, it could help to diffuse conflicts (Aibinu 2009). Similarly, Thibaut and Walker (1978) proposed that allowing control to the dispute participants for influencing the outcome of dispute will make them believe in the fairness of the process and will increase the chances of outcome acceptance (non-instrumental effect).

METHOD

This research is phenomenological and has adopted a qualitative method for its data collection. Phenomenological research is used to describe the real experience of participants (Creswell and Clark 2017), which owing to the complexities around disruption claims is vital to consider. To ensure that the data generated depicts the first-hand experience of participants with disruption claims, descriptive phenomenological approach is applied. Descriptive phenomenology helps to investigate, analyse, and describe a phenomenon while keeping its richness, breadth, and depth in order to obtain "a near-real picture" of it (Speziale *et al.,* 2011). Similarly, the qualitative method fosters a deeper understanding of participants' perspectives (Tashakkori and Teddlie 1998) and is found to be more suitable for achieving the goals of this research. Data collection was done through interviews, which can aid to reduce non-responses and collection of quality data (Lavrakas 2008). The interview format was set as semi-structured because it allows asking a set of questions based on certain themes and probing when necessary.

Data Collection

To address the objectives of this research, 22 disruption claims experts in Australia were interviewed. A purposive sampling technique was used to select participants for this research requiring experts who have experience working on different stages of disruption claims for construction projects. For sample selection, experts were shortlisted and contacted from the major contractor and owner companies, independent 3rd party companies offering disruption claims' analysis, and dispute resolution services. 22 interviews were conducted in this research, which according to Creswell (1998) also aligns with the recommended sample size for qualitative interviews in phenomenological research i.e., at least 6 or between 5 to 25.

Figure 1 shows the experience and roles of experts recruited as research participants for this study. Most interviewees had the experience of working in multiple roles while handling disruption claims on construction projects including commercial managers, contract managers, project managers, contract administrators, delay analysts, project planners, construction lawyers, adjudicators, expert witnesses, arbitrators and mediators. Selected participants had decades of experience working in the construction industry with 55 % of participants having more than 20 years and 36 % of participants having between 10-20 years of construction experience.

Similarly, the interviewed participants were experts in different stages of disruption claims and have dealt with several disruption claims in their professional careers. The experience of the interview participants across disruption claims including preparation and submission, assessment, and resolution (negotiation, adjudication, arbitration, mediation, litigation, dispute avoidance board, and expert determination) is shown in Figure 1.

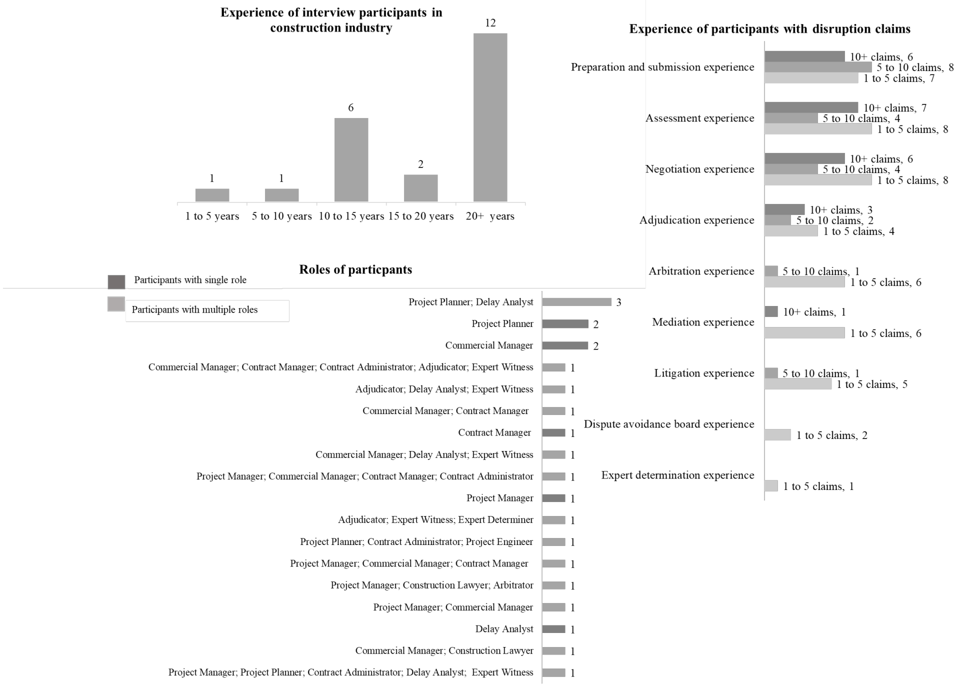

Figure 1: Demographics of interview participants

Interview Themes

Apart from asking about the professional experience of participants and their involvement with disruption claims, the following were the key themes of interviews during data collection.

Identification of Recommended Disruption Analysis Methods
This theme helped to identify the disruption analysis methods recommended by experts for analysing disruption claims. For this theme, a list of disruption analysis methods identified from literature was presented to the experts and were asked to select the method/methods they prefer to use for analysing disruption claims.

Reason of Preference for a Disruption Analysis Method
This theme helped to understand the reason for the preference for the selection of certain disruption analysis methods by the experts. As part of the interview, experts were asked to provide the reason for their selection and preference of a particular disruption analysis method/methods and how it can help in improving the process of disruption claims.

Data Analysis

Content analysis was the data analysis technique employed in this study, which can help to detect the frequency of words while analysing qualitative data and is one of the effective means of analysing qualitative research data. It (Mayring 2004). It was used to perform the frequency analysis of the recommended analysis methods for disruption claims. Besides content analysis, a thematic analysis of the interview transcripts was also conducted. Thematic analysis is defined as "a strategy for detecting, analysing, and reporting patterns (themes) within data" (Braun and Clarke, 2006). It helped to organise and separate data from textual and qualitative data sets into helpful themes of reasons of preference. The analysis was done in a computer-based software, NVivo 12. Figure 2 displays the word cloud for top 50 words from the interview transcripts generated in NVivo 12 during data analysis. Some of the notable words identified during the interview transcripts included baseline, productivity, measured, mile, method, program, objectivity, information etc.

Figure 2: Word Cloud of Interview Transcripts

FINDINGS

Figure 3 shows the recommended methods for analysing disruption claims. Mixed responses were identified from the collected data.

Single Method Approach

Majority of experts (68%) prefer using a single method. Out of 68%, most experts (23%) have selected the "baseline productivity" method as their go-to method. According to experts, it is the most objective method among other methods as it tries to analyse the disruption events by reference to the most relevant comparative data. It shows the causes and impacts of disruption events, which is key for any disruption claims. Also, most experts were of the view that it allows presenting the claim in a way to owners or their representatives that is simple to understand.

Similarly, the measured mile method was also reported as best disruption analysis method by 18% of experts. Experts opined that it could help in logical reasoning and analysis of causes and impacts.

The next preferred method by experts is program analysis (18%). For program analysis, experts believed that it is easier to show the impacts through program analysis. Experts said it is viable to use program analysis for demonstrating the impact on resources as it helps to load the program with the resources to show the impact on resources.

Then, there were 14% of experts, who have selected earned value analysis as their preferred method for disruption analysis. Regarding earned value analysis experts responded that it could help you to track the impacts on completion time and cost. Moreover, earned value can measure the schedule variance and the cost variance to complete your project.

Hybrid Approach

Similarly, some experts (18%) chose to use a hybrid approach or combination of methods for disruption analysis because it can help to fully apprehend the disruption causes and its impacts on the project. These recommended combinations according to experts include program analysis and cost-based methods (9%), measured mile method and program analysis (5%), and measured mile method and direct evidence (5%). For program analysis and cost-based methods, experts said program analysis helps to quantify the time loss, whereas cost-based methods can help to track the impact on the project budget. Experts believed program analysis can provide the strongest basis for a disruption claim as it determines how much time is lost and what impacts it has on the project's milestones. Later, the cost-based method would then help in calculating cost impact of the disruption events. Similarly, by combining the measured mile method with program analysis, it is easy to establish the cause-and-effect valuation through the measured mile method and show the difference between the plan and actual achievements through program analysis. One of the experts also talked about using the measured mile approach with direct evidence because sometimes the measured mile method does not track the additional cost on its own and direct evidence is required to quantify the additional incurred cost.

Inexplicit Approach

The remaining experts (14%) did not specify a particular method as their preferred method and said that it depends upon the information availability and how they can achieve the most suitable financial outcomes. According to these experts, to be able to negotiate a reasonable settlement, it is important to consider the information available and different ways to get the greatest outcome in terms of financial impact. Therefore, the selection of an appropriate method for analysis and getting the anticipated outcome is dependent on the quality of available information.

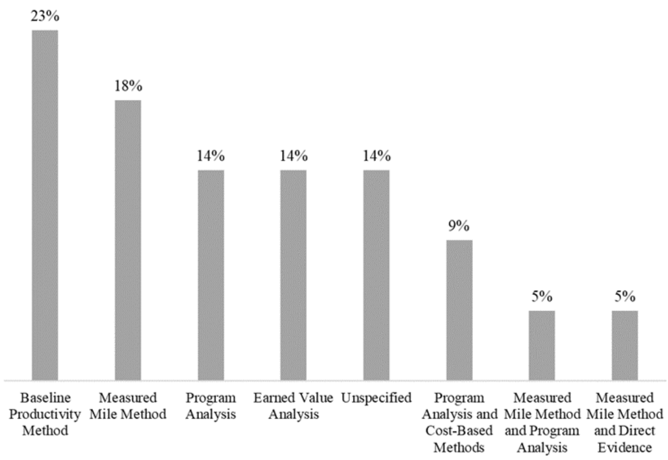

Figure 3: Recommended methods for disruption analysis

DISCUSSION

Objectivity

From the analysis of the interviews, it can be perceived that during disruption claims "objectivity" is a key factor parties consider and can help increase agreement by parties on a uniform disruption analysis method. The reason behind most experts being in favour of the baseline productivity method can be traced back to its objective nature. It relies on a comparison of actual work done (what the contractor was able to achieve) during the unimpacted period with the work performed during the impacted period (Robert 2017). It represents the best and most consistent productivity that the contractor was able to maintain on the project. Further, it is a cause-and-effect analysis method, therefore, to perform baseline productivity analysis, relevant contemporaneous information on the disruption events is essential. The relevant contemporaneous information acts as evidence to substantiate the disruption claim objectively rather than relying on verbal witnesses, which can be subjective at times due to a strong underlying conflict of interest between contracting parties (Aibinu 2009).

Similarly, the second highest recommended method by experts i.e. measured mile method is also similar to the baseline productivity method, but it uses a continuous baseline of unimpacted productivity period as compared to the baseline productivity method, which uses several periods of unimpacted productivity period. This also involves cause and effect analysis that requires contemporaneous evidence and promotes objectivity in the analysis of disruption claims.

Disruption claims if analysed with such analysis methods can promote objectivity or neutrality in the quality of decision-making for the entitlement and compensation for the losses incurred by the contractor due to the occurrence of disruption events in projects. Thus, the higher the objectivity of a disruption analysis method, the higher is its preference of use to decide on the outcome of a disruption claim. In other words, the more objective an analysis and assessment method is, the easier it to agree contracting parties on its use for disruption claims.

Information Availability

To perform the suggested objective disruption analysis methods, the availability of relevant information is vital. The contractor must be able to substantiate its claim through the best possible information to prove the cause and effect of events, actions or inactions of the owner or other parties (Ali *et al.,* 2023). Many claims have been unsuccessful due to poor documentation, inadequate supporting evidence, and lack of accurate records (Aibinu 2009). The reason for not specifying a particular disruption analysis method by certain experts is also related to the availability and quality of information. Hence, it is important to improve the process of information management of disruption claims for the application of the most effective disruption analysis method.

Similarly, in addition to the agreement between contracting parties on the disruption analysis method, agreement on the information sources is also very important to promote objectivity and avoid disputes (Aibinu 2009). The information used by contracting parties during disruption claims may contain uncertainties and inaccuracies that are in favour of presenting party, which results in doubts and disagreements on the presented information. Consequently, contracting parties usually do not agree on each other's information and the outcome of these claims, which then leads to disputes between them.

In addition, the agreement on the disruption analysis method and on information use can have a social psychological impact on contracting parties as it will promote fairness in the process of disruption claims and disputes settlement. This concept was put forward by Thibaut and Walker (1978) for disputes who suggested that the procedure which is most likely to promote fairness among the disputants and help in resolving conflicts is the one that gives them control over the process. In terms of disruption claims, control over the process will mean providing control to the contracting parties to agree on the disruption analysis method and information sources.

CONCLUSIONS

One way of minimising the intensity of disputes between contracting parties is the agreement between contracting parties on the methodology for analysing disruption claims (Aibinu 2009). However, there are various disruption analysis methods currently available for selection and each of them provides a different outcome. These differences in the outcome of an analysis method are also one of the causes of disputes between contracting parties. Hence, the question remains which disruption analysis method provides better results and is predominantly recommended by experts in this area? The answer to this question can enable contracting parties to select and agree on a uniform method for analysing and assessing disruption claims. To do so, this study attempts to explore the most preferred method for analysing disruption claims. For this purpose, 22 experts with a wide range of experience in disruption claims were interviewed. According to most experts, the objectivity of an analysis method is key to agree contracting parties on the outcome of an analysis method and the decision of a disruption claim. Therefore, the top 2 methods for analysing disruption claims are the baseline productivity method and the measured mile method, which are recommended by 23% and 18% of experts. These methods provide an objective outcome by looking into the most relevant contemporaneous records to show the cause and effects of disruption events on construction projects.

For effective implementation of the suggested disruption analysis methods (baseline productivity and measured mile), it is important to manage the relevant information required for disruption claims. However, there are various challenges and difficulties associated with the current practices of information management for disruption claims (Ali *et al.,* 2022; Ali *et al.,* 2023). To improve the process of information management and availability of contemporaneous records for implementation of suggested objective disruption analysis methods, the traditional manner of information management should be replaced with the wide application of modern available technologies. For instance, drones, laser scanners, cameras, Radio-Frequency Identifiers (RFIDs), and Building Information Modeling (BIM) can be used to collect information efficiently without any loss. Similarly, Big Data Analytics and Machine Learning can improve the storage, access, and usage of information required for disruption claims for effective and objective analysis.

This study was performed in Australia. However, because disruption claims and disputes are a global issue, the results of the study can also be used for international comparison.

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WHAT HAVE NEC CONTRACTS DONE TO PUBLIC INFRASTRUCTURE PROJECTS IN PERU?

Benjamin Antonio Gutierrez Espinoza[1]

University of Leeds, Woodhouse Lane, Leeds, West Yorkshire, LS2 9JT, UK

Kroll, The Shard 32 London, Bridge Street London, SE1 9SG, UK

The developers of NEC contracts state that these contracts and their benefits are applicable for projects in any country. This has been widely investigated in New Zealand and Hong Kong. This paper aims to determine which international benefits of NEC have been experienced in public infrastructure projects from Peru, which is an interesting case considering that it is a Spanish speaking, first South American country that uses NEC and developing country with several local issues in its construction industry. An online survey with a Likert scale was created based on literature review before data was collected with the voluntary participation of 46 practitioners of NEC contracts in Peru. Finally, the benefits experienced was determined by a statistical analysis (one sided t-test) that considers different test values. Results show that, depending on the test value chosen, the number of benefits experienced in Peru can vary from 5 to 21. This research would help decision makers in Peru to take advantage of the identified benefits to improve the procurement of public projects.

Keywords: contract management; public projects; NEC contracts; infrastructure

INTRODUCTION

The construction industry represents a significative proportion of the economic activity, and it is widespread the concerns of its underperformance (Wright and Fergusson 2008), which can be caused by ineffective contracts (Chan *et al.,* 2010). The developers (Barnes 2002; NEC 2023) and several researchers and practitioners of NEC (Wright and Fergusson 2008; Dickson 2013; Lord 2008) emphasis its multiple benefits to the performance of projects since 1993. In addition, the White Paper History of NEC (2023) states that its unique characteristics give a complete procurement solution for projects in any country.

Nevertheless, the international implementation of NEC contracts has certain challenges when it comes to the need of training (Li *et al.,* 2016), the increased level of management activity (Fox 2006), and the fact that a contract should aim to be readily intelligible for its users (Herga 1995). These challenges might influence the benefits given by NEC contracts when they are used outside the UK. Therefore, several researchers have studied the applicability of the benefits of NEC in areas such

[1] benjaminguess17@gmail.com

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as Hong Kong (Dickson 2013; Li *et al.,* 2016) and New Zealand (Wright and Fergusson 2008).

To contribute to the knowledge of this topic, the objective of this paper is to determine whether the perceived benefits of NEC contracts in these contexts are applicable to the Peruvian public construction industry. Peru stands out as a unique case of study given its position as a developing country, where English is not an official language and experience with standardized forms of contracts is almost invisible. Meanwhile, Peru has several local problems (extreme distrust, among others) in its construction industry (Flint *et al.,* 2021). In addition, Peru is the first country in South America in using NEC contracts (NEC 2022).

This current study would have important implications for how to better implement NEC globally in the future. Particularly, through the lens of Peru, it would contribute to the understanding of the benefits of NEC contracts experienced in a different country with unique regional features.

LITERATURE REVIEW

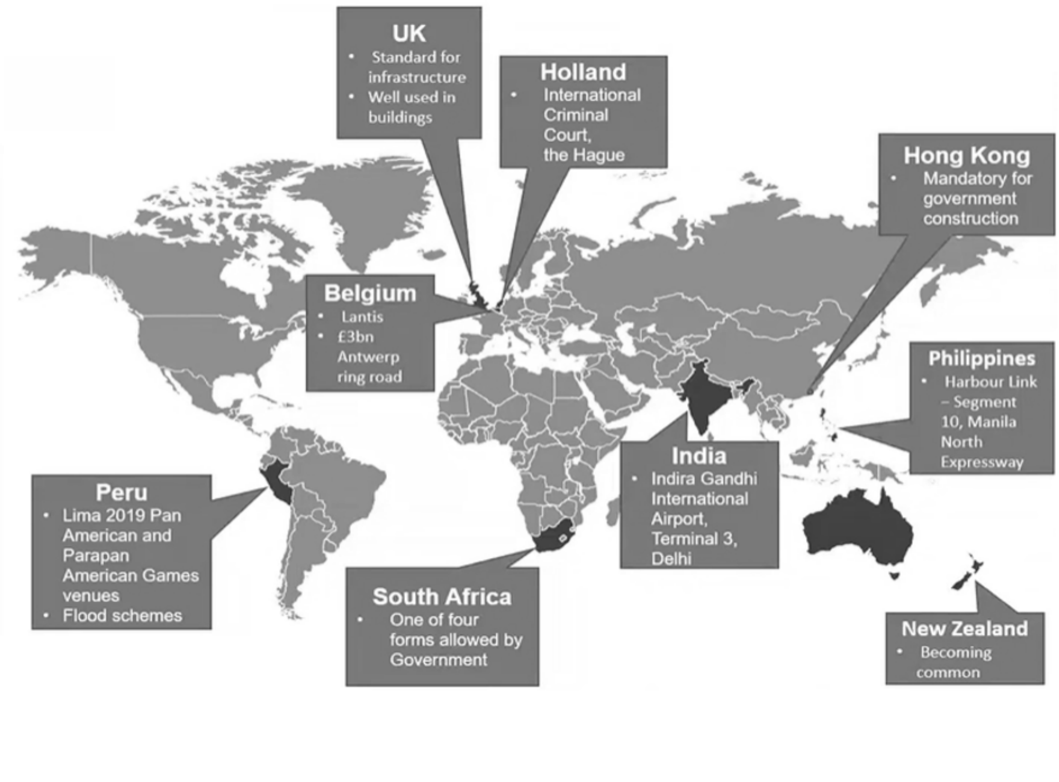
NEC Contracts and their International Application

In 1985, under the auspice of the Institution of Civil Engineers in the UK, the standardized form of contract NEC now known to the world started to be developed and its first version was issued in 1993 (Wright and Fergusson 2008). Since its beginning, NEC has been created for the purpose of bring new benefits to the construction industry including clarity and simplicity, flexibility of use and stimulus of good management (Barnes 2002).

International Application of NEC Contracts

According to the website of NEC (2022), at least 67 projects were done in 12 countries outside the UK. The most representative cases can be seen in Figure 1

Figure 1: Application of NEC contracts across the world (NEC, 2022)



In areas such as Hong Kong and New Zealand, the use of NEC is widespread. In fact, there was already research done on exploring the benefits of NEC from more than 8 years ago (Dickson, 2013; Wright and Fergusson, 2008). In contrast, from Figure 1, it is seen that Peru is the only country from Latin America as well as the only Spanish-speaking country where NEC contracts have been used. This application is relatively recent (it started from 2017) and has been only applied for specific projects by 3 public institutions.

Public Infrastructure Procurement in Peru

The traditional Peruvian public procurement system has experienced several problems for long, including extreme distrust, stalled projects and lack of expertise and technical knowledge (Flint *et al.,* 2021).. To address the infrastructure gap, apart from the traditional approach[2], the government has been implementing different investment mechanisms in the form of Government-to-Government (G2G) agreements (Rivera 2020). One of the fundamental causes for these issues are the characteristics of the Peruvian procurement laws. Regarding this, the Institute of Infrastructure Institutionality and Management (2020) indicates that the Peruvian procurement laws are an obstacle to a smooth flow of construction projects because they are complicated regulations with a high level of bureaucratic formalities. To alleviate these issues, these procurement laws are in constantly change (IIG 2020) with amends over all the last years from 2017 to 2021 (OSCE 2022). In addition, some Government-to-Government agreements have been signed to allow to use other type of contracts, as NEC contracts, for specific projects (Fraguela Handal *et al.,* 2021).

NEC contracts in Peru

Since 2017, a new approach has been taken for the mentioned issues of the Peruvian construction industry for specific projects such as the Lima Pan American Games; this approach consisted of signing G2G agreements to be exempt from the use of the Law No 30225, State Procurement Law (Peru), and therefore the Peruvian public procurement system (IIG, 2020). By this approach, G2G agreements were signed where international procurement laws were used, and new contracting tools were proposed (from the government international partner) as international standardized contract forms such as NEC ECC contracts (NEC Engineering and Construction Contract).

Later in 2020, the second G2G agreement that implemented NEC contracts was signed, it has the goal of assisting the delivery of the Program for Reconstruction with Changes (Fraguela Handal *et al.,* 2021).Finally in 2021, the third G2G agreement that implemented NEC contracts was signed, with a portfolio of projects would be built in 9 regions of the country as well as the Capital of Peru (PEIP-Bicentennial Schools 2022). It is worth mentioning that this portfolio of projects has its execution phase planned for this year and therefore it is not included in this research.

Contribution of this Research

The NEC ECC contracts are being used as a mechanism by the Peruvian government to improve the delivery of relevant projects, where special constraints were held. These projects are the ones held by Pan American Games from 2017 to 2019 and those from the Authority for Reconstruction with Changes (ARCC) from 2020 until

[2] Law No 30225, State Procurement Law (Peru) states that every public construction project in Peru must use the Peruvian public formats of contract.

now (Fraguela Handal *et al.,* 2021). As the applications of NEC in Peru are relatively new, previous research done has been mostly focused on the projects from the Pan American Lima 2019. The principal research is from Cuellar Rodriguez (2021), in which only 8 benefits of NEC in these projects were tested and later presented using descriptive analysis. The major limitations of this research are the number of benefits tested, the descriptive analysis used and the fact that it is based in the use of NEC contracts in mega projects such as those from the Pan American Games Lima 2019.

Therefore, this research tested 21 international benefits (from an extensive literature review) using statistical analysis. In addition, this research takes into consideration the NEC contracts used in the projects from the Program for Reconstruction with Changes from the ARCC. A relevant characteristic of analysing this kind of projects is that this public institution has done several similar projects with the traditional Peruvian contracting system that gives the project managers and public managers, the knowledge of how project management improves by using NEC contracts in comparison with the traditional Peruvian form of contracting.

METHOD

Overview

There are two stages of data collection in this project. First, existing literature was reviewed regarding research that has conducted to determine the claimed benefits of NEC in different areas globally, such as United Kingdom (Lord *et al.,* 2010), Hong Kong (Dickson 2013) and NZ (Wright and Fergusson 2008) (see more in Findings).

In the second stage, an online survey with three parts was used: General data, NEC closed-ended questions and NEC open-ended questions. For this paper, the first and second part of the survey was used. The NEC closed-ended questions with a 1-5 Likert scale[3] have the objective to determine which of the international benefits of the use of NEC in Peru was experienced in comparison to the traditional public contracting system. The survey participants would be practitioners who participated by managing and controlling NEC contracts in Peruvian public projects. Then, these data were analysed statistically using one sample t-test in SPSS to determine from the data collected which of the international benefits of NEC were experienced in Peru.

Design of the questionnaire

The content of the questionnaire was adapted from Dickson (2013) from the University of Bath and Cuellar Rodriguez (2021) from the Pontifical Catholic University of Peru, which are related to benefits of NEC contracts. Adopting questions from other studies allow reliability and it is more efficient than developing new questions (Saunders *et al.,* 2017).

Sampling

For non-probabilistic sampling, the sample size is ambiguous and dependent on the research objectives (Saunders *et al.,* 2019). Therefore, it was acknowledged that in research with similar topics, researchers used 30 valid responses (Dickson 2013) and 26 valid responses (Cuellar Rodriguez 2021). In addition, it was taken into

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[3] The scale was determined from 1 (Strongly Disagree) to 5 (Strongly Agree) and the format of the questions was "In comparison to traditional contracts of the Peruvian public procurement system, NEC [benefit: encourages more collaboration between parties]" taking the first international benefit tested from the Table 1 as an example.

consideration that some researchers suggest a sample size more than 30 (Saunders *et al.,* 2019) or 32 (Fellows and Liu 2015). The expected sample size was 32 participants.

Data analysis

The statistical analysis would be done for each potential benefit using one sample t-test in SPSS, and then it would be shown the average score of each of them and determine which of them are benefits of NEC in Peru if they have an average score more than a range of values from 2.50 to 3.50 (including 3.50, 3.25, 3.00 and 2.50). This approach was taken with the objective that the audience would acknowledge which are benefits of NEC depending on the test value of their preference. In addition, the researcher recommends using a test value of 3.25[4].

As an example, with the recommendation of the researcher the mean would be compared with 3.25, therefore H0 for each benefit would be:

H0x: Mean benefit x $\leq$ 3.25

Hax: Mean benefit x > 3.25

However, as it was mentioned the results were given taking into consideration using a range for test values as it was mentioned before.

Regarding the use of t-test without considering the normality of the answers, this approach was taken into consideration as even if the distributions were not normal, applying t-test has the same power for hypothesis testing as Kolmogorov-Smirnov and Shapiro-Wilk rules (Meek *et al.,* 2007).

FINDINGS

International benefits of NEC contracts

From literature review, the following international benefits of NEC contracts was collected (Table 1).

These benefits were tested as fundamental part of the online questionnaire.

General data of responses

The survey received 46 valid responses with the content given by all participants in advance.

The results further captured opinions from different kinds of professionals giving a fair representation of the roles that participated in managing and controlling construction contracts including project managers, coordinators, contract managers and others. Their average work experience in managing or controlling projects in Peru was circa 9 years with traditional Peruvian contracts and 2 years with NEC contracts.

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[4] This number was used as taking into account two approaches of determining when a contract would be better than other if the scale was determined from 1 (Strongly Disagree) to 5 (Strongly Agree). The first approach was to take the limit as 3 as this number represent the answer “neither agree to disagree”, therefore it seems that if the value is more than 3 then that contract is better. However, there was another approach to consider the limit as 3.5 as considering that the range of “neither agree to disagree” could be considered from 2.5 to 3.5. In conclusion, there are several discussions if Likert-type scales could be analyzed as ordinal values or interval data elements (Stratton, 2018), therefore the researcher proposes to take the mean of these both approaches, establishing the limit value as 3.25.

List of benefits of NEC in Peru

With the results of comparing the mean of the data collected with range of values as 3.50, 3.25, 3.00 and 2.50, the following experienced benefits of NEC were determined for each case as summarized in the Table 2.

Table 1: International benefits of NEC from literature review

N	Benefit	Source
1	Encourages collaboration between the contractor and employer and promotes an environment of goodwill and fair dealing between parties	(Lord *et al.*, 2010) (Barnes 2002) (Wright and Fergusson 2008) (Lord 2008)
2	Clear allocation of risk to the contract parties with flexibility of which party can manage it	(Wright and Fergusson 2008)
3	Clear definition of contract roles and allocation of responsibility	(Dickson 2013)
4	Ease of understanding, simple English language	(Lord *et al.*, 2010) (Barnes 2002) (Lord 2008)
5	Speedy dispute resolution	(Wright and Fergusson 2008)
6	Clear and flexible payment operating mechanisms	(Dickson 2013)
7	Incentives for remarkable performance	(Lord *et al.*, 2010) (Wright and Fergusson 2008) (Lord 2008)
8	Reduced number of conflicts or disputes	(Wright and Fergusson 2008)
9	Efficient ability to deal with unexpected events	(Lord *et al.*, 2010) (Lord 2008)
10	Range of procurement options	(Wright and Fergusson 2008)
11	Employer, via PM, with a strong position to control the project	(Dickson 2013)
12	Possibility to include key dates	(Lord *et al.*, 2010) (Lord 2008)
13	Effective time management	(Lord *et al.*, 2010)
14	After completion it can be finalised faster than other contract forms	(Wright and Fergusson 2008)
15	Faster closing phase after completion of the project	(Lord *et al.*, 2010) (Lord 2008)
16	Focus on management rather than the obligations and liabilities of the parties	(Fox 2006) (Barnes 2002)
17	Well defined contract procedures	(Wright and Fergusson 2008)
18	Effective cost control	(Dickson 2013)
19	Encourages a safe working environment	(Shaw 2002) (Lord 2008)
20	Encourages comprehensive works information	(Dickson 2013)
21	Effective management of environmental issues	(Fox 2006)

CONCLUSIONS

This study has investigated the benefits brought to Peruvian construction industry by NEC ECC contracts, it was found that there are 5 to 21 benefits were experienced, depending on the test value chosen in the range of 3.50 or 2.50.

Benefits of NEC Experienced in Peru

The researcher recommends a test value of 3.25 as mentioned in the Methodology. Therefore, this research has identified 17 benefits of NEC experienced in Peru and has indicated that 4 international benefits were not experienced. These are shown in Table 2. From the results, this research makes a contribution by identifying the experienced benefits from the second application of NEC in Peru, which were not determined before.

Table 2: List of Benefits of NEC contracts applicable in Peru

N	Question	Benefit	Test value 2.50	3.00	3.25	3.50
1	Q8.1	NEC encourages more collaboration between the parties.	✓	✓	✓	✓
2	Q8.2	NEC has a clearer allocation of risk with more flexibility of which party can manage it.	✓	✓	✓	✓
3	Q8.3	NEC has a clearer definition of contract roles and allocation of responsibility.	✓	✓	✓	✓
4	Q8.4	NEC is easier to understand because it is simple English language.	✓	✓	✕	✕
5	Q8.5	NEC promotes faster dispute resolution.	✓	✓	✓	✕
6	Q8.6	NEC has clearer and more flexible payment mechanisms.	✓	✓	✓	✕
7	Q8.7	NEC has more incentives for remarkable performance.	✓	✓	✓	✕
8	Q8.8	NEC promotes a reduction of number of conflicts and disputes.	✓	✓	✕	✕
9	Q8.9	NEC is more efficient to deal with unexpected events.	✓	✓	✓	✕
10	Q8.10	NEC has a wider range of procurement options.	✓	✓	✓	✓
11	Q8.11	NEC gives the employer (via the project manager) a stronger position to control the project.	✓	✓	✓	✕
12	Q8.12	NEC has the possibility to include key dates.	✓	✓	✓	✓
13	Q8.13	NEC enables more effective time management.	✓	✓	✓	✕
14	Q8.14	NEC has a faster closing phase after completion of the project.	✓	✓	✕	✕
15	Q8.15	NEC is more focused on management rather than the obligations and liabilities of the parties.	✓	✓	✓	✕
16	Q8.16	NEC has better defined contract procedures.	✓	✓	✓	✕
17	Q8.17	NEC enables more effective cost control.	✓	✕	✕	✕
18	Q8.18	NEC enables a safer working environment.	✓	✓	✓	✕
19	Q8.19	NEC encourages more comprehensive works information.	✓	✓	✓	✕
20	Q8.20	NEC enables more effective management of environmental issues.	✓	✓	✓	✕
21	Q8.21	NEC enables more effective quality control.	✓	✓	✓	✕
		Number of benefits for each case	21	20	17	5

Comments related to the international benefits not experienced in Peru

One of the main characteristics of NEC and cited international benefits of its application is the use of more plain English language. However, according to the results of the current study, this international benefit was not experienced in Peru (using a test value of 3.25 or higher). This might be related to the fact that English is not an official language in Peru, in contrast to the international application of NEC in other areas as New Zealand, Hong Kong and Australia.

In terms of the benefit of reducing conflicts and disputes that NEC offers, the results shows that this benefit was not experienced in Peru. This might be related to the extreme distrust between different parties within the Peruvian construction industry (mentioned in the Literature review). Regarding the length of the closing phase of a project and effective cost control, this research determines that practitioners in Peru did not experience a comparative advantage by using NEC contracts. This might be related that the application of NEC is relatively new in Peru (circa 5 years).

Implications of the Research

As a principal implication, this research would help decision makers and practitioners in Peru to acknowledge the benefits brought by NEC to take actions to take advantage of these benefits. Meanwhile, the unexperienced benefits that were identified in this study would increase practical knowledge of NEC for its future applications internationally, which might in turn help to improve the broader environment of the industry in Peru and potentially beyond.

Moreover, this research might serve as a first step to help Peruvian government to improve its procurement law or to include NEC as an option for public projects, like the way it has been implemented in Hong Kong (Lau *et al.,* 2019). What was found in this study could offer new insights and transferrable knowledge beyond Peru to other South American countries, which that share contextual similarities in their laws, languages and features of construction industries.

To get there, the author suggests undertaking further research considering qualitative approaches to probe into why particular international benefits of NEC were or were not experienced in certain contexts from the perspectives of practitioners. Due to the tight timeline, the sample size of the current project is relatively limited. In the future, the field may benefit from a larger sample size to reach a stronger generalization in quantitative investigations.

The results show that not all the benefits of NEC were experienced in Peru, which can open opportunities for further research. When applying NEC abroad, we need to consider the various local characteristics that may cause challenges in its application. For example, as discussed earlier, the benefit of NEC using plain English was not experienced in Peru, given it is a Spanish speaking country where English is rarely spoken. In this sense, we could consider translating local languages (there have been attempts in China, see more in NEC 2021), which would help enable the wider accessibility of NEC globally.

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AVOIDING DISPUTES THROUGH EFFECTIVE PROCUREMENT IN LARGE CONSTRUCTION PROJECTS

Matthew Arikosi Otim[1], Charles Kyalisiima[2], Apollo Tutesigensi[3], Harrison E Mutikanga[4] and Muzafalu Kayondo[5]

[1,2,4&5] Uganda Electricity Generation Company Ltd (UEGCL), PO Box 75831, Kampala, Uganda

[3] School of Civil Engineering, University of Leeds, Leeds, LS2 9JT, UK

Disputes in construction projects are known to adversely affect project and project management success. Fortunately, it is possible to avoid some disputes in construction projects despite the widespread belief that they are inevitable. Research shows that disputes in construction projects in some developing countries are rooted in incompetence and a general lack of professionalism of internal project stakeholders, which are linked to inadequate procurement of goods and services in projects. Accordingly, the research reported in this paper aimed to develop a framework to minimise the occurrence of major contract disputes in large construction projects in a certain developing country. The framework is expected to facilitate effective procurement across the project's pre-construction and construction phases and foster successful project delivery and performance. The research employed problem-solving methodology focusing on two case study projects in the developing country. This involved problem definition; information gathering; generation of multiple solutions; analysis and selection of a solution; and intra-design verification. The research highlights that minimising disputes on large construction projects should involve ensuring effective procurement of goods and services.

Keywords: contracts; disputes; developing countries; procurement

INTRODUCTION

Occurrence of disputes in construction projects is frequent (Iskandar *et al.,* 2021) and inevitable, more so in complex projects (Cheung and Yiu 2006; Hardjomuljadi 2020). These disputes are generally unfavourable to a project as they usually hinder the realisation of the project's main objectives (Fenn 2007). Although they are perceived as inevitable, construction disputes, fortunately, can be managed by, preferably, entirely avoiding them or at least minimising their negative effects (Kyalisiima *et al.,* 2022; Otim *et al.,* 2022). To accomplish that, it is important to understand the events and conditions that cause the disputes and be able to anticipate and predict their occurrence (Fenn 2007; Tanriverdi *et al.,* 2021).

[1] matthewarikosi@gmail.com

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Although construction disputes are attributed to various sources including poor contracts, changes in project scope, and opportunistic behaviour, among others (Kumaraswamy 1997; Fenn *et al.,* 1997; Cheung and Yiu 2006), some studies have shown that some disputes are rooted in lack of professionalism among internal project stakeholders (Otim *et al.,* 2022) and incompetence of internal stakeholders (Kyalisiima *et al.,* 2022). Competence, however, is a part of professionalism, whose other principles include integrity and responsibility (Otim *et al.,* 2022). In their respective research, Kyalisiima *et al. (*2022) and Otim *et al. (*2022) show that incompetence and a general lack of professionalism are linked to inadequate procurement of goods and services in projects. As Flyvbjerg (2022) states that projects do not go but rather start wrong, construction projects often commence with inadequate procurement that escalates to a chain of events and challenges that culminate in disputes. As such, the research reported in this paper aimed to develop a framework to minimise the occurrence of major contract disputes in large construction projects in a certain developing country (anonymised as per the ethical structure under which the study was done). The framework is expected to facilitate effective procurement across a project's pre-construction and construction phases, fostering successful project delivery and performance. Procurement in construction entails the purchase of construction-related services with the aim of creation of new structures, alteration, refurbishment, or demolition of existing structures (Scottish Government 2011). Construction procurement processes are key in ensuring the right project delivery stakeholders are engaged in the project. As averred by some authors, procurement is arguably one of the most important processes in the project cycle (Otim *et al. (*2022). Correct procurement for construction projects leads to adequate project delivery stakeholders (especially contractors and consultants) hence eliminating the downstream causal factors for construction disputes and mitigating dispute occurrence (Kyalisiima *et al.,* 2022). Conversely, inadequate procurement increases project exposure to construction disputes. As such, construction procurement should be managed effectively. Crucially, construction projects are unique in various aspects including design and location (Davis *et al.,* 2008) and, therefore, different procurement strategies/systems suit different construction projects (Turner 2007).

A procurement strategy is an organisational system that assigns specific responsibilities and authorities to people and organisations and defines the various elements in the construction of a project (Davis *et al.,* 2008). It outlines the key means by which the objectives of the project are to be achieved (Morledge *et al.,* 2006), and includes traditional, integrated, management and collaborative strategies (Davis *et al.,* 2008). However, an effective procurement process is not limited to procurement strategies. Morledge *et al. (*2006), for instance, suggests that a procurement procedure should include functional needs assessment, selection of an overall procurement philosophy, design of procurement system, setting of contractual relationships and appropriate supply chain, and implementation. Several governments have created comprehensive procurement procedures tailored to their policies (OGC 2007; Scottish Government 2011). That, however, is not the case for some developing countries, such as the subject country, for which studies have shown that the systematic selection of procurement strategies is often ignored (Kyalisiima *et al.,* 2022). The resulting use of inappropriate procurement strategies is a catalyst for the occurrence of disputes.

METHOD

Whereas this paper focuses on the case studies in Otim *et al. (*2022) and Kyalisiima *et al. (*2022), other literature recognise that inadequate procurement is one of the primary factors in the causation of construction disputes (Conlin *et al.,* 1996). Both case studies were debt-financed public sector infrastructure projects in a certain developing country, implemented under EPC (Engineering, Procurement and Construction) contract arrangements involving multinational stakeholders, and costing between half a billion to two billion US Dollars. Case studies enable in-depth investigation of a subject or phenomenon in its natural setting (Yin 2014).

To develop a framework to minimise the occurrence of major contract disputes in large construction projects in the case study developing country, this paper adopts the problem-solving methodology. The problem-solving methodology is a well-established and widely adapted process of finding solutions to various difficult or complex issues including design problems (Khandani 2005; Vorus 2017). It is a process of closing the gap between what is and what is desired and involves devising ways to answer questions and to meet or satisfy a situation which presents a challenge, offers an opportunity, or is a concern (Isaksen *et al.,* 2000). As guided and inspired by Isaksen *et al. (*2000), Khandani (2005), Pahl *et al. (*2007) and Vorus (2017), the problem-solving methodology, as adopted in this paper, involved the following:

(1) Problem definition - Establishing the need and stating it in clear and unambiguous terms to create a statement of specifications to be achieved by the solution.

(2) Information gathering - Collecting information through searching relevant literature, particularly papers in major industry journals and textbooks, to aid in both active and passive discovery of solutions. This helped in the identification of the weaknesses and strengths of existing or previous solutions from which inspiration could be drawn in the proceeding phases of the problem-solving process.

(3) Generation of multiple solutions - Creating a set of concepts that potentially satisfy the specifications of the solution, and creatively building new ideas and adapting existing solutions to improve the solutions to the problem. Brainstorming—the most common creativity technique—was used to generate ideas due to its simplicity and ease of adaption. Concept maps were used in generating and recording ideas during brainstorming to organise ideas and stimulate creative thinking.

(4) Analysis and selection of a solution - Reviewing/examining the different options and selecting the best solution for the problem. This entailed evaluating the options, modifying and/or merging them into a preferred solution. Evaluation involved subjecting the options to common criteria and selecting the one that best met them.

(5) Intra-design verification: Problem-solving would typically involve implementing and evaluating (validating and verifying) the solution to ascertain whether it achieves the intended purpose (Khandani 2005). However, due to the limitation of time, the evaluation of the proposed framework was limited to intra-design verification i.e. checking that the solution was built right during the process of designing it. Intra-design verification was done on a concurrent engineering basis (Khandani, 2005), with the resulting process/flow chart being analysed and continuously fine-tuned while the framework was being designed by a focus group (the authors), until the solution was deemed appropriate.

Framework to Improve Procurement

"Projects do not go wrong, they start wrong." Research has demonstrated that projects often start wrong by getting the front-end wrong (Flyvbjerg 2022), and a project going wrong manifests in several ways including frequent and protracted disputes. It is, therefore, reasonable to theorise that the conditions suitable for the roots of disputes are usually created at the start of a project and, correspondingly, those conditions can be prevented at that stage. So how can incompetence and a lack of professionalism—the identified root of disputes in the case study projects—be quashed at the start of a project and later in its execution? It boils down to ensuring that the right people (i.e., individuals, contractors, consultants likely to uphold the principles and values of professionalism) are engaged and maintained at the right time and under the right circumstances. This falls within the ambits of procurement management and contract administration. Indeed, research has identified the improper application of procurement and project delivery systems as a root cause of incompetence on projects (Long *et al.,* 2004). The following 2-stage framework—focusing on the selection and effective implementation of an appropriate project procurement system, and the selection and maintenance of the right key players/people—is, therefore, proposed to ensure that, with respect to professionalism, a project starts right and stays right during its execution.

STAGE 1: Choosing an Appropriate Project Procurement System

Masterman (2002) defines a procurement system as the organisational structure a client adopts for the implementation, and at times the eventual operation, of a project i.e., traditional/separated, integrated or management-oriented procurement systems, and their variants. Correctly choosing the most appropriate procurement system best guarantees that a construction project is unlikely to encounter significant difficulties and is concluded successfully (Masterman 1992). Procurement systems/approaches—particularly the contract strategy component—should be chosen on a case-by-case basis as projects, whether being undertaken by the same client and/or in the same environment, are still unique. If an integrated EPC/turnkey arrangement, for instance, worked well for one construction project, it does not necessarily mean it will be appropriate for a similar project since key factors like competence, maturity and experience of the contractor may not be replicated. Considering the design weaknesses, the EPC Contractors exhibited in the case study projects, it might have borne better results to engage more competent specialist designers separately and works contractors to implement the designs under the supervision of competent project managers (consultants), in management-oriented, instead of an integrated, procurement systems.

Much as the public procurement guidelines of the case study country highlight a few conditions under which procurement systems such as turnkey, traditional, integrated, etc., can be adopted, they are insufficient as there are no specific and systematic guidelines/ procedures for selecting an appropriate procurement system, considering the uniqueness and complexity of large construction projects. Adapted from the literature on the subject (Alhazmi and McCaffer 2000; Masterman 2002; Love *et al.,* 2010; Greenhalgh 2011), the 7-step procedure presented hereafter is proposed for the selection of an appropriate procurement system (Figure 2).

Step 1 - Identification and clarification of project objectives and constraints (e.g., site conditions, regulations, risk appetite etc.)

Step 2 - Preliminary/rough screening of the different procurement systems: List the merits and demerits of the different procurement systems with respect to the project's identified objectives and constraints. With expert judgement, feasible procurement systems can be shortlisted for further evaluation.

Step 3 - Definition of procurement assessment criteria (PACs): Define criteria for evaluating the procurement systems based on the client's needs. Criteria (which can be modified to suit the project's context) may include (but not limited to) risk avoidance, timing/programme, and controlling variation, managing complexity, level of quality, cost certainty, competition, management, and accountability.

Step 4 - Determination of client's value system/priorities (weighting and ranking PACs): Use pairwise comparison to prioritise/ assign weights to the PACs (client needs) to determine their level of importance to the client/project and the magnitude of the difference in importance. Pairwise comparison is a simple additive weighting method based on multi-attribute utility analysis—a often-used; easy-to-learn methodology applicable to appraisal of complex engineering projects (Rogers 2012).

Step 5 - Weighting of feasible procurement systems from preliminary screening: Guided by procurement appropriateness charts such as in Figure 1, use expert judgement to assign scores to the feasible procurement systems for each PAC i.e., a 1-to-5 scale (poor, acceptable, good, very good, excellent).

		Appropriateness of contract strategy in meeting project objectives				
Project objectives parameter	*Objectives*	*Traditional*	*Construction management*	*Management contracting*	*Design and manage*	*Design and build*
Timing	Early completion	×	✓	✓	✓	✓
Cost	Price certainty before construction start	✓	×	×	×	✓
Quality	Prestige level in design and construction	✓	✓	✓	×	×
Variations	Avoid prohibitive costs of change	✓	✓	✓	✓	×
Complexity	Technically advanced/ highly complex building	×	✓	✓	×	×
Responsibility	Single contractual link for project execution	×	×	×	✓	✓
Professional responsibility	Need for design team to report to sponsor	✓	✓	✓	×	×
Risk avoidance	Desire to transfer complete risk	×	×	×	×	✓
Damage recovery	Ability to recover costs direct from the contractor	✓	×	✓	✓	✓
Buildability	Contractor input to economic construction to benefit the department	×	✓	✓	✓	×

Figure 1: Appropriateness of procurement routes, Source: (Greenhalgh 2011)

Step 6 - Evaluation of procurement systems (weighted matrix): For each procurement system, get the sum of the product of the scores and their respective PAC weights.

Step 7 - Selection of the most appropriate procurement system: The procurement system with the highest total weighted score is considered the most appropriate for the project with respect to the client's needs. After this step, a Gateway Review should be done as a compliance mechanism to provide assurance that the selection of the procurement system was done right.

Note, however, that it is important to have suitably competent people within the organisation to undertake choosing the appropriate project procurement system. This can be achieved by employing individuals with the requisite qualities (experience and qualifications) and/or training/upskilling them, where feasible, to undertake the task. Otherwise, external expert guidance (consultants) would need to be procured as per the guidelines in Stage 2 (choosing and maintaining the right people).

STAGE 2: Choosing and Maintaining the Right People

Once an appropriate project procurement system is chosen, it is imperative that the right players (contractors, consultants, etc.) are selected to implement the project. The selection of project players is guided by a procurement process involving tendering/bid submission, bid evaluation and award of contract. The right players, in this case, are those who are most likely to uphold the fundamental principles of professionalism i.e., are competent, responsible and have integrity.

Selecting the right players can be facilitated by setting bid evaluation criteria that target those desired qualities in a potential contractor or consultant (as in Table 1). Studies, however, show that, traditionally, the evaluation of tenders and selection of contractors for public projects are typically based on the idea of taking the lowest bid price—an approach which is one of the leading causes of problems in project delivery, including delays, poor quality and prevalence of claims and disputes (Russell and Skibniewski 1988; Holt *et al.,* 1994; Mbachu 2008; Horta *et al.,* 2013; Cheaitou *et al.,* 2019). That being the case, many studies believe that the most crucial factors/criteria are (and should be) capability, reputation, and experience (Tiong and Alum 1997; Singh and Tiong 2006; Cheaitou *et al.,* 2019). Correspondingly, (Kumaraswamy 1997) puts forth that investigating performance on recent projects is one step in the process of attempting to anticipate contractor performance with reference to an upcoming project. Moreover, the specific procurement guidelines/regulations and criteria for such public construction projects tend to vary from one country to another (Bochenek, 2014). Accordingly, procurement process decisions, such as the choice of an appropriate tendering system (e.g., open competitive, selective/restricted competitive, negotiated etc.), should be in accordance with prevailing local procurement regulations. Figure 3 illustrates the public procurement process/cycle as per the case study projects' local guidelines/regulations.

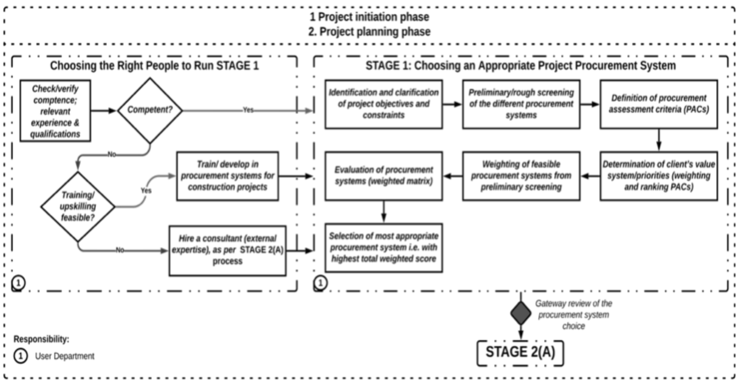

Figure 2: STAGE 1-Choosing an Appropriate Project Procurement System

Noticeably missing in this procurement process were provisions for Gateway Reviews after significant milestones/phases (e.g., decision by the Contracts Committee), which would be a compliance mechanism to provide assurance that the procurement was done right. Also, to ensure selection of suitably qualified contractors or consultants, the case study projects' local regulations provided for due diligence; however, they fell short of specifying when due diligence should be done in the procurement process and left that to the discretion of the procuring entity. Ideally, this should inform the evaluation process. Figure 4 illustrates Stage 2 of solution framework regarding selection of the right contractor/consultant in the context of the case study country's public procurement process/cycle.

Similarly, the selection of specific individuals to serve in key roles on the project (e.g., project managers, designers, construction managers etc.) should be thorough to ensure that the right people are appointed. Contracts usually provide staffing requirements and guidance on how project personnel can be appointed or dismissed. But are those provisions sufficient or even effectively implemented? The case study projects' contracts, for instance, only specified the required experience and qualifications for the key roles, and the evaluation of proposed candidates was based on submitted curricula vitae (CVs) with no evidence of any extra effort to verify the contents of those CVs. Experience on the projects showed that evaluating proposed candidates solely based on their CVs was insufficient as cases of a stellar CV leading to the appointment of an individual ill-suited for the task were recorded e.g., a resident project manager with poor communication skills.

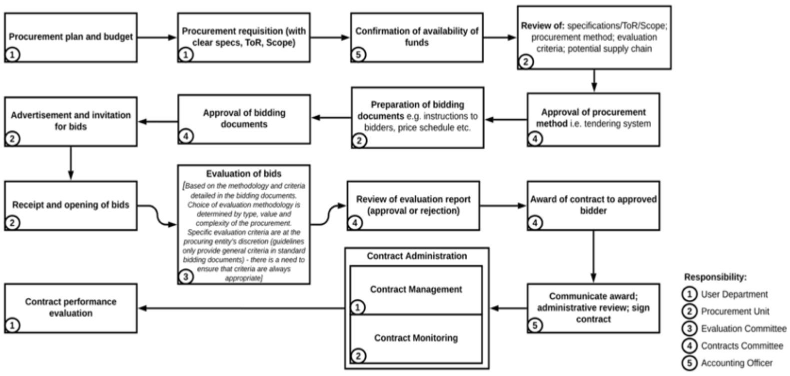

Figure 3: Case study projects' local public procurement process/cycle

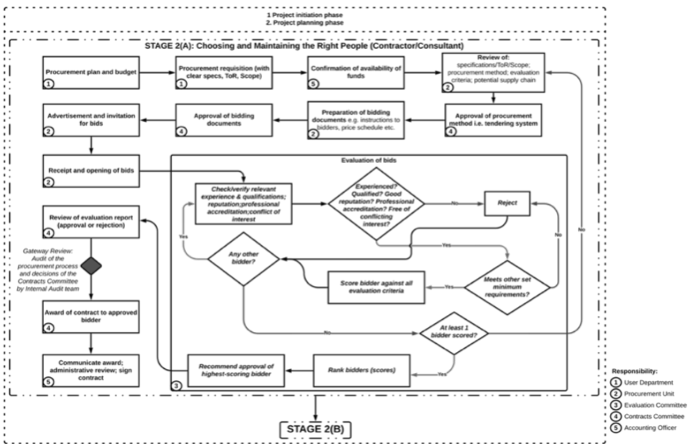

Figure 4: STAGE 2(A)-Choosing and Maintaining the Right People (Contractor/Consultant)

On that account, it is proposed that the evaluation of appointees to key roles in implementation of a project's contract should be in-depth, verifying and guided by the criteria in Table 1, as a minimum. Further, new appointees to key roles should be required to serve a probationary period that ends with an assessment of their performance in the assigned roles on the project, upon which their approval for permanent deployment should be based. That notwithstanding, continuous monitoring of the performance of key roles during project implementation should be done to verify and encourage the individuals' strengths while enabling timely identification and addressing of any weaknesses.

This could entail/invoke measures such as upskilling, reskilling, reassignment, or termination, as may be deemed appropriate for the improvement of the performance of the key roles on a case-by-case basis. To get some indication of the professionalism of a potential player e.g., employer, contractor, consultant and/or their proposed personnel, the following criteria (Table 1) should be included among the evaluation criteria within the project's tendering and personnel appointment processes. On a project, human resource matters can be devolved so that each party deals with the personnel under their direct control following the proposed framework. The parties' relationship regarding human resource management (e.g., performance appraisal and feedback) would be guided by the contract(s) between them.

Table 1: Professionalism evaluation criteria

Criteria	Requirement	Principle of professionalism
Relevant qualifications	Skills/knowledge to satisfactorily perform the respective roles on the project.	Competence
Relevant experience	Experience in delivering similar projects or roles.	Competence
Professional accreditation/regulation	Affiliated/accountable to and/or regulated by a recognised professional body.	Integrity; Responsibility; Competence
Reputation	Past clients/supervisors have a good opinion of them and vouch for their performance, work ethic/conduct.	Integrity; Responsibility; Competence
Conflict-of-interest	No vested interest that may compromise judgement and proper performance of functions on the project.	Integrity

Figure 5 shows Stage 2 of the solution framework regarding choosing and maintaining the right key personnel/roles during project execution, in the context of the case study country's public procurement process/cycle.

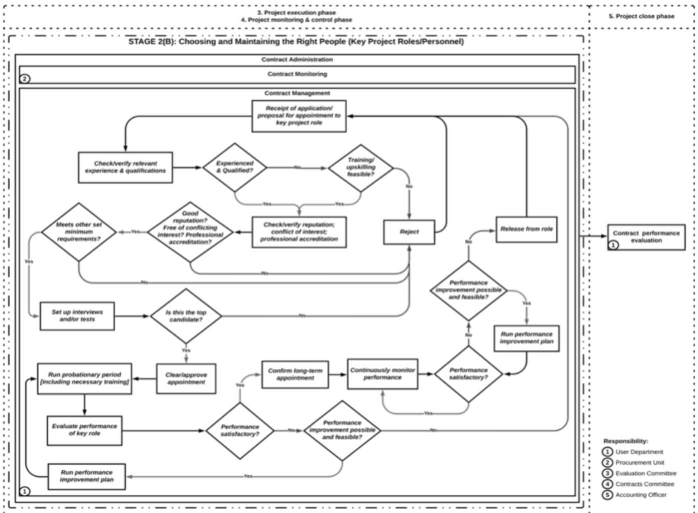

Figure 5: STAGE 2(B)-Choosing and Maintaining the Right People (Key Roles/Personnel)

CONCLUSIONS

Studies in a certain developing country—upon which this paper is based—have linked incompetence of project delivery stakeholders and their general lack of professionalism to contract disputes in large construction projects. Incompetence and a lack of professionalism in large construction projects were in turn associated with inadequate procurement of goods and services in the projects. The roots of some contract disputes in the large construction projects in the country in question could have been severed at both the preconstruction and construction phases of the projects by ensuring effective procurement of good and services. Accordingly, this paper proposes a solution framework for such contract disputes that provides a systematic process for choosing an appropriate procurement system for a construction project from the onset and choosing and maintaining the right people to deliver the project (i.e., people/contractors/consultants likely to uphold the principles of professionalism:

competence, integrity, and responsibility). By preventing the emergence of contract disputes, the proposed solution framework should foster successful delivery and performance of large construction projects. We therefore recommend the solution for empirical evaluation and eventual implementation.

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DESIGN AND TECHNOLOGY

THE IMPACT OF ARTIFICIAL INTELLIGENCE ON CONSTRUCTION COSTING PRACTICE

Kudirat Ayinla[1], Abdullahi Saka[2] Rafiu Seidu[3], and Upeksha Madanayake[4]

[1 & 2] *School of the Built Environment and Architecture, London South Bank University, Borough Road, London, SE1 0AA, UK*

[3] *School of Built Environment and Computing, Leeds Beckett University, Leeds, LS2 8AG, UK*

[4] *School of Construction Management and Engineering, University of Reading, Chancellors Way, Reading, RG6 6AG, UK*

Cost estimation is a crucial process in the construction sector as the efficiency of the overall project cost serves as one metric in determining project success. Prevailing traditional approach suffers from human subjectivity and bias which affect accuracy. With the development and adoption of Artificial Intelligence (AI) such as the use of machine learning (ML) and deep learning (DL) algorithms, the construction industry is experiencing brisk technological change and new ways of working, particularly in terms of cost predictions and estimations. However, the application of AI is still in its infancy and the industry still prioritises traditional cost modelling approaches in determining early estimates. This research explores the application of the various ML methods for costing and assesses their usage and application in the costing practice via an exploratory critical review. Findings indicate that ML algorithms would improve the accuracy and efficiency of costing practice but cannot replace the professionals and data availability.

Keywords: AI; artificial neural network; cost estimating; machine learning

INTRODUCTION

Every construction project is faced with a series of risks and uncertainties at the early design stages and throughout the project's life cycle. One of the major contributors to this challenge is cost estimation inaccuracies (Alqahtani and Whyte 2016), whereby lack of accurate cost data leads to failure to realise set project objectives. Therefore, cost is a major criterion in decision-making throughout the life cycle of a project (Juszczyk 2017, Elhegazy *et al.,* 2022). Cost estimation is argued as one of the most important preliminary processes in a construction project (Elfaki *et al.,* 2014) and it involves the prediction of the cost required to perform the work within project the scope. At the early stage of a project, where the scope of the project is uncertain and involves lots of ambiguities, it is particularly challenging to obtain input data for cost estimation. Therefore, the impact of overestimating or underestimating may lead to resource allocation challenges and cost overrun (Hashemi *et al.,* 2020). The accuracy and comprehensiveness of cost estimation at this stage are perceived as delicate issues that can be easily influenced by various parameters. Meanwhile, this crucial task of

[1] ayinlak@lsbu.ac.uk

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predicting cost and generating accurate estimates has in the past depended on the expertise of human professionals, despite the notion that an expert is prone to subjectivity and unconscious bias which can influence the result (Elfaki *et al.,* 2014, Elmousalami 2021). Traditionally, this process depends on the know-how of an estimator and assumptions are made based on experience and comparison (Bodendorf *et al.,* 2021). Therefore, it is argued that the level of accuracy required in the estimating process is largely impossible to achieve manually (Elfaki *et al.,* 2014).

The importance of the use of intelligent techniques in dealing with the challenges faced with cost estimating in the construction sector has been overemphasised since intelligent costing methods have the potential to significantly reduce effort and time (Bodendorf *et al.,* 2021). The implementation of machine learning (ML), a subgroup of artificial intelligence (AI) in the construction industry is transforming project delivery and redefining tasks executed by construction professionals and has the potential to shape construction delivery processes (Xu *et al.,* 2021). ML focuses on mimicking human intelligence and is generally described as the ability of a computer to learn without being explicitly programmed because of extracting patterns from historical data (Akinosho *et al.,* 2020). This aspect of AI investigates the work and composition of algorithms which can take advantage of and create assumptions about data thus enabling computers to make decisions, recognize speech, and visualize in 3D (Ford 2015). There has been a growing interest in ML research particularly deep learning (DL), a branch of ML, due to its capabilities in automating construction processes and improving productivity and performance (Xu *et al.,* 2021), with some studies focused on how construction processes can benefit from digitisation and AI (Adesi *et al.,* 2018).

While machine and deep learning are arguably in their infancy in the construction sector (Hong *et al.,* 2020, Xu *et al.,* 2021, Ang 2022), they present opportunities in addressing challenges with early cost prediction (Ang 2022). AI techniques are now being considered as a key solution in handling the ambiguity and challenges with cost estimation in construction projects (Elhegazy *et al.,* 2022). Therefore, this study explores the application of ML in relation to the practice of construction cost estimating throughout a project lifecycle and critically analyses the impact of ML techniques on practices of cost estimating and the challenges and opportunities presented. The outcome of this study will provide necessary information on the current use of various AI techniques and their application in costing practice in the construction sector and provide information on strategic future directions on these practices and how to harness emerging opportunities that AI presents.

METHOD

This study employs an exploratory research approach through systematic identification of publications on the theme of Artificial Intelligence techniques for costing practice in the construction industry. Search queries on AI techniques ('Machine learning', OR 'Artificial intelligence' OR 'Artificial Neural Network'), costing practice ('Costing' OR 'Estimating' OR 'Cost modelling'), and construction industry ('Construction Industry' OR 'AEC industry' OR Architecture Construction and Engineering*') were developed and searched on Scopus, Web of Science and Google scholar. This is because these databases house relevant publications and have been employed in similar studies. Inclusion criteria include publications in English language and are limited to ‘Construction Building Technology’ and 'Engineering civil' categories without year limitations and document type restrictions. The final publications were critically reviewed to identify and aggregate key findings and lesson learnt from these studies which forms the basis of the output of this research.

LITERATURE REVIEW

Evolution of Construction Cost Modelling and Estimating Practice

There are various methods and models for generating the cost of a product. The suitability of each model is often dependent on the type of project, the information required for completing the cost estimate, and the field of application. Particularly in the construction field, the use of these cost models could be a question of what phase the project is and what data is available at that point in time (Günaydin and Doğan 2004). Niazi *et al.,* 2006) gave a comprehensive classification system for construction cost modelling methods using a 2-category classification namely the quantitative and qualitative approaches (Figure 1). This classification simply groups cost modelling techniques based on the level of information required to generate an estimate. For instance, the parametric and analytical methods which require some form of computational analysis and requires a lower level of granularity to derive the cost falls into the quantitative category, while the more subjective method such as intuitive and analogical methods are grouped under the qualitative approach. The basis of use for these categories of cost modelling methods will be reviewed next.

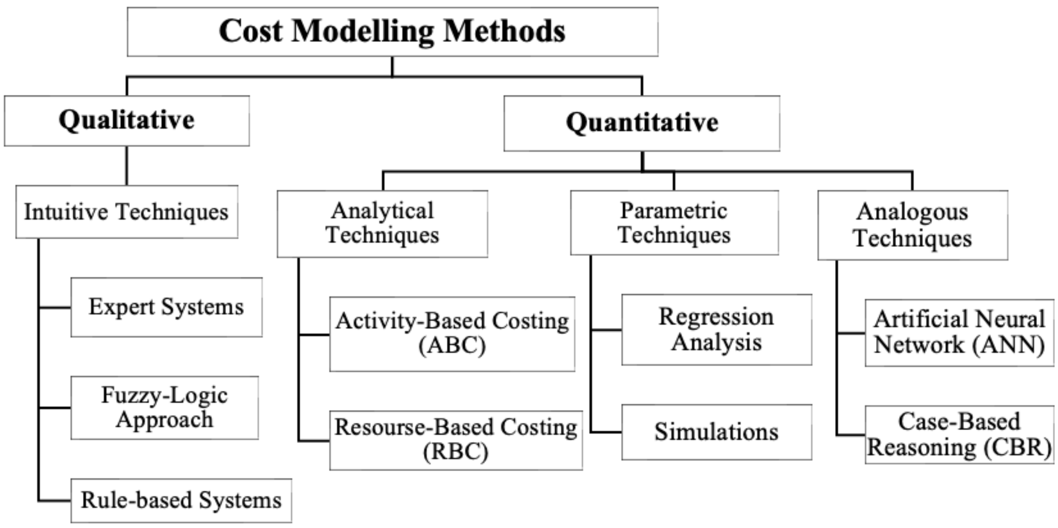

Figure 1: Classification of cost modelling techniques

Progression of the cost modelling practices.

The prediction of project cost received great interest during the early 1970s to the late 1980s in the construction industry because of the need for more accurate estimation due to the capital value of construction projects and the level of uncertainties involved throughout a project life cycle. Although few models were already in existence before this time, the early cost models were criticised for being less value-driven because of their failure to account for future uncertainties in construction and their inability to generate reliable cost estimates (Khosrowshahi and Kakat 1996, Yaman and Tas 2007). Accordingly, the historical development of cost-estimating techniques/tools have progressed from three stages in the construction industry: first, second and third generations, however given the recent technology drive in the construction sector, a fourth category is now necessary. As outlined in Table 1, the first-generation techniques are based majorly on building functional cost analysis approaches and consist of resource-based costing (RBC), also known as elemental-based costing (EBC) and activity-based costing (ABC) methods. The RBC method is the most widely used method in the construction sector and forms the basis of construction cost estimating guides for professionals as seen in the RICS new rules of measurements (RICS 2021). The ABC approach, on the other hand, presents an advancement to the RBC method in terms of its ability to accurately trace the cost/unit of products, thus improving the accuracy of the cost data. However, both these first-generation models (RBC and ABC) have limitations in the aspect of cost prediction (Khosrowshahi and Kakat 1996). This led to the development of other tools to fill this gap in the early 70s.

The parametric method is based on statistical approaches such as regression analysis (linear regression and multiple regression models) involving the use of historical data to predict cost. These methods became popular in the late 1970s and are described as second-generation methods. This method is considered powerful at the feasibility stage of a project due to its ease, and speed of application (Chou 2011). However, the accuracy of the method when relationships are non-linear has been an issue as they are augured to undermine the role of many variable cost drivers that influence a project cost. Third-generation cost modelling tools used for construction projects experienced usage at the beginning of the 1980s. These techniques are based on simulations and risk models such as the Monte Carlo simulation and are initiated as the field of project management continues to expand in the sector. The Monte Carlo simulation method significantly reduces the risk associated with cost estimates using a range estimating approach where estimators determine the minimum, most likely, and maximum possible cost (Chou *et al.,* 2009) and the probability of exceeding the 'most likely' estimate.

More novel approaches have since arrived after the simulation method because of the application of artificial intelligence and its implementation into cost modelling. Artificial intelligence (AI) approaches such as artificial neural networks (ANN), expert systems (ES) and case-based reasoning (CBR) models have been investigated since the late 1980s (Kim and Shim 2014) and classified as the fourth-generation models. These methods imitate the human brain function by learning from previous experience to predict cost and produce very accurate results as well as reducing the time for estimation. The recent technological advancement in the construction sector over the last decades has propagated the use and implementation of Building Information Modelling (BIM), which can be regarded as the fifth-generation approach. However, this method uses the first-generation RBC/EBC techniques and differs in that the quantity take-offs and estimation are now automated and supported by BIM applications (Wu *et al.,* 2014). Measurements are automatically taken off from digital models of a building, which traditionally has been very time-consuming. However, there is still a limitation to this method as BIM-based cost estimations are generated only based on the information in the BIM model while disregarding possible other external factors (Abioye *et al.,* 2021). More recently, there is ongoing research on the integration of the combination of AI and BIM to create more accurate estimates through the application of AI-based prediction models in the estimation and predictions of construction costs (Ang 2022). Therefore, the next section will focus on the progress with the use of AI-based approaches in cost-estimating practice and the benefits and challenges they present.

Table 1: Progressive development of Cost Estimating Practices

Timeline	Methods	Strength	Weaknesses	Source
First Generation (Pre - 1960s)	Elemental-Based Costing Activity-Based Costing	Detailed breakdown on cost information Provides information on different levels of analysis. More accurate with ability to track product cost.	Lack of detailed consideration for risk and uncertainties. Not suitable for early development stage. Lacks process view. Not suitable for cost prediction	(Khosrowshahi and Kakat 1996, Akintoye and Fitzgerald 2000). (Günaydin and Doğan 2004, Ayachit *et al.,* 2014)
Second Generation (Early - Late 1970s)	Parametric	Easy to understand due to string mathematical basis. Good at prediction Speed of execution Considerably accurate	Over simplistic and undermine many variables. Inaccuracies when relationship is non-linear	(Khosrowshahi and Kakat 1996, Günaydin and Doğan 2004)
Third Generation (Early 1980s)	Probabilistic Method	Reduces risk with cost estimates	Need advanced user data quantity and quality. Mostly based on the assumption of triangular distribution	(Chou *et al.,* 2009, Chou 2011)
Fourth Generation (Late 1980s)	Network-Based Approaches	Needs less statistical training to perform prediction. Can detect non-linear relationship among variables. Accuracy due to capability developed by numerous training algorithms	Black box method without user understanding Difficult to explain the outcome. Requires large pool of data to be dependable.	(Juszczyk 2017, Elmousalami 2021)
Fifth Generation (Post 2000s)	Building Information Modelling	Speeds up traditional estimating process Ability to link cost information to building model	Based on the quality of the BIM model Cannot automatically identify missing or unmeasured elements	(Wu *et al.,* 2014)

Impact of ML Techniques on Costing Practice

To develop machines that can simulate human cognitive mechanisms (machines), different AI methods have been developed. AI systems utilise different inter-connected sensors for data collection through a process known as data fusion to integrate and detect possible inferences and characterisations from the data (Pan and Zhang 2021). Machine learning (ML) is concerned with the design of computer programs and algorithms that are capable of cognitive skills and capable of reaching decisions which are traditionally regarded as human skills (Abioye *et al.,* 2021, Xu *et al.,* 2021, Oluleye *et al.,* 2023). ML has 3 categories (i) supervised learning (ii) unsupervised learning (iii) reinforcement. Other studies have also used classifications based on (i) shallow learning which uses a single layer of neural network nodes (ii) deep learning which uses multiple layers to process large amounts of training data (Xu *et al.,* 2021). Deep learning (DL) being the current state-of-the-art in ML has been proven to provide more accurate predictions than conventional ML techniques.

There has been a growing interest in research on ML in the AEC industry which is partly because these technologies can play an important role in processing the 'huge' amount of data being generated and used by construction professionals during a project lifecycle and can be attributed to their potential impact on the cloud-based computing technologies used within the industry. The idea of AI technologies implementation in the AEC industry is to improve the industry's productivity and efficiency to support the complexities in factors such as varying roles, uncertainty in environmental hazards and others (Pan and Zhang 2021, Oluleye *et al.,* 2023). It is expected that the development of ML and DL will reshape the whole costing practice, however, the use of human-based methods is still common in the construction costing practice. ML techniques could be employed to solve classification or regression problems. Costing practice that deals with regression and ML algorithms such as ANN, Logistic Regression, Support Vector Regression (SVR), and Deep neural networks (DNN) can be leveraged. The following section presents a brief discussion of the algorithms and studies that have employed them for costing practice in the extant literature.

Artificial Neural Network (ANN)

Artificial neural network (ANN) is one of the many algorithms of machine learning which models biological learning processes by computers (Hashemi *et al.,* 2020), and is commonly used for cost prediction/forecasting. ANN has been applied to mimic the human system of information processing and can predict the cost of relevant construction tasks. Its application in the construction sector is well documented in existing literature. For instance, Aibinu *et al.,* (2011) predicted the cost of pre-tender cost estimates using ANN algorithm. Similarly, Bala *et al.,* 2014) employed ANN for predicting the cost of institutional buildings. The method has also been used for life cycle cost modelling for buildings (Alqahtani and Whyte 2016) and for predicting the cost of composite flooring systems for multistorey buildings (Elhegazy *et al.,* 2022). The main limitation of ANN like any other ML algorithm is the need for adequate cost data from past projects to prevent overfitting of the ANN models (Elmousalami 2021). Furthermore, the 'black box' nature of ANN models makes it difficult for the stakeholders to understand how the predictions were made.

Case-Based Reasoning (CBR)

CBR is a technique that makes use of the information contained in past cases (i.e., previous projects) to generate cost estimates. This is a data mining technique which tends to remember information and uses the solution implemented for similar projects in solving new problems (Ji *et al.,* 2011). The best matching example like the project at hand is determined to cost of the new project (Niazi *et al.,* 2006). CBR has experienced wide application in construction costing practice such as for modelling the cost of new construction projects (An *et al.,* 2007, Ji *et al.,* 2011, Ahn *et al.,* 2020). Information on previous projects is usually stored in a database and the characteristics that match the specification of the new project (based on percentage similarity score) while taking note of changes in systems. There have been well-documented efforts in improving the result of CBR (Ahn *et al.,* 2020). However, there are still challenges with the attribution of weight values (Ji *et al.,* 2011).

Regression Algorithm (R)

There are different regression algorithms that could be employed for costing practice in the construction industry such as single learners and ensembles. Single-learner algorithms include linear regression, multiple linear regression, polynomial regression, decision tree regression and support vector regression. On the other hand, ensemble algorithms include random forest regression, gradient boosting regression and Bayesian regression. Ensemble algorithms do outperform single learners and single algorithm such as Support Vector Regression (SVR) has an advantage in self-learning and high performance in generalisation (Kim *et al.,* 2013). The limitations of these algorithms are linearity assumption, overfitting, underfitting, sensitivity to outliers, extrapolation, multicollinearity, and difficulty in handling categorical variables (Géron 2022).

Deep Neural Networks (DNNs)

Deep neural network (DNN) provides more depth to a standard neural network and are typically trained to model complex non-linear relationships through their ability to extract unique features (Akinosho *et al.,* 2020) Diverse DNN algorithms can be leveraged for costing practice in the construction industry. For instance, Convolutional Neural Network (CNN) can be employed for automated quantity estimation from images and blueprints, Recurrent Neural Networks (RNN) can be employed for time series analysis in construction cost forecasting, Generative Adversarial Networks (GAN) can generate synthetic cost data based on past historical data to improve accuracy; and lastly, transformer networks like ChatGPT which are large language model can be prompt with textual specification and project description to automate cost estimation (Saka *et al.,* 2023). However, the use of DNNs in costing practice is limited because of the data and expertise needed in deploying these models for costing. One instance found in published journals is Wang *et al.,* (2022)where it was used to determine the effects of economic factors on construction costs for public school projects. This technique, therefore, needs more practical applications in constriction costing practices.

CONCLUSIONS

The practice of construction cost estimating continues to be a major area of interest to construction researchers due to the importance of accurate cost estimation in decision-making for construction projects. Application of AI such as machine learning algorithms hold immeasurable benefits for costing practice because of their predictive strengths, capability to infer complex relationships and accuracy. However, the findings of this study revealed that the use of ML algorithms for costing practice is limited and majorly in the early estimating stage. There is limited deployment of these algorithms in tendering and construction phase of the project because of the unavailability of data to train the model and 'black box' nature of AI which affects trust.

There is a need for quality and structured data to improve the accuracy of the ML models and adequate size to prevent overfitting and underfitting of the models. The study highlighted that although the current applications are limited, there are opportunities for deploying ANN, regression models, and DNNs for costing practice in the construction industry. These ML algorithms would improve the accuracy and efficiency of the costing and estimating practice but cannot replace the professionals. Domain knowledge is required in fitting of the model - determining the right predictors and understanding the data - explaining and deploying the models in practice. As such, it is important for professionals to leverage these algorithms and not see them as competitors and usurpers.

Lastly, this study is a critical review on the impact of AI on costing practice and is limited by the size of publications employed for the review. Further study would employ a systematic review to evaluate the impact of ML on costing practice whilst highlighting the challenges, and opportunities and providing a case validation.

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ADDRESSING COLLABORATIVE CHALLENGES IN HUMAN-ROBOT TEAMS THROUGH THE DEVELOPMENT OF AN IMMERSIVE VIRTUAL ENVIRONMENT

Adetayo Onososen[1], Innocent Musonda, Ramabodu Molusiwa and Christopher Dzuwa

Centre for Applied Research and Innovation in the Built Environment, Department of Construction Management and Quantity Surveying, Faculty of Engineering and the Built Environment, University of Johannesburg, Johannesburg, 2092, South Africa

Technological innovations in construction, like robots, pose a challenge in collaborating effectively with humans. An immersive virtual environment (IVE) addresses this by simulating human-robot interactions safely. This study developed an IVE that accurately represents the real-world setting for human-robot teams. It integrates essential elements like equipment, tools, and objects for construction tasks. The virtual environment depicts real-time interaction between human operators and virtual robots as typical of construction environments and scenarios. It effectively enhances construction workers' and operators' interaction and collaboration with robots, familiarising them with capabilities, limitations, and behaviour. Moreover, it facilitates testing and evaluating different human-robot interaction methods, interfaces, and control approaches to precede implementation on construction sites. Overall, the IVE provides a controlled and safe platform for training, allowing operators to become proficient in working with construction robots while optimising their performance and safety in real-world construction settings.

Keywords: collaboration; human-robot teams; virtual reality

INTRODUCTION

The use of collaborative robots teaming with humans in future industrialised networks is inevitable in delivering sustainable and quality infrastructure to meet socio-economic demands. The adoption of robots is hinged on their characteristics to be highly skilled in performing physically repetitive tasks, which abounds in the built environment (Malik and Brem, 2021). With the potential to cut down waste, reduce injuries and perform work better and faster, design and development in collaborative robots are progressing very fast with optimism and concerns about what it connotes for the future of work between workers and robots (Lucas, 2018). However, effective collaboration between humans and robots remains a significant challenge due to the differences in their capabilities, skills, and cognitive processes. Developing immersive virtual environments can help address these challenges by providing a

[1] Onososen@outlook.com

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platform for training, testing, and optimising human-robot team performance (Adami *et al.,* 2021). This article presents an overview of collaborative challenges in human-robot teams. It showcases how they can be addressed through human-robot collaborative learning in an immersive virtual environment as a solution to these challenges.

Background to Study

The construction industry has been vulnerable to high rates of deaths and fatal injuries than any of the other main industries because of the unstructured and dynamic nature of building sites and the significant physical demand that construction labour places on workers (Kurien *et al.,* 2018; Wang *et al.,* 2021). This has led to increased interest in the development of robots. Yet, due to the unstructured and complicated nature of construction settings and the relatively loose tolerances of building projects, construction robots confront various problems, which may lead to frequent robot failures while executing duties on-site. In addition to collaboration issues, this poses myriad challenges to human-robot teams' collaboration.

Immersive Virtual Environments

Immersive virtual environments (IVEs) are computer-generated environments that simulate real-world scenarios and allow humans and robots to interact in a controlled setting (Lucas, 2018). IVEs provide a platform for training, testing, and optimising human-robot team performance, as they allow researchers to manipulate various parameters and observe their effects on team dynamics (Albeaino and Eiris, 2021). IVEs can also be used to evaluate new communication protocols and interfaces and to identify potential sources of errors and misunderstandings (Onososen, Musonda and Ramabodu, 2022).

IVEs can be designed to simulate various scenarios, such as manufacturing, healthcare, and disaster response. In a manufacturing setting, for example, an IVE can simulate a production line where humans and robots work together to assemble products (Dallel *et al.,* 2023). In a healthcare setting, an IVE can simulate a hospital ward where robots assist nurses in patient care (Bermúdez I Badia *et al.,* 2022). In a disaster response setting, an IVE can simulate a rescue mission where robots and humans work together to locate and rescue victims (Sermet and Demir, 2022). In the built environment, their applications range from site visits/education, training for rooftop workers, human-machine skills development training, health, and safety training on-site, and recently on, human-robot collaboration simulations and training. They are also extensively used for design visualisation in communicating project concepts and progress (Albeaino and Eiris, 2021).

Constructing New Future

Developing IVEs for human-robot teams represents a significant step towards creating a future where robots and humans can collaborate effectively and safely. IVEs can help bridge the communication gap between humans and robots and provide a platform for testing and optimising new communication protocols and interfaces (Alisadehsalehi and Hadavi, 2021). Moreover, IVEs can enable researchers to identify potential sources of errors and misunderstandings before deploying robots in real-world settings (Matsas *et al.,* 2017). However, developing IVEs is the first step to achieving effective human-robot collaboration. Further research is needed to explore the effects of different communication protocols, modalities, and interfaces on team dynamics and performance. Moreover, researchers need to develop new methods for evaluating the effectiveness of IVEs and transferring the lessons learned in virtual environments to real-world settings.

Therefore, the development of IVEs for human-robot teams is an exciting and promising field that has the potential to revolutionise the way humans and robots work together. IVEs can help create a future where robots and humans collaborate seamlessly and safely by addressing the collaborative challenges in human-robot teams.

METHOD

To examine how the immersive virtual environment can address the collaborative challenges associated with human-robot teams, an immersive VR interface for human-robot interaction for construction task execution was developed. This approach is an experimental study followed by a post-experiment discussion based on the participants' perceptions (Matsas *et al.,* 2017)). The result for this paper is drawn from piloted experiments with robots and human participants to simulate real-life construction environments (Kurien *et al.,* 2018). Seven student participants who were postgraduate construction management students were recruited for the experiment. All the respondents had completed several subjects related to construction project management and gained basic construction industry experience through internships at construction companies. Before the experimental sessions commenced, they were briefed on the study's purpose and process, and their background information was collected through a survey. A group post-experiment question was asked to examine their perception of an immersive virtual environment and how it can address the collaborative challenges associated with human-robot teams. Their responses were categorised and summarised into themes, as presented in Table 2. The immersive VR interface, developed on the Unity platform, allows users to interact with robots and other humans in the environment (Bermúdez. *et al.,* 2022). It consists of the robot, construction workspace, and humans in the environment. Humans can perform environmental tasks such as site inspection, progress monitoring and interacting with drones.

Already-built structures, such as static building components and temporary structures, were included inside the workspace. The environment was implemented in Unity 2022.1.16 using the C# programming language. Following the importation of the model into unity, parameters to measure the participant's task performance and ability to collaborate with robots in the environment were included. This included the safety of colliding with materials and robots in the environment, the number of tasks performed, the position of the participants at every point in the environment, the command prompts sent to the VR, and other parameters. Scripting involves simulating the rotor animations, object gripping, grip retraction and extension, switching between cameras, robot motion control, robot powering and starting, collision tracking, and payload delivery logging. The robot was controlled using a controller with a display screen. The flight environment was a construction site with four uncompleted buildings. Other objects commonly found on construction sites were also added to the scene (Figure 1).

Virtual reality was utilised in the running of the simulation so that the experience could be as lifelike as feasible (Dallel *et al.,* 2023). The simulation included virtual reality capabilities thanks to the XR interaction tools. This involves moving around, turning, and conversing with other characters or things in the scenario. Because it supports various virtual reality devices, including SteamVR, Oculus Quest 2, Oculus

Rift, HTC Vive, and others, the XR interaction toolkit was selected as the best option. The motion speed was kept at 1.5 meters per second, and the turning speed was kept at 1.0 degrees per second because these speeds proved effective in preventing motion sickness while using virtual reality. The Oculus Quest 2 was utilised in user testing, which took place. Ten minutes were allotted to every user for them to perform the tasks assigned in the virtual environment.

Figure 1: Images showing the VR environment and a participant using the system

FINDINGS

Collaborative Challenges in Human-Robot Teams

The main questions/issues addressed in this paper are what are the collaborative challenges construction workers are likely to face in working with robots, and how can VR be utilised to address these challenges? The findings reveal that human-robot teams' success depends on effective collaboration, which requires a shared understanding of tasks, goals, and communication protocols (Liang *et al.,* 2021). However, humans and robots have different capabilities and limitations, leading to misunderstandings and errors. For example, humans rely on social cues and nonverbal communication, while robots may not recognise or respond to these cues (Liu *et al.,* 2016). Similarly, humans have cognitive flexibility and can adapt to new situations, while robots may struggle to handle unexpected events (Yazdani, Brieber and Beetz, 2016).

The challenges identified in the post-experiment group discussion are the communication gap between humans and robots, as they use different languages and modalities (Groom and Nass, 2007). Humans use natural language, gestures, and facial expressions, while robots use programming languages, sensors, and actuators (Bainbridge *et al.,* 2011). Bridging this gap requires developing new communication protocols that allow humans and robots to understand each other's intentions and actions. Other challenges identified and described in the table 1 are; Role confusion (Berx, Decré and Pintelon, 2022), trust and confidence (Hancock *et al.,* 2021), Adaptability (Malik and Brem, 2021), Task allocation (Tsarouchi *et al.,* 2017), Decision-making (Le, Sajtos and Fernandez, 2022), Technical difficulties (Atabay, Pelin Gurgun and Koc, 2020), Safety concerns (R. Wang *et al.,* 2021), Compatibility issues (Faber, Bützler and Schlick, 2015), Ergonomics in Human-robot interaction (Onososen and Musonda, 2022).

Table 1: Collaborative Challenges in Human-Robot Teams

S/N	Collaborative Challenges	Description	Sources
1.	Communication	Differences in communication styles, modalities, or languages can create misunderstandings and hinder effective collaboration.	(Akiho and Sugaya, 2016)
2.	Role confusion	Lack of clarity about team members' roles and responsibilities can lead to duplication of effort or gaps in task completion.	(Berx, Decré and Pintelon, 2022)
3.	Trust and confidence	Building trust and confidence between humans and robots can be challenging, as robots may be perceived as unpredictable or untrustworthy.	(Hancock *et al.,* 2021)
4.	Adaptability	Human-robot teams must be able to adapt to changing circumstances, such as unexpected events or changes in the environment.	(Malik and Brem, 2021)
5.	Task allocation	Assigning tasks and responsibilities to the appropriate team member can be complex, especially when considering task difficulty, robot capabilities, and expertise.	(Tsarouchi *et al.,* 2017)
6.	Decision-making	Human-robot teams may face challenges in decision-making, particularly when dealing with complex or ambiguous situations.	(Le, Sajtos and Fernandez, 2022)
7.	Technical difficulties	Technical issues, such as malfunctions or software bugs, can impede collaboration and cause delays or errors.	(Atabay, Pelin Gurgun and Koc, 2020)
8.	Safety concerns	Ensuring the safety of human team members when working with robots is crucial, as robots may pose physical risks or hazards.	(Wang *et al.,* 2021)
9.	Compatibility issues	The compatibility of hardware, software, and other technologies used by human-robot teams must be carefully considered to ensure seamless collaboration.	(Faber, Bützler and Schlick, 2015)
10.	Ergonomics Human-robot interaction	Designing interfaces and interaction modalities that enable effective and natural human-robot interaction can be challenging, as humans and robots have different capabilities and limitations.	(Onososen and Musonda, 2022)

How Virtual Reality Addresses Collaborative Challenges in Human-Robot Teams

One of the most natural ways humans and robots work together is to lead the robot through physical touch. This method calls for human operators to apply physical forces directly to the robot or the object the robot is carrying to guide the robot to comparable places (Wang *et al.,* 2021). Virtual reality applications offer an immersive environment for human workers to virtually rehearse such contact and use scenarios with the robot to enhance safety and human-robot interaction learning. In the virtual environment developed, the robot executes the physically demanding task to enable the human workers to pay more attention to the task execution details. The human worker is responsible for high-level task planning and supervision, and the robot undertakes detailed workspace sensing and monitoring, path planning, and physical execution of the work.

Moreso, the workspace can be visualised from the building information model for human workers to understand workflows associated with the robot's movement and task performance. The reaction of the robots to tasks and commands can also be tested in the VR environment before actual work on-site to build trust. Collision-free motion plans can be visualised in the virtual environment and rehearsed to evaluate safety.

Identified challenges, such as communication factors, can utilise haptic and audio-visual systems to reflect operator and robot responses (Adami, 2021). This includes using vision-based systems to identify human gestures for robot guidance. Other studies have also identified using wearable sensors, inclinometers, orientation sensors, and rotary encoders to detect human arm movement to operate a robot. As suggested by the participants, collaboration challenges in human-robot teams can also be addressed using VR through robot role plan preview and evaluation, simulating realistic scenarios, and testing the performance of robots in various situations, helping to build trust and confidence in their capabilities, simulating complex tasks and allocate responsibilities among team members based on their expertise and capabilities. Also, Table 2 suggests that users should simulate dangerous situations, allowing team members to practice safety procedures and minimise risks to humans. Other factors stated that the environment should provide a simulated scenario that allows team members to test and optimise the compatibility of different hardware and software components.

Table 2: Role of VR in Collaborative Challenges in Human-Robot Teams

S/N	Collaborative Challenges	Role of Virtual Reality
1.	Communication	Virtual reality can provide a shared visual and auditory environment that can help overcome language and communication barriers. For example, virtual reality can create a shared workspace where team members can communicate through avatars, overcoming differences in communication styles and modalities.
2.	Role confusion	Virtual reality can provide an immersive simulation environment that allows team members to experience different roles and responsibilities. This can help clarify expectations and promote a better understanding of each other's roles. Robot role plan preview and evaluation
3.	Trust and confidence	Virtual reality can be used to simulate realistic scenarios and test the performance of robots in various situations, helping to build trust and confidence in their capabilities. For example, virtual reality can simulate dangerous or high-stress situations, allowing team members to test robots' ability to perform under pressure.
4.	Adaptability	Virtual reality can provide a flexible and dynamic simulation environment that can be easily modified to reflect changing circumstances. This can help human-robot teams practice and develop adaptability skills in a safe and controlled environment.
5.	Task allocation	Virtual reality can simulate complex tasks and allocate responsibilities among team members based on their expertise and capabilities. This can help optimise task allocation and improve task completion times. Robot motion plan review and evaluation.
6.	Decision-making	Virtual reality can provide a realistic and immersive environment that allows team members to practice decision-making in complex and ambiguous situations. For example, virtual reality can simulate emergencies, allowing team members to practice decision-making in a safe and controlled environment.
7.	Technical difficulties	Virtual reality can provide a simulated environment that allows team members to practice troubleshooting and problem-solving during technical difficulties. This can help minimise delays and errors caused by technical issues.
8.	Safety concerns	Virtual reality can simulate hazardous situations, allowing team members to practice safety procedures and minimise risks to human team members.
9.	Compatibility issues	Virtual reality can provide a simulated environment that allows team members to test and optimise the compatibility of different hardware and software components. This can help ensure seamless collaboration and reduce technical issues caused by incompatible technologies.
10.	Ergonomics Human-robot interaction	Virtual reality can be used to design and test interfaces and interaction modalities that promote effective and natural human-robot interaction. This can help overcome the challenges of designing intuitive and user-friendly interfaces for both humans and robots.

CONCLUSIONS

This paper developed an immersive virtual environment approach to addressing challenges associated with collaboration in human-robot teams. First, it highlights how the environment was developed and demonstrates how the environment can enable collaboration amongst human-robot teams. The study's findings imply that VR can enhance collaboration by providing a virtual environment where human team members and robots can interact and work together seamlessly. This can lead to better coordination, increased efficiency, and overall team performance. The study suggests that collaborative robots will play a crucial role in future industrialised networks, and immersive virtual environments can help overcome the communication gap between humans and robots, leading to effective collaboration. The findings also indicate that these environments can enhance safety, optimise robot performance, and facilitate skill development and training for construction team members, while further research is needed to explore communication protocols and transfer virtual environment lessons to real-world settings. Overall, immersive virtual environments have the potential to revolutionise human-robot collaboration in the construction industry. Also, these help us to understand enhanced training and skill development in the learning process for construction team members and robots. By simulating realistic scenarios, individuals can gain valuable experience and develop the necessary skills to navigate complex collaborative challenges. This can lead to faster skill acquisition, reduced training costs, and increased readiness for real-world deployments.

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AUTOMATED WORKFLOWS FOR DESIGN COORDINATION: SUPPORTING MEP SYSTEMS

Harshul Singh[1], Faris Elghaish[2] and Tara Brooks[3]

[1,2&3] *School of Natural and Built Environment, Queen's University Belfast, Elmwood Avenue, Belfast, BT7 1NN, UK*

[1] *TetraTech, Locksley Business Park, Belfast, BT6 9UP, UK*

Mechanical, electrical, and plumbing (MEP) are becoming more complex with increasing project scope and technological advancements. Automated tools to support design and coordination workflows like plug-ins and programming scripts can provide a data-centric positioning to designers to generate more accurate and timely outputs. However, ongoing automated processes for MEP revolve around individual tasks and do not focus on coordination and interoperability. This study presents the development of a solution for coordinating MEP design systems by enabling interoperability. The solution is called the Live Clash Detection System [LCDS]. The solution enables an automated clash detection tool. A Design Science Research Method (DSRM) approach is adopted, where LCDS is tested and evaluated using a real-life case study. The findings show that the proposed workflow and its automated clash detection tool create significant efficiency for its users, minimising the required time and effort to develop MEP design. The results demonstrate the huge potential for increased automation for both routine and more complex operations in MEP design using BIM.

Keywords: automation; BIM; MEP coordination; information management

INTRODUCTION

Architecture, engineering, and construction [AEC] companies are being challenged by the changing dynamics of the industry (Walters *et al.,* 2003; Bock, 2015; Mc Kinsey, 2020). In the case of the mechanical, electrical, and plumbing [MEP] sectors, this has resulted in increased complexity in the design of these systems (Lee and Kim, 2014; Hu *et al.,* 2017). This situation will become more intense for the MEP design firms with a projected substantial increase in the number and complexity of private and public projects in MEP-oriented sectors like healthcare and education (ONS, 2021).

Building Information Modelling [BIM] supports the engineering industry by facilitating management approaches and workflows (Pan and Zhang, 2022). BIM is a set of processes to analyse and communicate information (Sacks *et al.,* 2018a). It can potentially drive and guide project processes with its implementation at business and project levels (Dainty *et al.,* 2017; Sacks *et al.,* 2018a). This assists teams to manage work effectively (Whyte, 2019), effectively supporting MEP workflows.

[1] harshulsingh@gmail.com

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BIM-based models are structured and data-intrusive and are a highly proficient resource to transfer quality design and construction information (Elghaish *et al.,* 2022, Onososen and Musonda, 2022). The industry heavily relies on Industry Foundation Class [IFC] for information exchange, but IFC files cannot reliably transfer information across platforms (Steel *et al.,* 2012; Sacks *et al.,* 2018b, Elghaish *et al.,* 2022). Transaction of information and control of the accuracy of information often remains unclear using IFC (Fulford and Standing, 2014, Hu *et al.,* 2018, Shirowzhan *et al.,* 2020). This creates a need for a manual inspection of the extracted and transferred information, which is tedious to undertake manually, especially for something like clash detection (Sacks *et al.,* 2018d).

This manual process becomes repetitive and increases a company's cost of employees per hour for each process (Tserng *et al.,* 2011; Kang *et al.,* 2020). This implies that there is a need to support BIM with additional systems that remove manual checking. In response to these issues, the focus of this study is the use of automation to support BIM (Bock, 2015; Kang *et al.,* 2020; Zhang *et al.,* 2022) in an MEP design environment. The study introduces an automated coordination process using a generative design solution that supports the running of a synchronized clash detection test as the MEP design progresses. The aim is to explore the crude aspect of BIM automation, forming the basis of artificial intelligence in projects (Autor, 2015; Pan and Zhang, 2022).

Automation in construction targets increasing the efficiency with the use of computing capabilities (Bock, 2015; Sacks *et al.,* 2018b). Automation of these repetitive and tedious tasks will reduce the cost to the company per employee per task. The proposed solution enables the user to run automatic clash detection tests directly from the MEP design environment. It is achieved through developing a visual programming script and the use of Python codes that interact with BIM software (Revit) and run the clash detection tool (Navisworks). The key element of the solution that simplifies the clash detection process is the ability to select specific MEP systems to run individual clashes.

BIM Automation and the MEP Design Environment

Automation is observed as key to improving workflows that deal with data formats, company processes, and technology (Awwad *et al.,* 2020, Onososen and Musonda, 2022, Sacks *et al.,* 2018c, 2018d). In construction, BIM Automation can be observed on site via robotic interventions for assembly, drones for surveying, automated bulldozers, and other labour-intensive works (Bock, 2015; Soto et al.,). BIM Automation is observed to support other emerging technologies in construction like digital twins and the Internet of Things, with widespread presence and acceptance (Chen *et al.,* 2021, Sepasgozar *et al.,* 2020, Wang *et al.,* 2016). Thus, BIM Automation addresses the challenges of integration (Heaton *et al.,* 2019); but it has not yet been widely used to automate processes and address interoperability in MEP Design.

In the MEP environment BIM Automation is observed in targeted aspects of design like automated drainage design systems (Zhang *et al.,* 2022), BIM integration across platforms for facility management (Hu *et al.,* 2017), and rule-based automation to support operation and maintenance (Kang t al., 2020); thereby increasing the efficiency of MEP workflows (Teo *et al.,* 2022). However, these studies explore the applicability of BIM automation by enhancing modelling work, adding information for precision, or analysing project cost data. They are focused individually and lack focus on issues of interoperability.

These isolated solutions do not give a clear depiction of their accountability in an environment (i.e., BIM) where collaboration and coordination are the foundation of processes (Hagedorn *et al.,* 2022). BIM automation can support workflows with basic to complex processes for the MEP design system (Pan and Zhang, 2022). However, its practical applicability is challenged by a lack of focus on the BIM deployment process, increasing the gap between theory and practice, and leading to the gradual disintegration and reduction in the use of integrated workflows (Shirowzhan *et al.,* 2020; Pan and Zhang, 2022). BIM, ideally, should be implemented across every part of a company to support and generate cost benefits for the company (Sacks *et al.,* 2018a). To achieve 'buy-in' from key stakeholders for companywide implementation, BIM automation strategies require evidence-based approaches (Onososen and Musonda, 2022). A company's top management can accelerate or pull back the implementation of automation in a company (Chen *et al.,* 2018). Therefore, the question of how to implement BIM automation across the company will be discussed in this study supported by a practically applied solution.

The challenge addressed in this study is the use of automation to avoid the use of multiple software programs that can be a reason for the inconsistency of information and increase the number of tedious tasks in BIM (Hagedorn *et al.,* 2022). The framework of a developed solution addresses interoperability issues within MEP workflows (Shirowzhan *et al.,* 2020). The developed solution is called the Live Clash Detection System [LCDS] and it enables the running of clash detection tests from the MEP design environment. The user does not need training in external software for clash detection through LCDS. This increases the efficiency of routine workflows and generates long-term economic gains.

METHOD

This study aims to develop a solution that collects information from a BIM model (Revit) and runs the clash detection tool (Navisworks) in the background to retrieve and analyse information. The solution is based on a visual programming script that contains Python codes. The solution uses a graphical user interface [GUI] to initiate clash detection to process and identify clashes. This is done from within the MEP design (Revit) environment and supports design development.

Undertaking a literature review increases methodological rigor, creates a knowledge base to assist technological rules, and identifies challenges (Baumeister and Leary,1997; Tranfield *et al.,* 2003). It supports the development of the solution by providing an in-depth understanding of practical challenges that need to be addressed in the MEP environment (Sacks *et al.,* 2018e; Johannesson and Perjons, 2014). Design Science Research [DSR] aims to solve practical problems of interest and can be applied to disparate problems to achieve a solution (Henver *et al.,* 2004, Johannesson and Perjons, 2014, Elghaish *et al.,* 2022) Hence, this study adopts DSR method to develop the solution for the identified practical problem. Based on the DSR principles, this study follows the DSR guidelines (Henver *et al.,* 2004), as depicted in Figure 1.

Figure 2 addresses the development process of the solution guided by DSR for the MEP sector (Henver *et al.,* 2004). The solution and its process are clearly demonstrated using a graphical user interface for users of all technical proficiency. To check the accuracy and effectiveness of the developed solution, it is trialled across projects at an MEP design consultancy via the United Kingdom's [UK's] academia-industry-oriented Knowledge Transfer Partnership [KTP] programme. The solution is tested in a single organisation, allowing intense, iterative investigation of an issue in its context, as is acceptable using the DSR method (Henver *et al.,* 2004).

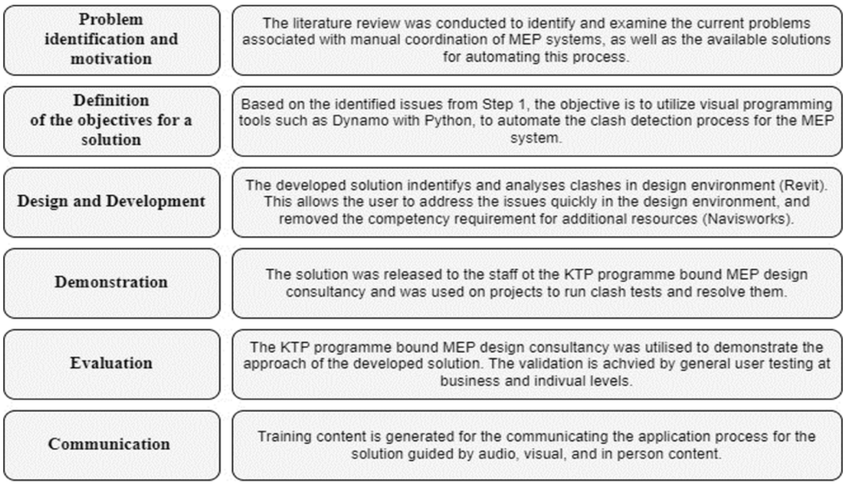

Figure 1: DSR steps of development of LCDS (based on: Henver et al., 2004)

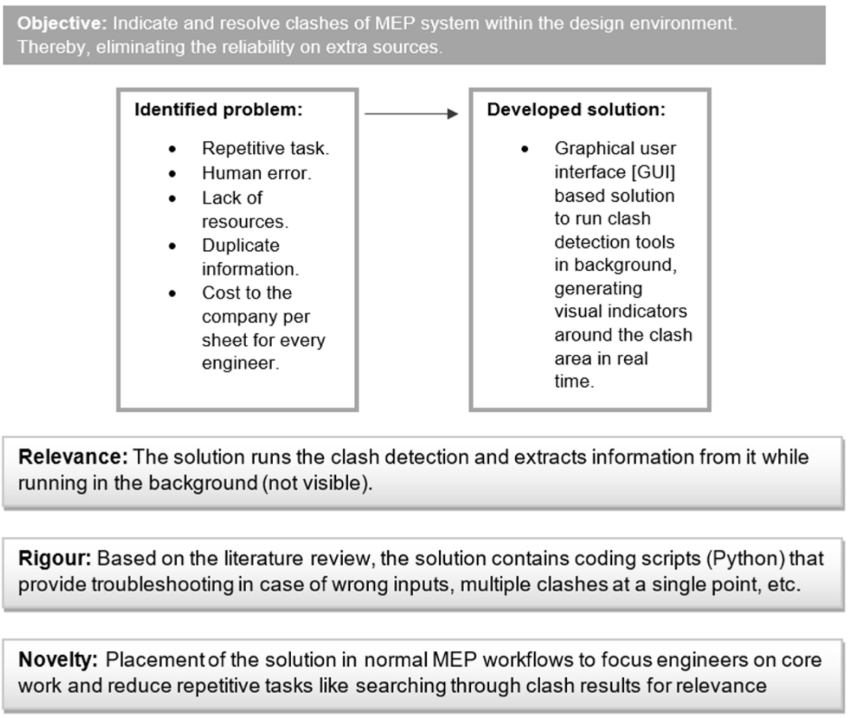

Figure 2: Demonstration of the problem statement guided by DSR (based on: Henver et al., 2004; Engstrom et al., 2020)

FINDINGS

Solution Development

The proposed solution aims to address the challenge of interoperability and issues that arise when more than one software is used to process information in BIM (Shirowzhan *et al.,* 2020; Pan and Zhang, 2022). The solution focuses on indicating clashes in the design environment to quickly address the clashes by visually analysing them in the same environment. This is achieved using visual programming (Dynamo) and coding scripts (Python) with BIM software (Revit). Similar workflows have been commercially produced (Autodesk, 2017), however, their approach is a linear workflow in the ideal situation, where the user interface has not been considered and a third software is introduced (Autodesk, 2017). This does not address user issues like wrong input, duplicate results, multiple clash results in proximity, sequencing of data, etc. (Steel *et al.,* 2012; Sacks *et al.,* 2018b). LCDS produces output considering stakeholders' requirements with added rigour (Engstrom *et al.,* 2020). This addresses user-based challenges and supports the integrity of the information.

To address the problem identified in Figure 2, This solution enables MEP designers to receive immediate warnings for any potential clashes using the newly created synchronous/live clash detection tool.

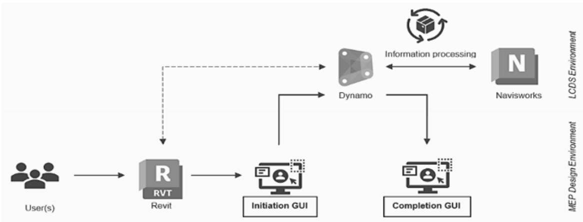

Figure 3: Indicative workflow of Live Clash Detection System [LCDS]

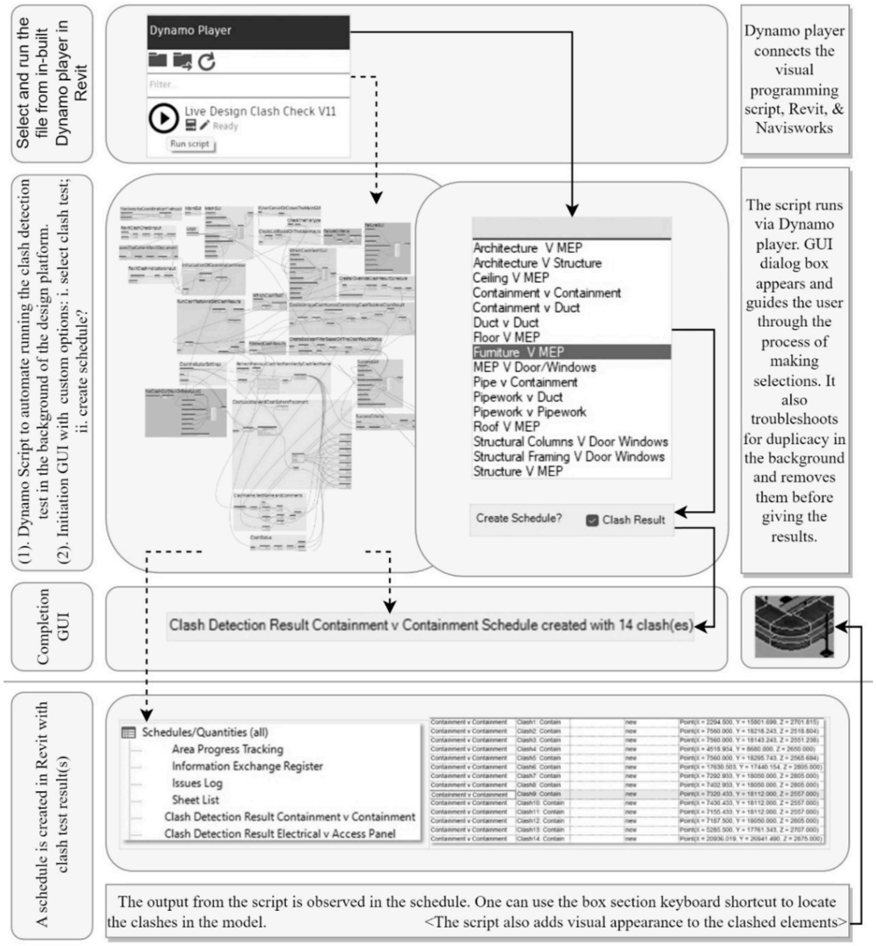

Figure 4: LCDS design and process mapping

This supports the per-employee cost to the company. The solution is developed based on a rigorous methodological approach. Thus, first, based on the literature review, the challenges in the MEP work environment are identified in the context of information management. Second, ne is used to develop a visual programming script in the Revit environment. Next, Microsoft's Dot Net library, Revit's Application Programming Interface, and Dynamo-based packages are used to add Graphical User Interface [GUI] for user simplicity and flexibility (Figure 3). The GUI provides an added advantage by providing the user with information on the application process and outcome. GUI-based user inputs simplify the clash detection process for the user by allowing them to choose what elements to run in the clash test (Figure 4). It also identifies and puts forward user-based issues (if any). All of this is done from the design environment (Revit) and does not require running any external tools.

Evaluation of Solution

A leading MEP design consultancy that is taking part in the UK's academia-industry-oriented KTP programme is the base for the evaluation of the developed solution. An observational method is used to iteratively evaluate the developed solution, LCDS (Henver *et al.,* 2004); observing and recording the use of the developed solution on live projects in a business environment. For robust scrutiny of the developed solution, LCDS was initially added to the workflow for a single project. The use of the LCDS assisted the MEP engineers to reduce time on non-core activities across the project, like undertaking multiple clash results and analysing the results. The outputs from the solution were then used by the human resource department to account for the time required per person on a project by recording time per task per employee for a project, thereby giving a full description of the cost to the company per employee per project. After the successful trial of LCDS on one project, the results were discussed with the company CEO and directors. Results supported by the human resources department showed substantial benefits for business by reducing repetitive/tedious tasks; time saved varied from 0-15 minutes per task (1 employee) to over 90 minutes per task (1 employee) with the median result 30 to 90 minutes (4 employees).

Even though attempts have been made to create similar solutions, their usage is vaguely defined under ideal situations (Autodesk, 2017). The uniqueness of this solution comes from the added agility to modify the solution according to each workflow in the MEP environment. The Python script in Dynamo troubleshoots the possible errors and lets the user know what the next step should be. Thus, creating an automated workflow between the LCDS and the user that excludes relying on external assistance or multiple software to get the task done. One of the key elements of the solution is that it lets the user choose if the clash detection should be done for the entire model or between specific elements of the model (Figure 4). This simplifies and sort clashes to be analysed specifically by the respective project member.

DISCUSSION

The development of LCDS results in a five-click process. LCDS provides a Graphical User Interface [GUI] that runs a clash detection application in the background (clash detection application not visible, nor requires to be started by the user), resulting in the creation of clash indicators within the design environment (Revit). A visual highlight is added to the clashing elements with the use of Revit's graphic styles via LCDS.

On average, running a clash detection test in a specific software does not take a lot of time. However, on a large project, the results typically generate enormous numbers of clashes. The user then needs to go through each result to identify relevant clashes and ignore the rest - a tedious and time-consuming task. LCDS demonstrates clashes directly in the design environment. This incremental improvement rolled out across a project, creates a clear reduction in the number of hours per project per employee. Further, it frees up additional employee hours for more value-adding business activity. LCDS also provides the opportunity to add and update automatic troubleshooting guidance, in case of project or company-specific requirements, without depending on external assistance.

This solution, LCDS, addresses some of the challenges that come with growing knowledge of BIM and complex models (Sacks *et al.,* 2018e). The complexity of the BIM documents and the probability of human error is directly proportional to human competency (Sacks *et al.,* 2018c). Instead of relying on manual competence to verify clash results, LCDS allows the selection-specific MEP system to process the information. For example, an architecture versus MEP model-based clash test will generate thousands of results. In this case, for the MEP engineer, some clashes will be more crucial than others, like the clashes between opening (door and windows) or furniture placement. This is sorted by elements using LCDS with its system-oriented clash detection process based on the user input. It makes it systematically simpler to rule out element-specific clashes. This also relates to increased accuracy and efficiency of the information.

Given that using the GUI for LCDS does not require MEP engineers to have competence in Dynamo or Python, the solution is user-friendly and practical. The user can run Dynamo Player and select LCDS to run the solution. The GUI appears and asks for a four-click input and a final click to confirm the details. The clashes are grouped by the MEP design system before running the clash detection tests via the design environment, making them much easier to analyse and resolve.

LCDS is adaptive by nature and provides an opportunity to increase or reduce clash tests per project. For example, if required, a fire system-based clash test can be added. This allows the company to have the flexibility in their project decision to sign the contract to one or more service systems (mechanical, electrical, plumbing, fire, acoustics, vacuum, etc.) (Wang *et al.,* 2016; Tea *et al.,* 2022) and continue the use of automation via LCDS across projects, new or ongoing.

LCDS is a scalable solution designed with multiple stakeholder engagement (business leaders, human resources, and MEP engineers). These factors make LCDS flexible to be applied to a wider industry and form basis for future studies of varying magnitude (Johannesson and Perjons, 2014, Arsiwala *et al.,* 2023). Further, LCDS, provides a framework for the development of similar other solutions in different situations depending on the requirements. For example, the use of programming to save and name drawings according to the requirements from within the design environment or extending the use of this LCDS with advanced features.

CONCLUSION

Visual programming and Python coding can aid in the process by creating simple, user-oriented solutions like LCDS. It supports user inputs and aids the MEP workflows by allowing ongoing element-specific clash detection as the project progresses. The DSR paradigm includes identification, development, and evaluations that were implemented properly to highlight the way like visual programming to automate the clash detection test and conduct individual clash tests to evaluate the created solution. The release and use of LCDS facilitate seamless working across BIM design platform and reduces the dependency on software proficiency. This study provides valuable insights into existing (clash detection tools) and emerging digital technologies (python coding, automation, etc.) that can enhance MEP design workflows by facilitating the transfer of information directly to the design platform. This provides engineers with extra time leading to economic gains for the company. The solution acts as a foundation for further development as its use progresses across projects.

This study describes the creation and evaluation of a tool, LCDS, to simplify and automate the BIM clash detection process, undertaken as part of a KTP project between industry and academia, aimed at addressing challenges faced by MEP designers. It has used a Design Science Research Method (DRSM) to demonstrate that automation can support MEP workflows, reducing repetitive procedures and providing added time for core design activities. The development of this solution is research-oriented to gain a robust outcome and support the MEP sector. Thereby, contributing to the technical knowledge and practical applicability of BIM Automation in the industry. This work highlights that the effective automation of BIM processes and evaluation of project data, in blend with literature work and emerging technologies can demonstrate the potential gains available, motivating further research in this area.

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VALUE OF MODULARISATION IN HEALTHCARE BUILDINGS: AN EXPLORATION OF THE NUCLEUS PROGRAMME

Kang Tong[1], Grant Mills and Mustafa Selçuk Çıdık

Bartlett School of Sustainable Construction, Faculty of the Built Environment, University College London, 1-19 Torrington Place, London, WC1E 7HB, UK

Minimal attention has been given to the whole-life assessment of modular healthcare building programmes, resulting in a critical lack of knowledge on the overall value of their modularisation. The primary objective of this research is to shed light on the complex questions associated with strategic intent, implementation, and impact of a modular approach to the delivery of healthcare buildings. Through an investigation into the national Nucleus modular hospital programme, this paper aims to articulate the trade-offs between the benefits and sacrifices inherent in a modular methodology for healthcare buildings. This will be accomplished by explicitly examining three dimensions of value, which are strategic (intent) Value, design construction (implementation) Value, and operational (impact) Value. This analysis adds to the conceptual understanding of the value of process modularity in healthcare buildings while also delineating an improved analytical framework for assessing modular value.

Keywords: hospital; modular; modern methods; nucleus; value

INTRODUCTION

Modularisation principles have garnered growing interest in the construction industry, with arguments predominantly emphasising their benefits in terms of cost, quality, logistics and project duration (Wood, 2017). Despite the prevalent positive rhetoric surrounding modularisation in construction, criticisms have emerged regarding the lack of evidence-based research and a narrow understanding of productivity and innovation underlying the modularisation agenda. Therefore, while the discourse of modularisation often refers to it as a value-adding approach in construction, there is a need for holistic analytical approaches to better comprehend its value (Green, 2022), specifically reflecting on the sacrifices made to embrace the benefits of modularity. Modularity has been historically and frequently used in healthcare, the value of modularisation for healthcare buildings has however not been well researched, and minimal attention has been dedicated to evaluating the whole-life perspective of modular healthcare buildings. This paper draws on an exploratory review of past national Nucleus programme, which delivered over 130 modular hospitals built across the UK until 1999 (Francis *et al.,* 1999). The value of modularisation for healthcare in terms of i) Strategic intent value, ii) Design and construction implementation value, and iii) Operational impact value will be explored. This adds to the conceptual

[1] kang.tong.20@ucl.ac.uk

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understanding of the modular value and provides an improved analytical framework to assess the value of modularisation for healthcare buildings.

Literature Review

There is a wide range of modular building terms, such as preassembly, prefabrication, offsite production, offsite manufacturing, and industrialised building (Rahman, 2014). While standard terms have emerged (MHCLG, 2019), these have remained technically oriented on the production process (e.g., pre-manufacturing, materials innovation and site-based) Or the innovations in offsite technology (Pan *et al.,* 2007). Some have focused on the delivery process (e.g., novel materials, manufacture, design optimisation, automation) (Wood, 2017), however few have evaluated the customers' view of value, nor looked at value from a whole life perspective of the programme of modular delivery through into operation. This often means there has been a narrow and short-term focus on the evidence (e.g., a strong focus on the benefits during construct alone). This raises the questions; how do we frame strategic decisions about the adoption of modular approaches? And why should modularity be chosen as a strategic option for a hospital building programme?

In a wider field of literature, modularity is the design of a production system, or a part thereof, to cope with the complexity of many separate items, constituent parts, and details. Baldwin and Clark (1997) Define modularity as a strategy for organising efficiently. It is a theory of design, industrial evolution, and adaptive systems where production-related structures are found within products, processes, organisations, and supply chains (Baldwin and Clark, 2000). This study focuses on process modularity specifically, to move beyond the technical (product-oriented) View of modularity that the construction industry often fixates on. e.g., standardised building system (Sparkman *et al.,* 1999), more latterly platforms (Wood, 2017) And Design for Manufacture and Assembly (Goulding *et al.,* 2015). However, there is a significant gap regarding the broader process of modularity and how it can deliver value in a wider operational service and system perspective, such as healthcare.

Modular process design requires the consideration of more intangible services and experience (Pine and Gilmore 2011). Healthcare systems and services are highly complex, and so modularity can help address this complexity, as can a focus on value and particularly sacrifices. This is the gap between what a customer settles for (as good enough) And their expectations. Compromise is the "cost of a one-size-fits-all solution," so reducing sacrifice is key to reducing the gap between expectations and delivery. This requires continuous learning to address the "sacrifice skew" and eliminate customer sacrifices by innovating, which can create new value (Gilmore and Pine, 2000). In addition, exploring the questions associated with modular systems and service sacrifices is rare within construction management research. We therefore raise the question: What sacrifices, if eliminated, would represent the greatest value to healthcare customers? Then, what has been done in the past to eliminate those sacrifices? This is critical in project-based environments, such as hospital construction, where sacrifices are rarely evaluated. This study addresses known benefits and sacrifices from a previous Nucleus modular hospital programme.

METHOD

The concept of value has a long and rich history, where different disciplines and industries proposed various definitions of value (Holbrook, 1999). In this research, the value of modularisation is conceptualised around the trade-offs between the 'benefits' and 'sacrifices' (Monroe, 1990) In terms of strategic choices, design and construction, and operations, of modular healthcare facilities. This research initially gathered all relevant materials on the Nucleus modular hospital delivery programme in the UK through an exploratory review. To effectively respond to the research questions, these limited materials were then subjected to an in-depth review, including original reports, research publications, journals, dissertations, etc. Data analysis was employed through a deductive coding approach to make sense of the reviewed information, which was categorised under the theoretical themes related to benefits and sacrifices for strategic intent, design and construction implementation, and operational impact. Collectively, these discussions strengthened the conceptual knowledge about the value of modularisation and underscored the significance of analysing such value from a more holistic life-cycle perspective for modular healthcare facilities.

Nucleus Hospital Programme

In 1974, the UK experienced high levels of inflation arising from the oil and financial crises, prompting the government was determined to control and reduce the expansion rate of public expenditure, particularly in terms of capital expenditure on the development of healthcare facilities in the National Health Service (NHS). Developed by the Department of Health and Social Security (DHSS), the concept of the Nucleus hospital programme was proposed as a new model in response to the severe economic challenges and fulfilling the demands of hospital development (Rawlinson, 1987; DHSS, 1987). The strategic intent of the Nucleus programme was to create modestly sized, low-cost hospitals for standard use across the NHS through the establishment of a standardised hospital briefing and planning system, which included standardising department plans and operational policies (Francis *et al.,* 1999; DHSS, 1987). The cost of all new developments and expansion projects was kept under £6 million (equivalent to £50-80m today), seeking to maximise economies in capital and running costs while providing adequate facilities and acceptable clinical service standards.

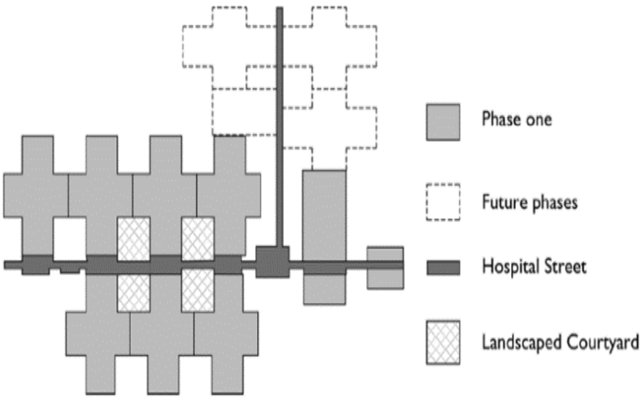

Figure 1: Sample layout of Nucleus modular hospital (Grey et al., 2017)

The first phase was designed for approximately 300 beds with sufficient but limited content provided that could be tailored to meet local needs based on different service planning priorities. Later phases could be expanded to 600-900 beds when more funding became available. Multi-use of space could be realised by establishing favourable functional relationships and clustering of departments. Maximising the use of natural light and ventilation and fire and escape requirements compliance were also among the specific objectives of the Nucleus hospital programme (DHSS, 1976). The concept of Nucleus emerged as a disciplined modular approach to hospital building in response to public expenditure cuts (Ward, 1990). The building shape of the Nucleus modular hospital (Figure 1) Consists of approximately 1000 m2 standardised cruciform units, known as 'templates', which can be aligned horizontally and stacked vertically either above or below any other templates. The layout of the cruciform templates can form whole departments, clusters of small departments, or a low-rise hospital. Vertical transportation involves lifts and stairs, while horizontal connections are formed through 3m wide hospital streets, which provide communications and interactions for goods, people and building services between different departments. Landscaped courtyards are created between the standard templates for facilitating natural daylight and natural ventilation (Rawlinson, 1987).

Three Dimensions of Modular Value

Benefits - Strategic Intent
Economic Advantage: The economics of the Nucleus hospital programme was effectively utilised in many developments by maximising the use of stacked standard templates distributed on both sides of the hospital street. Simple linear plans are the most economical among the various plan layouts, with no apparent abnormal cost penalties for connecting or expanding templates in a linear direction (DHSS, 1987).

Reusable, Adaptable and Updatable: Nucleus schemes can be generated from previously tested elements and solutions, which are adaptable to minor adjustments to meet local requirements and capable of being modified or upgraded in response to policy changes and feedback from user experiences (DHSS, 1985).

Flexible, Interchangeable, Manageable and Predictable: Compared to other hospital planning forms, Nucleus offers greater flexibility in terms of replanning, extension, and change of use. Its internal layouts can be easily reshaped and replanned, and departments can be interchangeable during both the planning and construction phases. Moreover, the scale of the Nucleus project is manageable, and its project outcomes and capital costs are more predictable at an earlier stage than traditional large hospital building contracts (Smith, 1984a; DHSS, 1989).

Versatility of Applications: Nucleus modular programme has been applied in a variety of hospital development scenarios, including the development of whole hospitals on new sites, redevelopments of existing hospital sites, replacements of single departments in existing hospitals, and additions of departments to existing non-Nucleus hospitals (DHSS, 1985).

Phasing and Expansion of Hospitals: The phasing and expansion of Nucleus modular hospitals can be accomplished using various strategies, which depend on the site conditions and development planning strategy adopted. Each kind of expansion solution has its inherent strength and weakness. For instance, a simple linear mode is very compact and economical but is only suitable for narrow sites and can only be extended in a single direction if the established entrance is not altered (DHSS, 1986).

Growth and Change in Departments: The Nucleus modular approach provides a range of growth strategies to accommodate the varied needs of hospital departments. For example, growth can be accomplished through functional changes to the templates and incorporating more standardised templates or small units of pods (DHSS, 1976).

Sacrifices - Strategic Intent
Economics Induced Compromises: The strategic intent of the Nucleus programme required all schemes to realise substantial economic benefits in capital and running costs resulting in a series of compromises. The entire hospital policies and departmental practices were planned with minimal space demands so that space

provisions would be either reduced or below established standards. All departments were required to be planned in compliance with a standard template to meet economic benefits (Francis *et al.,* 1999).

Fragmented Planning and Compartmentalization Across Phases: Financial resources and cost limits resulted in the Nucleus hospitals being built in small phases and departments being split across phases, both of which will cause insufficient service provision in departments and inefficient use of medical and other resources. Phasing process is complex and costly because some departments' functional relationships could be very crucial and close (DHSS, 1987).

One-Size-Fits-All Expansion: A typical Nucleus solution involves starting with limited functions in the first phase and gradually expanding them in subsequent phases. However, this approach could lead to the accumulation of problems that become increasingly difficult to solve later. In practice, expanding the operating departments would require a major redesign of portions of each template to avoid duplication of facilities (DHSS, 1989).

Inflexibility of Template: The flexibility and adaptability of Nucleus template were constrained by policies related to dimensions, structures, and fire safety disciplines (Rawlinson, 1987).

Clinical Service Compromises Limiting Local Innovation: Nucleus plans represent a national consensus, but this may lead to compromises on a local level. e.g., standard solutions and templates may not be suitable for fulfilling the specific needs of local healthcare settings (DHSS, 1989; Scher, 1989).

Low-rise Hospitals might not Fit the Local Context: Preferably, the building floor was restricted to two or a maximum of three storeys. The addition of more storeys proved as a costly option, particularly in the case of rooftop plant rooms (DHSS, 1976, 1987).

Benefits - Design and Construction Implementation
Timesaving: The use of the Nucleus concept as the basis for hospital design can save substantial time and cost on projects by eliminating the overall workload of preparing policies and design solutions. Standard template designs and department plans can also decrease the time spent on design and planning. Leveraging the Nucleus data and experience can assist in shortening the time spent on briefing and planning. However, if the Nucleus brief was not incorporated, disagreements were always challenging to resolve within the time frame of the scheme, resulting in increased time and resource consumption (DHSS, 1985, 1989; NHS Estates, 1993).

Lower Cost: The Nucleus design and construction have proven to be economical in terms of capital and revenue costs. The standard template shape and wall/floor area ratios have shown to be cost-effective compared with one-off hospitals. Predictable project capital cost control can be achieved through the implementation of standardised designs. Lower staffing costs can be achieved due to a reduced workload in project and design teams. Further cost savings can be realised by reducing the fees paid to design consultants and project teams (Smith, 1984b; DHSS, 1985, 1987).

Buildability and Productivity: Nucleus plan layouts allow for phased construction and benefit from the inherent buildability of its building shape, resulting in faster and more efficient project development and a high level of quality control. The use of Nucleus standardised briefs and solutions allows for the rapid assembly of whole hospital plans. The standard cruciform template enables all disciplines to proceed with their designs in a fixed and clear plan form so that the design team can concentrate on developing the non-standard parts of the hospital quickly while devoting their efforts to detailed design development (DHSS, 1985, 1989).

High Quality: Compared to a one-off scheme, utilising standardised solutions provides the designer more time to focus on the details while devoting more effort to creating a high-quality building. The use of Nucleus templates as a basis for design enables all members to work reasonably well on a known basis, which can largely avoid solution discrepancies between the project and design team. Errors in briefing, design and commissioning can be minimised by evaluating and learning from the experience of other similar schemes. Moreover, standardised solutions can present clear information, facilitating the integration of non-hospital specialists into the design team and contributing additional ideas (DHSS, 1985, 1989).

Design Flexibility: Nucleus designs are flexible to accommodate a variety of demands, such as additions, extensions, and internal changes. Standard templates can accommodate several different clinical functions, and non-standard departments can also be accommodated within standard template shapes. The layout of the templates can be clustered to form whole departments or even entire hospitals based on project or local needs. Moreover, single templates can be built as stand-alone units. The design solutions and building forms are readily understandable by a wide range of interested parties, ranging from medical and nursing professionals to planning authorities (DHSS, 1985, 1987, 1989).

Standardisation: The use of standard designs and briefing data that are created for a specific size department can also be applied to produce designs for other departments. Standardised solutions developed in one project could also be advantageous to other healthcare authorities. The use of standardised designs was beneficial to the time and cost. More standard systems would be implemented in a hospital, more time would be saved during the design and construction phase, and fewer costs would be spent on the design and project team (DHSS, 1985, 1989).

Fire and Escape Design: The spatial units of a template can serve as fire compartments and allow for effective containment of the spread of fire. Cruciform template shapes designed for a compact layout provided reasonable escape distances, and their combination formed courtyards offer effective smoke disposal and separation during a fire accident. Horizontal escape can be facilitated by templates on each floor that are linked to the hospital street. Vertical escape benefits from the design of a low-rise hospital building (DHSS, 1985, 1987; Rawlinson, 1987).

Sacrifices - Design and Construction Implementation

Sacrifices of Standardisation: Standardised solutions can be too prescriptive as they lack customisation for specific clients. Standardisation stifles creativity in programme design and eliminates the development of patient-centred solutions. Additionally, relying solely on standardised briefs may restrict designers from fully considering the unique demands of each project, which could be detrimental to the design process (DHSS, 1989; NHS Estates, 1993).

Limitations of the Template: The concept of Nucleus using a single building shape (a standard cruciform template) To fulfil the functional needs of various hospital departments was a source of concern. The fixed shapes and dimensions of templates have proved to be limiting factors, resulting in their inability to meet the requirements of some specific functions, such as the main entrance, energy centre, and catering. In addition, the Nucleus template has been criticised for failing to provide sufficient flexibility to avoid over-rationalising clinical departments into a single 1000 m2 cruciform template. The term "template tyranny" was coined to describe the preceding points (Scher, 1989; Montgomery, 2007).

Rigidity of Design Changes: The benefits offered by Nucleus may be lost if standard designs must be changed extensively, in which case a one-off design may be more appropriate (DHSS, 1985).

Unsuitable for Sloping Sites: Nucleus modular projects may not be an economical option for a sloping site as the structure of the cruciform template was unsuitable for 'cut and fill'. For instance, the site of Hastings District General Hospital had a steep slope from the access road, which made it an inappropriate choice for a Nucleus solution (DHSS, 1989).

Demand for Large Open Sites: Nucleus modular hospital buildings were limited to a maximum of three storeys, necessitating a large site that may not be applicable in an urban area. These hospitals can only be built on large open greenfield sites due to their structural constraints, which may potentially compel hospitals to move towards the surrounding areas of towns where larger and less expensive sites are available (DHSS, 1989).

Benefits - Operational Impact

Economical and Efficient Operations: Nucleus made a significant contribution to the operations of a more economical hospital by addressing the shortage of capital funds required for staffing, supplying, and maintaining facilities. To achieve operational efficiency, Nucleus implemented the zoning and grouping of departments. For example, most outpatients typically receive medical attention in the Outpatient Department (OPD) And require access to pharmacy, pathology, and X-rays. Therefore, grouping these departments in the same zone on the same floor is beneficial for operations. Operational efficiency can also be enhanced by clustering compatible departments and locating those with daily operations that require close collaboration on the same floor (DHSS, 1976, 1987).

Fire Safety: The parallel positioning of the Nucleus templates efficiently applied the principle of horizontal evacuation, allowing a ward or department to evacuate first to neighbouring templates and subsequently into the hospital street. The hospital street was not only a typical Hospital corridor but also a safe place to evacuate patients and escape in a fire. Thus, the connection between templates and hospital streets eventually realised the principle of horizontal evacuation. Nucleus hospital departments can be classified into different categories to improve fire safety measures. e.g., high-life risk departments (wards) And high-fire load departments (disinfection units) Can be separated vertically and horizontally (DHSS, 1987; Montgomery, 2007).

Energy Conservation: Cruciform template shapes performed well in energy efficiency against low-energy hospital design criteria. Their assembled courtyards optimise the efficient utilisation of natural light and ventilation in hospitals, particularly in the main circulation route and top-floor wards, significantly decreasing energy consumption. Concentrating all wards on upper floors maximises the benefits of natural light and ventilation, thereby contributing to energy conservation (Smith, 1984a; DHSS, 1987).

Longevity: 'Long life' view of buildings was considered one of the objectives pursued by the Nucleus modular approach. With proper planning, the expected building lifespan of Nucleus would exceed 60 years, but during this period, the building services configuration may require replanning or refurbishment, and the functions of the building may also change (DHSS, 1987).

Maintainability: Most engineered distribution ducts are situated outside the templates and on the roof of the hospital street zone. The location of the energy centre avoids passing fuel gas or service pipes through clinical department areas. Maintainability can be improved with this solution, as repair or installation service access would not cause excessive disruption of hospital operations (DHSS, 1987).

Shorter Travel Distances: In contrast to most other hospitals' plan forms, Nucleus offers a clearer and more compact circulation route and layout centred on hospital streets. This design provides the distinctive benefit of shortening travel distances within the building and lowering maintenance costs (DHSS, 1987; Rawlinson, 1987).

Humane Environment: Nucleus provided a humane and comforting environment for the hospitals by limiting most of the buildings to two or three storeys and incorporating a courtyard approach, which the patients and staff highly appreciated (DHSS, 1989; Montgomery, 2007).

Streaming Patients: Nucleus modular hospitals allow for an effective system of streaming patients by utilising special cruciform entrance templates (DHSS, 1987).

Wayfinding: The courtyards formed between the templates of each building allow for the entry of natural light, providing both clinical departments and hospital streets with access to daylight and views while assisting with wayfinding (Montgomery, 2007).

Sacrifices - Operational Impact

Shortage of Space: Lack of storage space in the wards has been criticised as a long-term issue, resulting in the accumulation of excessive equipment. Insufficient space in operating theatres affects multiple areas, including office space, restrooms, staff changing areas, and preparation rooms. For instance, the nursing staff's offices had to be set up outside the department due to a lack of available space in operating theatres. Inadequate working space and facilities supplied to staff are common criticisms of Nucleus hospitals, particularly when compared to space allocated to patients. A specific example highlighting this disparity was the shortage of workspace provided to doctors and their secretaries, which led to the conversion of seminar rooms into offices within the wards (Smith, 1984a, 1984b; Rawlinson, 1987; Scher, 1989).

Limitation of Space Reuse: The standard Nucleus paediatric department at Maidstone Hospital had 40 beds, but only 24 were in use. However, due to its location, this space is challenging to reuse and unable to assist in relieving the pressure caused by space shortage (Smith, 1984b).

Congestion in Shared Spaces: Too much activity occurs in a shared space. For example, additional and unforeseen activities created congestion in the shared exit areas of the two operating theatres (Rawlinson, 1987).

Limited Content and Squeeze: Limited content is a specific criticism of Nucleus hospitals raised by the medical profession. In some of the earliest Nucleus modular hospitals, there was a lack of proper preparation rooms for operating theatres. Nucleus offered flexibility in the overall layout of hospitals by cramming everything into a single template shape but squeezing emerged in some places e.g., accommodation was crammed into a small space (Smith, 1984a; Scher, 1989).

Imprecise Matching of Functions: Sometimes the Nucleus template plans, and the required functional content may be an imprecise match. A notable example is the case of Hastings District General Hospital, where the need for seven operating theatres and nine radio-diagnostic rooms did not align with the template plan (DHSS, 1989).

Compromises on Template Shape for Departments: The Nucleus template was considered too restrictive in terms of shape and area. A standard shape would be unlikely to accommodate all departments in all hospitals, and the cruciform structure often resulted in an uncomfortable and for some departments an ill adapted shape. Nucleus was constrained by its cruciform shape because a single building shape could be wasteful or unsuitable for local requirements. Instead of relying solely on a completely pre-planned template, it would be beneficial to have a set of different plan shapes that could be offered as options or used for guidance (DHSS, 1989).

Deficiencies of Wards: The wards were the most used and frequently criticised template. Many believe it was too small, poorly planned, and insufficiently functional, and even adding pods would not solve all these issues. In addition, the shortage of seminar space in the wards was a recurring criticism, and inadequate treatment rooms on the wards were a frequent request (DHSS, 1989).

CONCLUSIONS

As a national standard, the Nucleus hospital programme serves as a benchmark for all modular hospital schemes, and its success can be justified in the delivery of over 130 projects across the UK. However, the recurring criticisms have been reflected to some extent in the sacrifices made by the Nucleus hospital programme to integrate modularity. As a result, the benefits of the Nucleus modular solution must be balanced against the sacrifices incurred. Like any solution, Nucleus must navigate a trade-off between a range of benefits, priorities, compromises, and sacrifices. The overall value of Nucleus will depend on its appropriateness to local needs and circumstances, necessitating evaluation from a life-cycle perspective that considers the value dimensions of strategic intent, design/construction implementation, as well as operational impact.

Hence, when considering the value of modularisation for healthcare facilities, it is essential to adopt a holistic, life-cycle view that recognises the complex relationships and trade-offs within and among the three dimensions of value. This study provides a broader insight into the value of process modularity in healthcare systems through an assessment of the Nucleus programme. The outcomes will aid in the development of conceptual and analytical frameworks for evaluating the optimal solutions for the procurement of new hospital buildings and provide a basis for decisions on capital investments in future modular hospital programmes. However, the limitations of this study arise from the lack of investigation into the perspectives of Nucleus participants and real-life cases. Future studies should consider incorporating these elements to fortify the findings and refine the proposed analytical framework.

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TECHNOLOGY ADOPTION IN PUBLIC CLIENT ORGANISATIONS: INSTITUTIONAL PERSPECTIVES FROM SWEDEN AND THE NETHERLANDS

Daniella Troje[1] and Ruth Sloot[2]

[1] *Department of Real Estate and Construction Management, KTH Royal Institute of Technology, Teknikringen 10B, Stockholm, 100 44, Sweden*

[2] *Department of Civil Engineering and Management, Faculty of Engineering Technology University of Twente, PO Box 217, 7500 AE Enschede, The Netherlands*

Public construction clients are slow to adopt new sustainable technologies, which is problematic if public clients want to lead the charge of constructing for the future. This inertia is investigated by studying two cases: Swedish public housing companies and the Dutch public infrastructure agency. By applying an institutional logics framework and comparing the challenges of technology adoption in two different contexts (Sweden vs. the Netherlands, housing vs. infrastructure, small client vs. large client), the findings show how technology adoption is difficult due to uncertainty avoidance and institutionalised norms, values and physical infrastructure that do not support necessary changes needed to adopt new technologies. Also, the organisations struggle to reconcile conflicting logics of cost vs. sustainability, efficiency vs. flexibility, and a short-term project-related corporate logic vs. long-term asset management logic. The paper contributes an understanding of how and why changes that enable technology adoption is limited in public client organisations, and what issues must be addressed for public clients to construct for the future.

Keywords: change; institutional logics; public client; technology adoption

INTRODUCTION

For the construction and real estate sector to construct for the future, adopting new technologies will be especially vital to enable a transition to more efficient and sustainable practices (Bokrantz *et al.,* 2020). Public clients have a large role to play to drive innovation in the sector to contribute to sustainable development, due to their mission to fulfil public values, but also because of their influence over the market and considerable purchasing power. To adopt new technologies requires changing old ways or working and thinking, and the technologies themselves introduce new work practices, roles, and values. However, previous research has found that the sector in general, and public clients in particular, are risk averse and slow to adopt new sustainable technologies (Papadonikolaki *et al.,* 2022). In response, this paper seeks to understand the institutional mechanisms underlying this inertia that limits this change, where the purpose of this paper is to investigate the challenges that public client organisations face in adopting new technologies. An institutional logics

[1] troje@kth.se

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framework is applied as this can help explain what these challenges are and why they occur.

The paper builds on a multiple case study of two types of public client organisations in two geographical settings. The first case is of public housing companies in Sweden, and the second case is of the public infrastructure agency in the Netherlands. The two cases provide a good base for comparison, as they share some similar features, such as being well-developed economies and subject to EU regulations, and by working to manage, maintain, improve, and refurbish their assets. The studied organisations are thus conducting the same type of work, to maintain their assets as best possible, and both deal with the built environment and have a big impact on public well-being. They also share some dissimilarities, like the size of the organisations and types of assets. By comparing the experience of technology adoption in two different geographical contexts and in two different sub-sections of the sector (housing vs. infrastructure, small client vs. large client), we can get a more comprehensive understanding of why change to enable technology adoption is limited.

Institutional logics and the institutional context of public organisations within housing and infrastructure

To understand the challenges that public client organisations face when trying to adopt new technologies, it is useful to understand their institutional and socially constructed context, as this impacts on their ability to change to accommodate new technologies. Institutional logics is one way to do this. Institutional logics are widely held shared values and beliefs within a specific community, and these prevailing, taken-for-granted values and beliefs influence practice, change, and legitimacy (Friedland and Alford, 1991). This means that legitimacy often trumps efficiency (Battilana and D'Aunno 2009). Thereby, institutional logics provide scripts for action and create heterogeneity within the field (Martin *et al.,* 2017; Reay and Hinings 2009). Material and immaterial structures and values that support a dominant logic is difficult to divert from, and thereby limits ability to change (Modell *et al.,* 2007).

It is not uncommon for multiple parallel institutional logics to coexist within the same field. Sometimes these parallel logics are conflicting, causing instability within the field. This pluralism can arise either due to endogenous factors such as old logics no longer being useful, or due to exogenous factors such as the introduction of a new technology or crises that demands a shift in logics (Martin *et al.,* 2017). So, contradictions and conflicts between parallel institutional logics can lead to change where new logics become dominant and displace older logics (Reay and Hinings 2009).

Sweden and the Netherlands are similar in their institutional context in terms of public management practices, strong EU regulations, and structure of the built environment. Within both these contexts, public organisations are often described as institutionally pluralistic (Kadefors 1995; Volker and Hoezen 2017; Nederhand *et al.,* 2019; Fred 2020; Maine *et al.,* 2022). Since the introduction of the new public management movement with its market and industrial ideals of customer service, economic rationality and efficiency, public clients have long had to balance this mindset with the traditional public bureaucracy logic of regulation and democracy (Fred 2020).

Public housing companies influence sustainable development via its large square footage within the built environment, and its role in promoting well-being and quality of life. Public housing companies engage in facilities management (FM), which concerns the use, operation, development, maintenance, and improvement of housing

(Nielsen *et al.,* 2009). Public housing companies function like a hybrid organisation that are driven by market ideals and competitiveness that pursue financial prosperity, while simultaneously being driven by public, social and environmental goals of supplying housing for all demographics. This goal multiplicity creates ambiguity and tensions where different institutional logics compete (Maine *et al.,* 2022).

Infrastructure agencies also have a large role to play in sustainable development. Infrastructure projects negatively contribute to climate change through its large consumption of natural resources, waste generation, and global greenhouse gas emissions (Ahmed *et al.,* 2022), and public infrastructure agencies have considerable power over what gets built and how things are built (Volker and Hoezen 2017). Infrastructure agencies are also a type of hybrid organisation with institutional multiplicity where they embed a corporate logic of efficiency, and bureaucratic and public values. These agencies also embody a project-based logic with a more short-term focus, and a more long-term strategic asset management logic (Frederiksen *et al.,* 2021), which is concerned with management, maintenance, and renewal of the asset portfolio, like roads or bridges (Schraven 2015).

METHOD

Institutional logics come into being through material and immaterial symbols, practices, and language (Reay and Jones, 2016), which is why a qualitative research design was chosen. The paper builds on a multiple case study of two public client organisations, housing companies and an infrastructure agency, in two geographical contexts, Sweden and the Netherlands. This approach allows for a more comprehensive view and provides an opportunity to compare and distinguish the finer mechanisms governing two different types of organisations in two different contexts.

The first case study was conducted by the first author and is of Swedish public housing companies and their FM operations, i.e., organisations that own and/or manage residential housing for rent (>4000 apartments) of different kinds (high and low-income housing, old and new building stocks). These housing companies are trying to transform their daily FM operations to become more sustainable and efficient, partly through the addition of new technologies and 'proptech'. To get both breadth and depth to the results, 2-3 people from each housing company were interviewed, resulting in a total of 14 interviews (see Table 1). The interviewees were purposefully chosen because they worked on a strategic level within their respective organisations and thereby were overseeing and setting the strategic direction of FM and development work within their organisations. The interviews lasted approximately one hour and were conducted over Teams or Zoom in the winter and spring of 2021-2022. Observational data from three FM industry conferences was also collected. The conferences took place during the winter of 2021, 2022, and 2023, and had speakers from both industry and government organisations.

Table 1: Interviews from the public housing companies (PHC) in the Swedish case study

Organisation	Interviewees	Anonymous codes
Public housing company A	Business manager; CEO; FM manager	PHC A 1-3
Public housing company B	Property manager; Property developer; FM manager	PHC B 1-3
Public housing company C	FM manager; Sustainability manager; CEO	PHC C 1-3
Public housing company D	Business manager; CEO; Energy manager	PHC D 1-3
Public housing company E	Development manager; Chief project manager	PHC E 1-2

The second case study was conducted by the second author and is of the largest public infrastructure agency in the Netherlands. The principal data set was comprised of observations conducted at the start of a process to adopt a new digital platform which was meant to streamline and collect the organisation's core activities (project management and asset management) into one space. The observations followed the adoption process from its start in late 2019 and lasted until its end in late 2022. In total, 190 hours of observations of meetings were conducted, and secondary document data, such as digital archival material, emails, memos, and presentations were collected. Also, four managers that oversaw the technology adoption were chosen for observation and interviews, as they had both the strategic overview and operative responsibility of adopting the new digital platform. In total, four managers were interviewed 20 times (see Table 2). The interviews lasted approximately one hour and were conducted over MS Teams. The field notes are labelled FN#.

Table 1: Interviews from the public infrastructure agency (PIA) in the Dutch case study

Organisation	Number of interviews	Interviewees	Anonymous codes
Dutch public infrastructure agency	8	Project information manager	PIA1
	7	Managerial executive	PIA2
	3	Innovation manager A	PIA3
	2	Innovation manager B	PIA4

The multiple sources of data enabled triangulation and validation of the results, both within and between each case (Denzin 2009). The data were collected similarly, where observations were documented in detailed field notes and interviews were recorded and transcribed verbatim. Interviews were semi-structured for interview flexibility (Kvale 2007), and the interviewees were purposefully sampled based on their influential position and overview of technology adoption activities.

Both cases were thematically analysed (Braun and Clarke 2006) to identify patterns and themes in the data. The initial inductive coding round was conducted by each author respectively, due to the language barrier of the data sets, to identify excerpts in the data that described and explained the underlying mechanisms of technology adoption. These codes were given English labels that described their content. After this first coding round, a joint analysis to find common patterns across the two data sets were conducted jointly by the authors in person in a collaborative manner. After this, a more abductive analysis began where the themes identified in the data sets were compared to and contrasted with the theoretical framework of institutional logics in an iterative manner (van Maanen *et al.,* 2007). This produced more theoretically informed themes that were used to structure the Findings chapter. After writing up the findings, a final joint comparative analysis was conducted to find similarities and disparities between the two cases, moving abductively between the empirical data and theoretical framework. This final comparative analysis is presented in the Discussion chapter.

Findings from the Swedish Case

New resources and unfavourable institutionalised norms and practices
One major reason for why technology adoption is difficult in the Swedish housing sector is that the sector can be change resistant and technologically immature. According to the interviewees and speakers at the industry conferences, different types of 'proptech', i.e., digital solutions like AI-run buildings, BIM (building information modelling), digital twins, sensors to monitor building performance, and apps to

communicate with tenants, is an exciting, but complex, future development of the sector, but current systems, technologies and tools are under-developed, inefficient, and difficult to use. To change this negative situation, investments like technical and digital infrastructure, knowledge, time, and staff are inevitably required.

One necessary resource that is lacking relates to knowledge. Those working in the sector are unfamiliar with working with newer technologies and systems and are more used to working manually to manage the housing stocks: "We need skills to train our staff because newer buildings are very technical, so we need competence in how to actually manage these buildings and understand how they work" (PHC B3). Many of the more prominently discussed technologies, like BIM or digital twins, provide a magnitude of data that housing companies do not know how to interpret: "We have AI, and then we have a ton of data. And when we have all that data, we need to know what to do with all that data. Because we collect a bunch of data, but we don't know what to use it for" (PHC D2). The sector is thus technologically immature.

One speaker at the second industry conference emphasized that understanding how to manage buildings using digitalisation and tenants' digitalisation needs is one of the most vital issues for the future of FM. Unfortunately, in a survey taken during the third industry conference, client competency and experience were believed to be the foremost barriers to digitalising an existing building. This analogue and manual way of working is widespread, and because there is a lack of knowledge on how to manage complex technologies and digital systems, this can cause stress for employees who are not used to, or uninterested in, working more digitally. Another necessary resource relates to infrastructure to implement newer technical solutions. Most housing stocks are older, analogue buildings, that are not prepared for more technical solutions. For example, there is no use in installing a smart, more efficient heating system if the ventilation does not support it in the first place.

Another major barrier brought forth by the interviewees and industry speakers is the inability for many housing companies to scale up different initiatives: "This is where our industry is absolutely terrible, to scale up, because all we have are projects" (PHC C1). The interviewees express how housing companies are positive to test things out, but very bad at making it a permanent part of their organisation. Further aggravating the situation is that some housing companies have such a large housing stock: "Firstly, it becomes an insurmountable task. Secondly, its bloody expensive when you tabulate everything together. So that's when we say that we just won't do it, not in a single building" (PHC D2). There is also a fear to install new technologies before they have proven their usefulness. For example, older more manual features, like manual locks, may last for 50 years or more, while a digital lock requires service every few years. There are thus many practical and institutionalised barriers to technology adoption.

Trade-off between cost and sustainability

Adopting new technologies leads to a conflict between different goals, like sustainability, economy, and efficiency. Adopting new technologies means embedding new materials and energy consuming systems within the building stock, like digital twins, digital locks, or security cameras. In effect, it can be difficult to know if the technologies are more socially and environmentally sustainable, so it is important to think about the life-cycle impact of such technologies. A speaker at the second industry conference emphasized how using IT systems that in detail maps the housing stock also means new risks like cyber security. So, there can be a trade-off between efficiency and security, an unintended negative outcome of new technologies.

Another goal conflict relates to what tenants want and what housing companies want: “You think that tenants will demand a lot of digitalisation. But tenants don’t ask anything about digitalisation, it’s a non-issue, but housing companies think digitalisation is really exciting” (PHC C3). Also, public housing companies often provide housing to low-income demographics, who are sensitive to rent increases. Because technology adoption can be costly, this may negatively affect price sensitive tenants, who may be forced to find housing elsewhere if investments are too steep.

Cost vs. technology adoption is said to be a major trade-off. Despite many housing companies having good financial status, investing in technologies is expensive with uncertain value for money, especially if certain technologies are newer on the market or under development: “Development costs money. It’s a catch 22 really, because we are not willing to pay for something that isn’t yet developed, but you have to have money to develop something” (PHC B3). Technologies that are well-developed, like BIM or digital twins, is often seen as financially risky investments anyway, because there is a lack of business models substantiating such solutions: “We have a lot of smaller buildings, where it is difficult to get any financial gain. If we have a high-rise, it’s very simple, but in three story houses it’s more difficult, because digitalisation costs a lot” (PHC C1). This financial discourse centred on value for money, costs, and business models is a central theme of the Swedish study.

Findings from the Dutch Case

Segmentation of construction and maintenance practices
The Dutch public infrastructure agency faced challenges in adopting sustainable digital technologies mainly due to division of resources between a project-based sub-unit that was responsible for construction of infrastructure assets, and an asset management sub-unit that was responsible for the maintenance of infrastructure assets. Each organisational sub-unit made use of information systems that were specific to each and did not support communication with each other. The segmentation of resources for projects and for asset management have led to a lack of coherence in user needs, which hindered the adoption of digital technologies.

These two organisational sub-units represented conflicting strategic imperatives. Digital innovation managers struggled to adopt technologies that meet the needs of both project teams, who prioritise short-term project efficiency and deadlines, and asset managers, who prioritise long-term asset resilience and conservation. A digital innovation manager expressed in an email: "In addition to [the asset management] need, we see various developments around [digital technologies], the impact of which, timing, ownership and, above all, coherence, is not clear to us, so that we cannot estimate whether and how these initiatives provide a timely solution for [the] projects" (FN112). These conflicting user needs led to a split, where some actors pursued the needs of projects, while others pursued the needs of asset management. This conflict was evident in the year-long discussions regarding the goals of a pilot project, where users were unable to generate a consistent representation of their expectations.

Via email, one of the digital innovation managers emphasized that they should start from the bottom up: "Which organisational goals do we aim to contribute to? For whom do we [adopt digital technologies] and are our priorities right? … Who does the request come from and which 'higher purpose' is being pursued?" (FN112). Another digital innovation manager disagreed and expressed this in a reply: "On the first point we clearly have a disagreement. I understand that you approach your work from an asset management perspective. I also think that these are things that eventually must happen. But I just think that we're not doing it in the right order, and then we won't have a product that we can implement on projects. If this is ultimately not your goal, we should look at alternative ways of solving this" (FN42). The conflicting goals and logics of the two sub-units thus caused open conflicts between organisational members, who struggled to reconcile their differences.

Trade-off between efficiency and flexibility
Conflicting logics of efficiency and flexibility also hindered the adoption of digital technologies. Pilot projects are commonly used to test new technologies and determine their added value. However, the agency often demanded guarantees of added value, leading to reluctance to try out new technologies in complex infrastructure projects. This became apparent when one of the projects withdrew from the pilot: "[Withdrawing] takes the risk away from the contractor. At the moment, there will be no more investments from the project to work on [a digital technology]. Data exchange will occur in the way that is the standard at this time within [the organisation], starting with the traditional working method" (FN508). The organisation thus quickly reverted to their old, established practices.

Also, digital technologies continued to evolve even after adoption, as it was relatively easy to edit code and add new features to the software. The organisation found it difficult to understand the consequences of the ongoing modifications, which could result in changes to work procedures and project contracts vulnerable to contractor opportunism. As a digital innovation manager stated: "The contractor must come up with a transition plan for the moment that [the agency] is ready to migrate to the new [version of the digital platform]. But when is this moment?" (FN34). Project managers aimed to specify clear deliverables for contractors to estimate associated costs and capacity accurately, while the adoption of digital technologies demanded flexibility and adaptability from contractors, resulting in tension between striving for efficiency and allowing for flexibility. This conflict contributed to weak technology adoption.

DISCUSSION

It is clear from the two cases that both are struggling with technology adoption due to constraining and conflicting institutional logics that limit the ability to change, although the basis for these struggles somewhat differs. The institutional contexts are similar in the two cases, so what mainly differs is the section of the sector (housing vs. infrastructure) and size of the client (small vs. large). The Swedish case legitimise technology adoption mainly by claiming that the technologies will contribute to sustainable development, and operations will by default become more efficient. The Dutch case instead legitimise technology adoption by claiming that the technologies will be more efficient when the organisation shares one digital platform, and by doing so infrastructure assets can become more sustainable as asset management knowledge can be embedded in construction projects. The Swedish case thus focuses on sustainability, with efficiency as a positive by-product, while the Dutch case focuses on efficiency, with sustainability as a positive by-product. A reason for this difference may be because the housing companies are so much smaller; they may not have efficiency of scale to tie into. The infrastructure agency is on the other hand large enough to benefit from efficiencies of scale.

Another difference is how the Swedish case is very focused on the financial bottom line and cost of technologies, while the Dutch case is more focused on efficiency and coherence across the two sub-units. A reason for this may also be due to the smaller size, and thereby budget, of housing companies. Another reason may be because there are private equivalents that work very similarly to public housing companies. This means that there is a commercial business model that public housing companies can model themselves after. In contrast, there is no private equivalent to the infrastructure agency, so they do not have a private organisation or business model to imitate.

There are also similarities between the two cases, especially in terms of how they struggle to reconcile conflicting institutional logics. Housing companies are driven and shaped by an ideal to be more profit driven, and the infrastructure agency is driven by an ideal of being more professional and efficient. Both these ideals can be seen as part of a market logic (Fred 2020), albeit representing different features of this logic. Both cases also display signs of uncertainty avoidance, in terms of not adopting untested technologies or withdrawing from pilot projects. The introduction of a new technology can be an exogenous force causing institutional instability and pluralism (Martin *et al.,* 2017; Reay and Hinings 2009). As organisations prefer to be in status quo, disrupting the institutional environment by adopting a new technology may be something that organisations consciously or subconsciously try to avoid supressing conflict and uncertainty in the field.

Both cases share the tendency of projectification, where technologies are tested in projects but rarely embedded in the whole organisation, with a short-term perspective dominating planning activity. In addition, both cases show reluctance in abandoning old practices in favour of new ones, where there is hesitation to make the necessary knowledge, financial, and infrastructure investments to support technology adoption (Modell *et al.,* 2007). Smaller clients have the flexibility to test new technologies in individual housing stocks but fail to commit financial resources and scale up successful technology adoptions. Vice versa, the larger client can more easily secure resources for wider technology adoption but are unable to adopt the technology cohesively throughout the organisation's two sub-units. Both cases also share a problem with time horizons. Housing companies and the project sub-unit of the infrastructure agency both tend to overemphasize short-term goals, but to construct for the future a much more long-term perspective must be adopted, even in projects.

The collective struggle with adopting digital technologies also stems from the conflict between dominant logics in facility/asset management (Maine *et al.,* 2022; Schraven 2015) and the logics embedded in digital technologies. Both cases deal with managing tangible assets and physical space, and, although there may be exceptions in both cases, much of the facilities and assets are timeworn. The management of existing buildings and infrastructure are associated with logics that prioritise values such as stability, continuity, and preservation (Nielsen *et al.,* 2009; Schraven 2015). These are reflected in the use of familiar building materials and techniques, and the adherence to established building codes and regulations (Kadefors 1995). On the other hand, digital technologies are intangible and occupy virtual space, and are associated with logics that promote innovation, flexibility, and adaptability. These are reflected in the malleability of digital technologies, in which software code could be easily edited and features could be added or removed, where the opposite is true for existing buildings and assets. Due to these differences in logics, the public client organisations in the two cases found it difficult to adopt digital technologies.

CONCLUSIONS

This paper sought to investigate how public client organisations adopt new technologies to become more efficient and sustainable, by applying an institutional logics framework to two cases of public client organisations (housing companies and infrastructure agency) in Sweden and the Netherlands. It is clear from the findings that regardless of geographical context and organisation type, public client organisations struggle to change to enable the adoption of new technologies. This failure to adopt new technologies thereby becomes a failure to innovate and makes sustainable and efficient construction and operation under-institutionalised.

The findings show how there are many similarities in why technology adoption is limited in public client organisations. The main issues relate to institutionalised norms, values, and physical infrastructure that limits change that is necessary for adopting new technologies. In addition, the organisations struggle to reconcile conflicting institutional logics of cost vs. sustainability, efficiency vs. flexibility, and short-term project-related corporate market logics vs. long-term bureaucratic asset management logics. Hesitation to forgo old practices and invest in new, potentially costly, technologies limits adoption through actors' uncertainty avoidance.

The paper makes several contributions to construction management research and practice. For construction management research, the paper contributes an understanding of how and why technology adoption is limited in public client organisations. This is especially pertinent as housing and infrastructure are so closely tied to public values, individual well-being, and public accessibility (Frederiksen *et al.,* 2021; Nielsen *et al.,* 2009). Public clients need to drive innovation and lead by example to construct for the future to contribute to a more sustainable and efficient built environment. By applying an institutional logics framework, the paper illustrates underlying mechanisms that hinders change for technology adoption. If public clients fail to lead by example and fail to adopt new technologies, sustainable development in the sector may be diminished, which is problematic considering the sector's considerable detrimental impact in the environment (Nielsen *et al.,* 2009; Ahmed *et al.,* 2022). For practitioners, the paper highlights what challenges must be addressed and what change is needed for effective technology adoption. Future research could more closely look into how organisations prioritise between conflicting logics, and what consequences this has for innovation and sustainable development.

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DIGITALISATION

DRIVING CIRCULARITY WITH TOTAL BIM: AN INTEGRATED APPROACH TO DATA-DRIVEN DESIGN

Oliver Disney[1], Mattias Roupé and Mikael Johansson

[1] *Division of Construction Management, Architecture and Civil Engineering, Chalmers University of Technology, 412 96 Gothenburg, Sweden*

Despite the significant environmental impacts of the construction industry, the sector lacks practical decision-making tools to increase material reuse. Building Information Modelling (BIM) can address this by facilitating data-driven decision-making. Total BIM, a growing trend in the Nordic region, implements model-based design and construction with a single source of information. This research presents a case study of a Total BIM office renovation project, where innovative BIM and digitalisation processes were implemented to increase material reuse. These processes enabled proactive, data-driven decision-making, minimising CO2 emissions. The building's concrete structure was preserved, and various components such as plasterboards, radiators, ceiling panels, doors were all reused and evaluated for CO2 emissions. The Total BIM approach was enhanced by attaching material reuse data to objects to reduce waste. The data draws on interviews, workshops and a study visit from a unique case study project in Sweden. Findings highlight how tougher emissions regulations could be the tipping point for pushing BIM implementation in projects as we think about constructing for the future.

Keywords: digitalisation; BIM; model-based construction; circularity; drawingless

INTRODUCTION

According to the UN's Strategic Plan 2020-2023 climate change is one of the greatest challenges facing cities (United Nations Habitat 2019). Buildings in Europe account for 40 percent of energy use and 36 percent of greenhouse gas emissions (European Commission 2021). Renovation is an effective way of reducing the energy footprint of buildings since 85 percent of today's buildings will still be in use in 2050 (European Commission 2021). The construction sector in Europe is responsible for half of all resource extraction and a third of all waste (European Commission 2014). To address climate concerns, especially CO2 emissions from the construction industry, more attention needs to be given to material reuse and circularity in renovation projects.

In Sweden, emissions from the operating phase of a building are limited by energy management requirements (Boverket 2011). Until recently there have been no rules governing emissions during the construction phase. From 1st January 2022, a new act on climate declarations for buildings came into effect in Sweden, which aims "to reduce the climate impact from the construction stage" (Boverket 2021, Sadri *et al.,* 2022). However, this policy is limited. Contractors are required to report the climate

[1] oliver.disney@chalmers.se

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impact during the construction phase but there are no limits, requirements, or maximum permitted values (Boverket 2021, Sadri *et al.,* 2022). The policy intends to make contractors more aware of climate impacts (Sadri *et al.,* 2022), but it does not include all building elements. Furthermore, there are currently no requirements to make climate declarations for building refurbishments, which according to Boverket (2020), "involve the removal and use of large amounts of material, causing relatively large climate impacts which would, of course, be beneficial to reduce."

As tougher rules and regulations are gradually being enforced to meet the EU's goal of net-zero emissions by 2050 (European Commission 2019), construction industry actors are beginning to implement strategies to tackle the challenge. Companies that are prepared to change their approach to use digitalisation as the driving factor can lower the climate impact from new build and renovation projects by up to 40 percent (Smart Built Environment 2020). Therefore, climate declarations may drive the industry to become more digitalised as we construct for the future.

Circularity and BIM

Even though greenhouse gas emissions are decreasing relative to production in the Swedish construction industry, the amount of waste generated is still increasing (Bovkerket. 2023). Waste has increased by 16 percent from 2018 to 2020, and 55 percent since 2014 (Bovkerket. 2023). Since, Boverket (2023) gathered this data, new regulations have begun to be applied to handle waste. Construction and demolition waste must be sorted by type and stored separately from other types of waste. However, these regulations are aimed at sorting waste, rather than directly reducing waste on the construction site.

The European Commission (2020), as part of their Circular Economy Action Plan promote the use of "digital technologies for tracking, tracing and mapping of resources." The European Commission regard digital tools and skills as drivers for promoting circularity in building projects. BIM has significant potential for efficient waste management in building projects (Jin *et al.,* 2019). Implementing BIM, with the support of other digital technologies can improve circularity assessments, increase material recycling and reuse, and more accurately track environmental data throughout a building's lifecycle (Charef and Emmitt 2021). Green building trends and tougher climate regulations are leading clients to consider the overall environmental impact of their buildings (Sacks *et al.,* 2018). By using BIM for environmental analyses, clients are provided with many advantages over traditional 2D methods (Sacks *et al.,* 2018) due to BIM's ability to contain more information than 2D drawings. Digital CO2 and life expectancy data can be included on BIM objects, which supports work with circularity (Charef and Lu 2022).

To meet the net-zero emissions targets and reduce waste, the construction sector must rethink the cycle of "make, use and dispose" (Charef *et al.,* 2021) to include more circular activities e.g., "reduce, reuse and recycle" (Kirchherr *et al.,* 2017). Implementing circular activities requires industry actors to lead the change with practices, policies, and decision-making tools by exploring innovative concepts (Charef and Lu 2022). End users need to become more knowledgeable about reused and remanufactured products (Charef and Lu 2022). Suppliers also need to be incentivized to reprocess products rather than to always sell new ones.

Total BIM and Model-based Construction

Total BIM is a trend emerging in the Nordic region where model-based design and construction is implemented with a single source of information, notably even the construction phase (Brooks *et al.,* 2022; Disney *et al.,* 2022; Ulvestad and Vieira 2021). Since there are no paper drawings, the BIM is the contractual and legally binding construction document (Disney *et al.,* 2022). Without paper drawings, construction information must be derivable from the BIM. In Total BIM projects, the BIM must be significantly detailed during design to a level that is suitable for use in the construction phase (Disney *et al.,* 2022). Traditional construction projects do not usually create a high-quality and detailed BIM. A simplified model usually exists for purposes such as clash detection and coordination (Davies and Harty 2013), where a parallel process of creating BIM and detailed 2D drawings occurs (Disney *et al.,* 2022). Therefore, in traditional projects, it takes a significant amount of effort to extract environmental data. However, with model-based construction, objects are already accurately modelled, and including lifecycle data such as CO2 impact is less of a challenge. This digitalised data can be used at an early project stage to make accurate climate impact assessments as described by Jin *et al.,* (2019), Charef and Emmitt (2021), Sadri *et al.,* (2022) and Smart Built Environment (2020).

Research Gap and Motivation

Circularity is an important aspect of achieving the EU's net-zero emissions goals by 2050. Since, 85 percent of all buildings currently in use will still be in use by 2050 (European Commission 2021), renovation projects are a critical part of meeting these goals. Adopting digitalisation strategies in projects can lower the climate impact of the project by up to 40 percent (Smart Built Environment 2020). Moreover, implementing BIM can reduce waste (Jin *et al.,* 2019) and increase circularity (Charef and Emmitt 2021). Yet, there is a lack of research that explores BIM and emerging digital technology use to promote circularity in projects, especially renovation projects (Charef and Emmitt 2021; Charef 2022; Jin *et al.,* 2019). Therefore, this paper studies an innovative, renovation case study project in Sweden, where BIM and digitalisation processes have been used to work towards net-zero CO2 targets. By working this way, management teams were able to make real-time decisions based on the digitalised data, lowering the overall climate impact of the renovation project.

METHOD

Case Study Details

This research is based on a single case study of a leading, real-world, model-based construction project in Uppsala, Sweden. Our research draws on this specific case study as a "force of example" as supported by Flyvbjerg (2006) and a growing interest in experiences from implementing digital technologies in practice, advocated by Moum *et al.,* (2009). In the building renovation project, Lumi, Total BIM is implemented during design and construction as the single source of information (Disney *et al.,* 2022). Lumi, is centrally located in an old industrial area, which has been transformed, primarily into a residential area. Lumi is owned by a large client that have employed a small construction management (CM) company to manage the entire project. The client has aims to be climate neutral in their entire value chain by 2030. Previously, the site was several connected office buildings for large hire gusts. The renovation is split into three stages, new offices, a hotel, and 400 new apartments.

This study focuses on the processes implemented by the CM company to reduce waste and reuse materials during the renovation and creation of new offices.

Data Collection and Analysis

This research is part of an ongoing Ph.D. research project focusing on Total BIM (Disney *et al.,* 2022). The CM company responsible for the Lumi project has been recognized as an industry leader in digitalisation, having won the 2020 buildingSMART award for their previous project's digitalised construction process. Building on the success of their previous project, the CM company has further enhanced the level of digitalisation in their current project, Lumi, by implementing digital processes to address sustainability concerns. To understand and gather research data on these processes, the researchers of this paper organised a study trip to the Lumi project, accompanied by 22 industry experts in digitalisation. These industry experts are part of the Ph.D. project's study group. The visit commenced with a presentation by the CM company, during which they outlined their objective of preserving Lumi from demolition and explained the processes they have implemented to reduce waste and increase material reuse. A guided tour highlighted the reuse processes, including a demonstration of on-site test modules and ongoing challenges. Additionally, the tour underscored the interconnectedness between decision-making processes, CO2 impact and climate declarations. Further insights were provided by the CM company and architectural firm on the quality control processes necessary for working with Total BIM. The study visit to Lumi concluded with a workshop involving researchers, industry representatives and the CM company to engage in discussions on the project's material reuse process.

After the study visit, two online interviews were conducted with the CM company's VDC on-site engineer, who was mainly responsible for the development of the reuse processes. The interviews were semi-structured, aiming to delve into the digitalisation and decision-making processes that were implemented to increase material reuse. The interviewee was given the freedom to express their experiences and challenges with current practices. The online interviews were recorded and later transcribed.

A second workshop was held with the CM company and 12 industry digitalisation and sustainability experts from a large Swedish construction company. The workshop focused on discussing the intricacies of the waste minimisation and material reuse processes, and exploring how they were implemented.

The empirical data was analysed by adopting a thematic analysis, in accordance with relevant literature and current regulations. After the case analysis, an online discussion took place with the CM company's VDC on-site engineer and project manager. The paper's themes were presented to initiate a discussion, where the CM company were asked to provide specific case examples from the ongoing project, Lumi.

FINDINGS

The CM company implemented Total BIM processes to improve the data management and accuracy of construction information in their projects (Disney *et al.,* 2022). By adopting Total BIM and achieving better data management, the CM company has been able to improve work processes and implement improved circularity practices, such as material reuse and waste reduction, through data-driven decision-making.

Case Study Concept

Total BIM was successfully implemented in the CM company's previous project, improving data management, and helping to minimise design problems that frequently led to delays (Disney *et al.,* 2022). Building on this success, the CM company and the same client reached an agreement to expand and enhance their Total BIM approach to incorporate and address circularity concepts. In the Lumi renovation project, the CM company attempt to dismantle as many components on-site as possible for reuse in the finished building. This includes items such as plasterboard, joists, carpets, radiators, brick, suspended ceiling tiles, kitchenettes, sheet metal, windows, doors, glass partitions etc. The concept is not to force office hire guests to have reused materials, but to offer them an informed choice. They can choose to have the reused materials or pay extra for new materials. They are shown data to help them understand the CO2 implications of their decisions. Test modules were created on-site to showcase the material reuse. The CM company identified that they had an approximately 55,000 square meter traditional empty office building with cell offices. Within the building, there were approximately 800 doors and 800 glass partitions that were in good condition. The CM company therefore felt they had the opportunity and responsibility to change the existing practices of demolish and dispose.

Circularity Process

To commence the implementation of circularity processes, the CM company collaborated with architects to develop a BIM for the office renovation building. In this model, all objects were modelled as new (windows, doors, glass partitions etc.). By adopting this approach, they established a baseline that could effectively demonstrate the climate impact resulting from the exclusive use of new materials. Using this model, object properties were gradually changed to use recycled materials instead of new ones. They began with suspended ceiling tiles that they had identified as a typically problematic item that cannot be recycled and usually end up in landfill. By implementing this process, the CM company could efficiently compare the CO2 impact of using recycled materials with the ones modelled in the baseline.

The CM company also worked with a Swedish company that provides a service to calculate a construction project's climate impact. At the beginning of the Lumi project, the software company did not offer a service for model-based calculations. During the collaboration process a digital solution that automatically reads object properties from the BIM was created. The software differentiates between objects with recycled properties and those without. As a starting point, new materials were calculated using their full CO2 impact and reused objects had zero CO2 impact. Adjustments were made later if materials needed to be transported off-site or repainted etc.

Materials that could be reused needed to be dismantled, managed, stored, and tracked. The CM company used a cloud-based database and application for this process. Materials that had been selected for reuse were dismantled. After dismantling, information was entered into the database containing information such as a unique identifier, object name, description dimensions, material type, colour, location, sound rating, fire rating and photos (Figure 1). Materials were marked with RFID tags and sticky notes so that they could be tracked and located later for reuse (Figure 1).

Office hire guests are informed of potential reuse options, or the climate impact and additional cost if they decided to use new materials, which helped to raise awareness about sustainability issues. The BIM is regularly updated to reflect design decisions and the material choices by hire guests.

Figure 1: Left: Material database, Right: Generated product ID tag with EPC code

The cloud-based materials database and BIM are linked to a central database. Using this central database an algorithm attempts to find best matches between the designed objects in BIM and the available materials for reuse. Object properties are automatically updated in the BIM with the unique material identifier (EPC code) that was generated when the object was dismantled and inventoried. Using model-based construction techniques, site workers can access the cloud-based BIM on-site, on mobile devices. When an object is selected the properties are displayed, including the unique identifier (EPC code). This can be matched with the physical labels and RFID tags on stored materials to install the right reused item in the right location. Figure 2 shows the digital process for increased material reuse implemented by the CM company in the Lumi project.

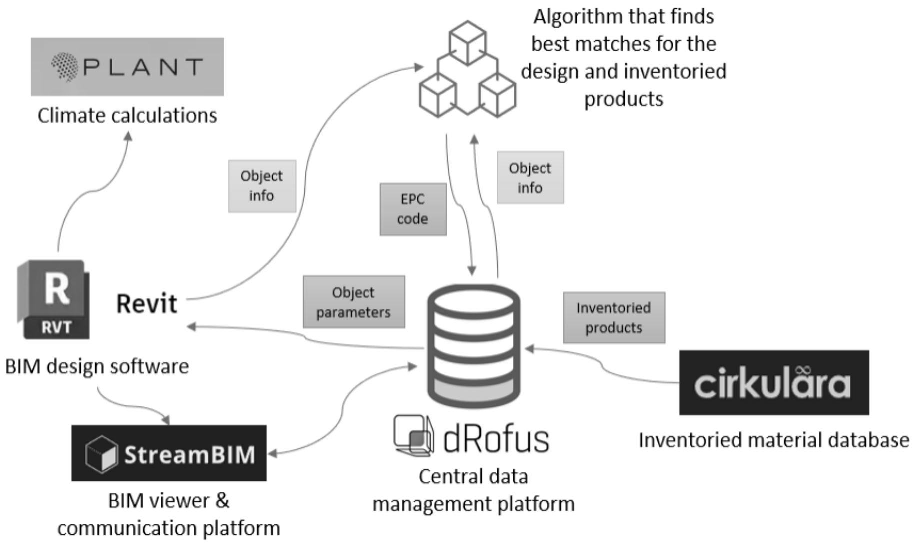

Figure 2: Digital process for increased material reuse in project Lumi.

This approach to addressing material reuse in the renovation project relies heavily on BIM. The processes developed during this project allow for the automatic generation of climate impact assessments from the BIM. Without implementing Total BIM, it is questionable if this approach would be feasible. Total BIM requires creating a high-quality, information rich BIM and the necessary investment to achieve this. While it may be possible to calculate climate impact from drawings, the accuracy and speed are challenging, which usually results in only having a climate pre-study and a declaration after construction is complete. By calculating the CO2 emissions directly from BIM, it is possible to have ongoing decision-making processes to reduce emissions throughout the project. This more flexible approach enables new opportunities to have discussions with clients and end users.

A digitalised approach to construction has been reported to lower the climate impact of projects (Charef and Emmitt 2021; Jin *et al.,* 2019; Smart Built Environment 2020). As environmental product declarations (EPDs), Life Cycle Assessments (LCAs) and climate declarations are being enforced across the EU, BIM may become necessary to handle this data in an effective way. Moreover, these climate impact tools may even be the incentive for promoting greater BIM use in projects. Cost has been a limiting factor related to developing a high-quality BIM (Brooks *et al.,* 2022; Disney *et al.,* 2022). However, if an information rich, accurate BIM is a necessity for climate impact studies, then one of the major barriers to model-based construction may be overcome. Currently model-based construction might not be possible in some countries due to regulations, but the benefits shown in this study of a data driven, model-based approach to material reuse in projects may highlight the need for reconsideration of existing regulations.

Decision-Making

Climate impact reports that show the CO2 contribution of building components are sent every six weeks to the CM company. The reports show the impact over time of the decisions made during the project and help to guide future decisions. These reports also show which components are most impactful for a project's CO2 emissions. In the Lumi project, beams, installations, and windows were overall the most impactful.

In the Lumi project a decision was made to reuse as much plasterboard as possible. It was noted that plasterboard is quite cheap to purchase, so normally it is not considered worth reusing. However, what they found in the project was that the time to dismantle plasterboard in traditional projects, separate and recycle materials was equal to the time it took them to prepare to reuse it. In the words of the VDC on-site engineer:

> You cannot compare the cost of recycling with blowing up a building, it does not work like that…it is clear that demolition will be chosen because it is cheaper and faster, but if you include the environmental aspect, which I think is becoming more and more important in the mindset of property owners and projects nowadays, you value the time and cost in the right way. That way you compare apples and apples and not apples and pears.

As Charef *et al.,* (2021) states, the construction sector must rethink material use cycles to become more circular. Innovative concepts and policies should be explored to lead the change towards more circularity in construction (Charef and Lu 2022). The VDC on-site engineer gave his opinion about how this could be implemented:

> There should be legal requirements and the industry should be taxed according to the remaining lifespan of the product they are disposing of.

If the industry was to be taxed in the way the interviewee describes, then the additional costs relating to recycling and reuse could be offset. A circular approach may even become the most economical. End users must become more knowledgeable about reused and remanufactured products (Charef and Lu 2022), so they can actively participate in these discussions. Responsibility for circularity also needs to be defined, is the client responsible, the contractor, the end user, or regulators? Would high-end clients be content with reused materials that perhaps in some cases show minor wear and tear? If a circular approach is to be adopted, which seems necessary to meet climate goals, then the CM's company's digital processes may help to guide future decision-making in projects.

Challenges

The project has also encountered several challenges. Not all products have pre-defined values for their environmental impact. Instead, standard values are usually calculated based on the size of the contract or net area, but the CM company found that these were inaccurate. As the VDC on-site engineer said:

> We got rid of all standard values for climate ratings in our calculations…standard climate ratings that exist, for example, for installations are completely useless. It presented a much worse image of the project…We couldn't go out to newspapers and say this is a good (sustainability) project, but we said that at least we know what we are working with and we can see the effect of our decisions.

The CM company invested time and effort into making their own, more accurate calculations based on material weight. This enabled them to gain an improved understanding on the climate impact of the decisions they made during the design and construction process.

It is not possible to reuse all materials. For example, some of the pipes in the project were not in a suitable state to be reused and replacement parts are no longer sold. The CM company worked with consultants to determine what was possible to reuse. In other cases, materials were suitable to reused but no longer comply with modern regulations. One relevant example from the project of this is doors that were too narrow to meet modern standards. Special hinges were purchased that extend the width of the doors when fully open, but even these resulted in a shortcoming of approximately 5 mm. The CM company decided to reuse the doors anyway as they found the climate impact of disposing of doors that were in good condition too impactful. There were also problems working with suppliers. Suppliers are usually incentivised to sell new products, and some had no support for refurbishment of existing ones. Storage of materials for reuse also became an issue. The VDC on-site engineer said that ideally materials would be sorted by zones and delivered to the construction zone just before construction begins.

As outlined previously there are currently many challenges implementing circularity in renovation projects. Boverket (2020), have recognised the importance of reducing material use in renovation projects, but lack regulations to enforce it and even lack requirements to declare resource use (Sadri *et al.,* 2022). The CM company implemented many strategies that may prove not to be beneficial to themselves, such as calculating a realistic environmental impact rather than using standard values and reusing doors that fail modern accessibility standards. They also reused items such as radiators that may have marginally worse performance than modern equivalents. These factors again raise the issue of who is responsible for reducing construction material use in projects. It is unreasonable to expect most clients to adopt a similar approach if it requires more resources and provides them with worse financial returns. Sustainability issues need to be addressed over a building's life cycle and current climate declarations need to be further developed from goals to requirements (Sadri *et al.,* 2022). The CM company have taken many steps towards digitalising resource reuse and decision-making processes for circularity in renovation projects. However, many challenges remain and the implementation of circular practices at a project level still needs support from external actors.

CONCLUSIONS

In the Lumi project, a new digital approach was implemented with the aim of increasing material reuse and circularity in renovation projects. This approach enabled the client, CM company, and tenants to make informed data-driven decisions that reduce waste and lower the overall climate impact of the project. Tougher regulations are being enforced to meet net-zero objectives, including climate declarations for new constructions. The requirement for climate declarations for renovation projects is also currently being investigated, with the aim of promoting efficient use and extending the life of existing building materials. These tougher regulations may be the tipping point for pushing greater BIM implementation in projects because climate calculations can be automatically and quickly calculated based on object properties in BIM. Using BIM in this way enables data-driven decisions throughout a project, assisting with meeting climate objectives and end users' needs as we think about constructing for the future. Furthermore, if the tipping point is reached and a high-quality BIM is created, the parallel processes of creating 2D drawings may not be necessary, promoting the use of the Total BIM approach with a single source of information.

Many challenges remain to maximize material reuse in renovation projects, such as, lack of support from suppliers, lack of replacement parts, reduced performance, and older materials not meeting new standards. However, if we are to achieve net-zero climate objectives, actors in construction projects should rethink how they value sustainability. This research contributes to regulators, researchers, and practitioners by investigating a digital approach that facilitates decision-making processes for reducing resource use in renovation projects.

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ENHANCING OFFSITE CONSTRUCTION FOR UK SMES THROUGH BUILDING INFORMATION MODELLING: A COMPREHENSIVE ANALYSIS

Victor Anukaenyi[1], Abdul-Quayyum Gbadamosi[2], Abdul-Majeed Mahamadu[3] and Oladimeji Olawale[4]

[1,2] *Architecture and Built Environment, Northumbria University, Newcastle, UK*

[3] *The Bartlett School of Sustainable Construction, University College of London, London, WC1E 6BT, UK*

[4] *Big Data Enterprise and Artificial Intelligence Lab, University of the West of England, Bristol, BS16 1QY, UK*

Numerous government publications have highlighted the need to address challenges within the construction sector. Many studies recommend adopting technologies such as offsite construction and expanding the use of Building Information Modelling (BIM) to resolve industry issues. Building Information Modelling (BIM) and offsite construction (OSC) have gained increasing popularity in the architecture; engineering; and construction (AEC) industry due to the various benefits they offer to project stakeholders; including enhanced design visualisation; efficient data exchange; reduced construction waste; and improved productivity and efficiency. Despite significant research in these areas and an extensive body of literature on BIM and OSC; many small and medium enterprises (SMEs) still need quantifiable benefits for adopting BIM in offsite construction processes. This study examines the impact of BIM on offsite construction in terms of cost; quality; time; and safety. The primary objective of this research is to encourage SMEs to adopt BIM for offsite construction projects. To achieve this goal; the study collected primary data using a questionnaire completed by 66 respondents from the construction industry. The study establishes that BIM for offsite construction outperforms offsite construction without BIM.

Keywords: BIM; impact; MMC; offsite construction; productivity

INTRODUCTION

Over the years, the construction industry has experienced a decline in cost efficiency, quality, timeliness, and safety compared to other sectors (Barbosa *et al.,* 2017). This has led to the adoption of innovative technologies and processes, such as Building Information Modeling (BIM) and off-site construction (OSC) (Abanda *et al.,* 2017). Both BIM and OSC have the potential to address persistent challenges in the construction industry, including productivity and efficiency issues, while significantly transforming the sector (Yin *et al.,* 2019). Various organisations have provided definitions for BIM. Abanda *et al.,* (2017) state that the Royal Institute of British

[3] a.mahamadu@ucl.ac.uk

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Architects (RIBA) and the Construction Project Information Committee (CPIC) have jointly defined BIM as a digital method for managing project information and data throughout the design, construction, and operation phases within the United Kingdom. BIM enhances sustainability in multiple scenarios across a building's life cycle, including construction, operation, design, planning, maintenance, and demolition (Liu *et al.,* 2018).

Stakeholders in the construction industry have persistently sought innovative ways to enhance productivity. Nonetheless, selecting the most suitable and practical construction method remains a prevalent challenge in the sector (Sabet and Chong, 2019). Low productivity in construction has been an ongoing issue, with government and private entities exploring various solutions to tackle it (Dixit and Sharma, 2020). Identifying the factors contributing to low productivity is crucial for improving the industry's performance. Fragmentation, resource scarcity, inadequate supervision, outdated tools and equipment, poor communication, rework, harsh weather conditions, and project cost and schedule overruns are among the factors that impact productivity in the construction sector (Durdyev and Ismail, 2019). The continuous pursuit of improvement in the construction sector has led to the development of innovative approaches to enhance design before construction, raise quality standards, increase safety, and reduce costs (Nawari, 2012). Some innovative construction methods used to address productivity issues include the application of lean principles, off-site construction, and using Building Information Modelling (BIM) in projects (Barbosa *et al.,* 2017).

This study aims to examine the significance of incorporating Building Information Modelling (BIM) in offsite construction, focusing on its impact on quality, time, safety, and cost. It also compares the performance of offsite construction projects with and without BIM. The objective is to provide quantitative evidence of the benefits of BIM in offsite construction, encouraging SMEs to adopt this approach in their processes. The study addresses the following aspects:

1. An examination of the effects of BIM on offsite construction in terms of quality, cost, time, and safety
2. An exploration of the barriers and drivers for BIM implementation in offsite construction
3. Recommendations for the construction industry regarding the integration of BIM in offsite construction projects

LITERATURE REVIEW

The Need for Offsite Construction Adoption

N Kamali and Hewage (2016) note that the implementation of offsite construction results in reduced construction costs, improved schedules, enhanced safety and quality, and decreased waste in the construction industry. Yin *et al.,* (2019) highlight various benefits of offsite construction, such as improved quality, structural reliability, increased productivity, reduced schedules, and minimized material waste. Kamali and Hewage (2016) also suggest that offsite construction offers numerous environmental and social benefits, making it well-suited for supporting sustainability initiatives. Offsite and onsite construction can be executed concurrently in a project schedule, resulting in time reduction, improved quality, enhanced safety, and cost savings. The Institute (2017) claims that most modular projects can achieve 30-50% time savings on construction, allowing clients to realise profits more quickly while significantly reducing labour and general condition costs. This is possible because onsite and offsite activities co-occur, with minimal risks such as weather-related delays, site theft, and vandalism (Mah, 2011).

Offsite construction contributes to lower construction costs for various reasons. Research by the Construction Industry Institute (CII) cited in several publications indicates that OSC projects save approximately 10% on the overall project budget and up to 25% on onsite labour costs (Chiu, 2012; Kamali and Hewage, 2016). Relocating most of the construction process to a controlled environment with more straightforward, repetitive operations can decrease workplace accidents caused by congestion, adverse weather, working at heights, and hazardous activities (Elnaas *et al.,* 2014; Chiu, 2012). Offsite construction ensures better quality because it takes place in a controlled environment, allowing for the improvement of product quality through repetitive procedures and operations. The application of BIM provides opportunities to capitalize on these benefits. Abanda *et al.,* (2017) suggest that the most substantial increase in construction productivity will come from BIM-enabled automated offsite activities.

BIM for Offsite Construction by UK SMEs

The adoption of Building Information Modeling (BIM) for offsite construction by UK SMEs is crucial for enhancing efficiency, reducing costs, and ensuring the timely completion of projects. BIM enables the detection and resolution of potential issues in the design and construction process, thereby improving the overall quality and reducing the likelihood of costly errors (Zhang *et al.,* 2016). When combined with offsite construction techniques, BIM can significantly enhance the benefits of both approaches. However, it is essential to recognise UK SMEs' barriers to adopting BIM for offsite construction. These barriers may include the need for more knowledge and expertise in BIM technology, the cost of software and training, and resistance to change within the organisation.

It is vital to examine the long-term benefits of BIM adoption for offsite construction to overcome SME barriers.

Impacts of BIM Application for Effective Offsite Construction Adoption

Ezcan *et al.,* (2013) argue that the most notable benefits of BIM for offsite construction include shorter lead times, cost reduction, minimised alteration challenges, enhanced collaboration, and the ability to handle a large volume of precise information. Using BIM to represent offsite construction components simplifies offsite construction projects' design and assembly processes. Sacks *et al.,* (2018) suggest that BIM is advantageous for offsite construction as it enables the machine-processing of construction information and production elements without the risk of human errors. The positive impact of BIM on offsite construction in terms of quality, cost, safety, and time has been discussed extensively in various studies (Vernikos *et al.,* 2014, Jayasena *et al.,* 2016, Lee *et al.,* 2020).

The seamless coordination and organisation of all operations in a BIM-OSC system reduce complexity and a lower likelihood of accidents, ultimately leading to more efficient project management (Sabet, 2019). By modelling the assembly of prefabricated components in BIM, contractors can virtually analyse the installation and positioning processes, potentially identifying and rectifying hidden safety hazards. The risk of falls and accidents caused by on-site plant activities in OSC-based projects can be mitigated using BIM to detect dangerous scenarios, ensure optimal accessibility for plant operations, and provide crane lifting drawings, thereby reducing the probability of reportable incidents (Darlow *et al.,* 2021).

Barriers to Implementing BIM in Offsite Construction

One critical obstacle in BIM deployment for building projects is the adaptation to BIM technology and processes (Elmualim and Gilder, 2014). Stakeholders, particularly in developing markets, face the challenge of effectively reengineering existing processes, which significantly hampers BIM implementation in offsite construction. Adopting BIM will inevitably alter the construction process and, in some cases, the organisation's structure (Sacks *et al.,* 2018). Historically, stakeholders in the construction industry have been slow to embrace change, relying on traditional paper-based methods and often expressing scepticism towards innovations or the implementation of new technologies.

Successful BIM deployment requires constant and dynamic professional collaboration throughout a project. However, the current construction sector needs more professional engagement (Jin *et al.,* 2017), which could impede the application of BIM for offsite construction. For small and medium-sized enterprises (SMEs), the cost of BIM experts and software presents a significant concern. Many need more financial resources to invest in new digital technologies and employ BIM specialists (Tan *et al.,* 2019). In addition to the initial investment, the risk associated with BIM tools contributes to SMEs' reluctance. The economic benefits of BIM for offsite construction often need to be clarified, further obstructing its adoption (Zhang *et al.,* 2018). Additionally, concerns surrounding intellectual property rights related to BIM implementation, such as BIM model ownership and data ownership within the model, have been raised by numerous scholars. Therefore, appropriate legislation to protect intellectual property rights is essential for BIM deployment (Ozorhon and Karahan, 2017).

Research Question

A review of the literature reveals that there is a need for quantitative analysis of the advantages that BIM offers over non-BIM approaches in offsite construction, with a focus on quality, time, cost, and safety. The research questions for this study are as follows:

1. Does the application of BIM positively influence offsite construction outcomes?
2. To what extent does BIM enhance quality, cost-efficiency, time management, and safety in offsite construction projects?
3. How does the performance of offsite construction projects using BIM compare to those without BIM implementation?

METHOD

The methodology employed in this study involved a combination of primary and secondary data collection methods to investigate the impact of BIM on offsite construction. The data collection approach for the primary research utilised structured interviews/questionnaires in the form of a survey. This method was selected due to its reliability, cost-effectiveness, and rapid response rate. Secondary data sources, such as case studies, journal articles, reviews, and books, provided valuable information about the impact of BIM on the construction industry (Igwenagu, 2016).

Questionnaires were distributed to various Architecture, Engineering, and Construction (AEC) professionals. The sample population consisted of AEC professionals with experience in both BIM and offsite construction, ensuring that the respondents had the necessary knowledge and background to provide insightful responses. Data collected from the survey were analysed using quantitative techniques. Descriptive statistics, such as frequencies and percentages, were used to present the general trends and patterns found in the data. Inferential statistics, such as correlation and regression analysis, were applied to determine the strength and direction of the relationships between variables and investigate the linear association between two continuous variables - the impact of BIM (Building Information Modeling) on offsite construction outcomes, specifically cost, quality, time, and safety. The Pearson correlation coefficient is ideally suited for this purpose, as it measures the strength and direction of a linear relationship between two continuous variables, which perfectly aligns with our research question.

RESULTS

The demographic analysis of the survey respondents revealed a diverse range of professionals and experts from various organisations within the construction industry. Most respondents worked in construction consultancy (45.5%), general contracting (27.3%), and research and development (18.2%). Most organisations focused on residential projects (57.6%), while 24.2% each concentrated on commercial or a combination of residential and commercial projects. The study sample mainly consisted of small organisations with 0-50 employees (48.5%) and a wide range of experience in offsite construction and BIM adoption. Most respondents held project management positions or worked as civil engineers, which brought valuable insights from project management perspectives.

Most organisations had been involved in offsite construction for up to 20 years, and their experience with BIM for offsite construction ranged from 0-5 years to 15-30 years. This highlights the recent trend of BIM adoption in offsite construction, allowing respondents to compare their experiences before and after BIM implementation. The demographics of the respondents ensured a reliable and valid data set, representing the views of professionals, experts, and researchers in the construction industry. The predominance of project managers and the inclusion of companies new to BIM adoption added valuable perspectives to the study.

Reliability Analysis Using Cronbach's Alpha and Correlation

An analysis of the reliability of the data set by measuring the internal consistency between items on a scale was conducted. A common convention in the literature suggests thresholds for interpreting the coefficient values: Above 0.9 as excellent, above 0.8 as good, above 0.7 as acceptable, above 0.6 as questionable, above 0.5 as poor, and below 0.5 as unacceptable (Gliem and Gliem, 2003). The reliability analysis of the data set from the variables is shown in Table 1. A Pearson correlation analysis was performed using SPSS to establish the statistical relationship between the variables. The computed variables used in this study were used in the correlation analysis. A 0.05 P-value or significance value shows the possibility of error is less than 5%. There is a strong relationship among the variables. This is indicated by a statistical significance, with a Pearson correlation value of -0.275, 0.165, 0.196, and -0.275, respectively, and significance values of 0.025, 0.00, 0.00, and 0.025, respectively.

Table 1: Reliability Analysis using Cronbach's Alpha

Cronbach's Alpha Cronbach's Alpha Based on Standardized Items N of Items	0.712
Cronbach's Alpha Cronbach's Alpha Based on Standardized Items N of Items	0.708
Cronbach's Alpha Cronbach's Alpha Based on Standardized Items N of Items	14

Table 2: Correlation Analysis of Variables for the Study

		B4OFFSITE	OFFSITE	BIM	BIMvsOFFSITE
B4OFFSITE	Pearson Correlation	1	.177	-.096	-.275*
	Sig. (2-tailed)		.155	.442	.025
	N	66	66	66	66
OFFSITE	Pearson Correlation	.177	1	.543**	.165
	Sig. (2-tailed)	.155		.000	.185
	N	66	66	66	66
BIM	Pearson Correlation	-.096	.543**	1	.196
	Sig. (2-tailed)	.442	.000		.115
	N	66	66	66	66
BIMvsOFFSITE	Pearson Correlation	-.275*	.165	.196	1
	Sig. (2-tailed)	.025	.185	.115	
	N	66	66	66	66

*. Correlation is significant at the 0.05 level (2-tailed)
**. Correlation is significant at the 0.01 level (2-tailed).

Test of Hypothesis

H1: BIM has a positive impact on offsite construction.

The one-sample T-test results indicate a non-statistical significance from the mean, leading to the acceptance of hypothesis 1. This is consistent with Kumar and Bhattacharjee's (2020) findings, which showed that the benefits of implementing BIM outweigh the costs in the long run.

H2: BIM improves quality, cost, time, and safety in offsite construction.

Like H1, the one-sample T-test results show a non-statistical significance from the mean, indicating that hypothesis 2 is accepted. This suggests that BIM positively affects various aspects of off-site construction projects.

H3: BIM for off-site by UK SMEs will determine project success or failure.

The one-sample T-test results also show a non-statistical significance from the mean for hypothesis 3, leading to its acceptance. This implies that the use of BIM in off-site construction projects plays a crucial role in determining the success or failure of these projects.

Comparative Analysis of Performance Between the Application of BIM for Offsite Construction and the Offsite Construction Without BIM

A comparative analysis was carried out using SPSS to determine the performance level of construction projects with the implementation of BIM for offsite construction and when offsite construction is carried out without BIM. The Correlation Analysis was carried out in SPSS; the result is shown in Table 3.

Table 3: Correlation between BIM vs non-BIM implementation in offsite construction projects

		OFFSITE	BIM
OFFSITE	Pearson Correlation	1	.543**
	Sig. (2-tailed)		.000
	Sum of Squares and Cross-products	14.530	8.777
	Covariance	.224	.135
	N	66	66
BIM	Pearson Correlation	.543**	1
	Sig. (2-tailed)	.000	
	Sum of Squares and Cross-products	8.777	18.008
	Covariance	.135	.277

**. Correlation is significant at the 0.01 level (2-tailed).

The correlation table shows the relationship between responses on the comparative views on the implementation of BIM for offsite construction, against when BIM is not used shows a Pearson's correlation of 0.543 and for both relationships and a statistical significance level of (2 tailed) of 0.00 which is below the threshold value of 0.05. Thus, there is a statistical significance in the relationship between using BIM to promote offsite construction.

The correlation analysis has helped to answer research question 3, which seeks to investigate whether the application of BIM for offsite construction performs better than offsite construction without BIM. This finding aligns with the study of Yin *et al.,* (2019), who made similar findings to review the promotional impact of implementing BIM in offsite construction.

Discussion

The current investigation of the impact of Building Information Modelling (BIM) on offsite construction in the UK SME context contributes to a broader, international discourse. To create a comprehensive understanding of the research topic, the study findings are compared with similar international studies. This approach not only enhances the appeal of the paper to an international audience but also provides richer insights by illuminating the relationship between the findings and those from diverse regions.

In a comparison of the benefits of BIM implementation, the study aligns with Abanda *et al.,* (2017) and Lee *et al.,* (2020). Abanda *et al.,* outlined significant efficiency and cost savings within the offsite manufacturing sector for buildings. Similarly, Lee et al.'s research identified a considerable enhancement in project performance in South Korea's modular construction projects. These findings correlate with the current research that underscores BIM's potential in improving efficiency, reducing costs, and boosting overall project performance within offsite construction. However, there is a divergence when it comes to the unique challenges facing SMEs in the adoption of BIM. Unlike Vernikos et al.'s (2014) findings, which suggested smooth integration of BIM among SMEs in Scandinavian countries due to supportive government policies, the present study highlights the constraints experienced by UK SMEs. Limited resources, financial restrictions, and a lack of state support emerged as significant obstacles hampering the full adoption of BIM within UK SMEs.

The current study reveals an isomorphic trend among UK organisations, demonstrating a leaning towards BIM and offsite construction adoption. Interestingly, a similar trend was observed by Zhang *et al.,* (2018) in the Australian construction industry, where BIM adoption became increasingly favoured despite initial reluctance due to perceived high costs and steep learning curves. This study, therefore, expands the understanding of the global discourse on BIM adoption in offsite construction. It offers insights unique to the UK context and strengthens the argument for the development of region-specific strategies and policies to overcome the challenges that SMEs encounter during their transition towards more innovative construction practices.

Going forward, the approach of international comparative research could continue to illuminate how regional variations in policy, industry maturity, and socio-cultural factors shape the adoption and success of BIM in offsite construction. The findings from such research will be invaluable to policymakers and industry practitioners globally, helping to foster a more comprehensive understanding and effective implementation of BIM in offsite construction.

CONCLUSIONS

The study presents insightful findings on the impact of Building Information Modelling (BIM) on offsite construction for UK's small and medium-sized enterprises (SMEs). It provides a critical understanding of the benefits and barriers experienced by SMEs in adopting BIM for offsite construction, thus contributing to the wider international discourse on this subject. The study's findings indicate that the implementation of BIM in offsite construction provides clear benefits, such as improved efficiency, cost reduction, and enhanced project performance. However, it also brings to light the unique challenges faced by SMEs, particularly in the UK, such as resource limitations and financial constraints. These challenges, unless addressed, could hinder the full-scale adoption of BIM in offsite construction by SMEs.

This study recommends further research into the exploration of specific strategies that SMEs can adopt to overcome the barriers to implementing BIM in offsite construction. This recommendation is informed by the limitations encountered in this study. Future research could aim to understand the long-term impacts of BIM adoption on the performance and competitiveness of SMEs in the construction industry, including how it might influence business growth, competitiveness, and sustainability.

Moreover, an in-depth investigation into the roles of different stakeholders in facilitating BIM adoption by SMEs could offer valuable insights. Such an analysis could delve into the contributions of larger corporations, government entities, and professional associations in supporting SMEs in their transition to BIM-based offsite construction. Understanding and addressing the unique challenges SMEs face in adopting BIM for offsite construction is pivotal for reaping the full benefits of this approach. It has the potential to lead to improved efficiency, cost savings, and enhanced project outcomes within the construction industry, both in the UK and globally.

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AN IMPLEMENTATION STRATEGY FOR THE APPLICATION OF DIGITAL TWIN FOR CONSTRUCTION PROGRESS MONITORING USING WEARABLE TECHNOLOGIES

Praveen Reddy Kothapally[1], Abdul-Quayyum Gbadamosi[2], Juan Manuel Davila Delgado[3], and Abdul-Majeed Mahamadu[4]

[1,2] *Architecture and Built Environment, Northumbria University, Newcastle, NE1 8ST, UK*

[3] *Big Data Enterprise and Artificial Intelligence Lab, University of the West of England, Bristol, BS16 1QY, UK*

[4] *The Bartlett School of Sustainable Construction, University College of London, WC1E 6BT, UK*

Challenges such as schedule delays and discrepancies between as built and planned structures are common issues in the construction industry. Consequently, effective monitoring and analysis of construction progress remain vital aspects of productivity. Digital twins provide a promising solution to these challenges by creating a digital replica of a corresponding real-world entity, enabling simulation, tracking, analysis, and various operations throughout its entire lifecycle. Digital twins have been applied to various construction lifecycle stages to address specific issues, including BIM, structural system integrity, facilities management, monitoring, logistics processes, and energy simulation. However, a significant gap remains in utilising digital twins for construction progress monitoring with safe, wearable technologies. Employing an exploratory mixed-method approach, the study combines qualitative and quantitative analyses to recommend using digital twin applications to monitor construction progress using wearable technologies. The study proposes an implementation strategy for construction progress monitoring by integrating BIM, multiple reality capture methods (GIS, IoT, UWB, WSN), digital twin technology, and wearable technology (AR). The framework outlines methods to create, record, synthesize, interpret, and visualise construction progress analytics, information, and summaries.

Keywords: digital twin; project management; internet of things; virtual reality

INTRODUCTION

The construction industry continuously evolves and incorporates innovative technologies to improve efficiency, productivity, and overall project management (Kopsida *et al.,* 2015). One such promising technological development is the concept of Digital Twins, which has garnered significant attention in recent years. Digital Twins are digital replicas of physical assets, processes, or systems that can be used for various purposes, including performance optimisation, real-time monitoring, and predictive maintenance (Lu *et al.,* 2020). The application of Digital Twins in the

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[14] a.mahamadu@ucl.ac.uk

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construction industry presents an opportunity to revolutionise construction progress monitoring by utilising advanced data analysis and visualisation techniques to provide valuable insights for decision-makers.

Although the potential benefits of Digital Twins in the construction sector are widely acknowledged, there is an ongoing debate on whether a process can have a digital twin. This discussion stems from the diverse nature of construction processes, the complexity of construction projects, and the challenges associated with modelling and simulating these processes in a digital environment. While some researchers argue that Digital Twins can be effectively applied to construction processes, others claim that their implementation may be limited to specific use cases, depending on the complexity and uniqueness of the process (Duarte-Vidal *et al.,* 2021).

In this context, the integration of wearable technologies presents an exciting opportunity to enhance the application of Digital Twins for construction progress monitoring. Wearable technologies, such as smart helmets, augmented reality glasses, and sensor-equipped vests, can provide real-time data on workers' activities, movements, and locations on-site (Elghaish *et al.,* 2020). When combined with the digital representation of the construction process, this data can create a more comprehensive and accurate Digital Twin, facilitating better monitoring and decision-making. In recent years, the concept of Digital Twins has emerged as a powerful tool for optimising built asset performance and enhancing facility management practices. However, there needs to be more research in the construction industry. Most of Digital Twin's research has focused primarily on built assets and their management rather than process-based functions. This emphasis on built assets has resulted in a limited understanding of the potential benefits and challenges of implementing Digital Twins for process-oriented tasks like logistics and manufacturing (Cai *et al.,* 2017).

The construction industry is characterised by many complex processes involving multiple stakeholders, resource constraints, and various construction activities. Effective progress monitoring and control of these processes are crucial for successful project delivery (Um *et al.,* 2017). In sectors such as logistics and manufacturing, Digital Twins have been successfully employed to monitor and optimise process-based functions, leading to significant improvements in efficiency, productivity, and decision-making.

Given the proven success of Digital Twins in other industries, examining their adoption for process-based functions in the construction sector is essential. This research proposes an implementation strategy for adopting Digital Twins in construction progress monitoring using process-based functions, focusing on addressing the existing research gap in the construction industry. The objectives are: (a) to investigate the potential barriers and challenges associated with implementing Digital Twins for process-based functions in the construction industry; (b) to explore the potential opportunities Digital Twins can offer the construction industry for progress monitoring, and (c) to develop a comprehensive framework for implementing Digital Twins in construction progress monitoring.

LITERATURE REVIEW

Digital Twins (DT) refer to virtual replicas of physical entities or systems that can be used for simulation, analysis, and optimisation. A DT is established on data collected from physical entities and reflects the real-time state, working condition, or position of corresponding physical entities (Al-Ali *et al.,* 2020). Wearable technologies refer to smart electronic devices worn on the body, either as an accessory or as a part of the material used in clothing. In the construction context, these devices can be used to capture field data and automate construction project progress monitoring (Alisadehsalehi *et al.,* 2020). Process-based tasks are part of a broader process, requiring coordination and integration for successful completion. In construction, such tasks could include site planning, design, procurement, construction, and maintenance.

The digital twin market and application in industries

The global market for Digital Twins has been experiencing significant growth in recent years, with increasing demand across various industries. The Global Digital Twin market is expected to grow at a Compound Annual Growth Rate (CAGR) of 38.5% from 2020 to 2026, reaching USD 36.6 billion by 2025. According to a Technavio analysis (Technavio, 2021), the Digital Twin market is anticipated to generate USD 24.81 billion between 2021 and 2025, with a CAGR of nearly 39% throughout the projected period. This growth can be attributed to the rising digitisation in the manufacturing and production industry, prompting many businesses to reconsider their operations and strategies to remain competitive. As the demand for digital solutions grows, businesses increasingly turn to Digital Twins to overcome limitations such as connectivity costs, storage constraints, and restricted computing.

The use of Digital Twins has been documented in various industries, showcasing their versatility and applicability. Most recognised use cases are related to manufacturing (Cai *et al.,* 2017), industrial facilities (Um *et al.,* 2017), and prototype engineering (Miller *et al.,* 2018). Other applications include 5G interaction for processing plants (Cheng *et al.,* 2018), aircraft health monitoring (Li *et al.,* 2017), composite optimisation, and smart vehicles (Damjanovic-Behrendt, 2018). The fundamental premise of the Digital Twin is to create a system that connects physical entities to their digital counterparts, harnessing the advantages of both digital and physical environments for the overall system's benefit. Product data is collected, stored, and analysed, with learnings applied to current and future products.

Digital Twins improve product quality and process optimisation in the manufacturing industry by managing batch-based operations in real-time, comparing them to the "golden batch" standard. Machine learning algorithms based on factual operational model simulations built on past failure data are used to predict equipment malfunction. Digital Twins are also used during operations to evaluate real-time compliance with regulations and safety requirements for classified equipment (Qin *et al.,* 2021).

Thus, there are three key aspects to the use of Digital Twins in the manufacturing industry: (1) monitoring the status of devices, production plants, and the entire facility in real-time; (2) collecting device data to enhance the quality and performance of the manufacturing process; and (3) analysing accurate and real operational data generated by the Digital Twin to perform predictive device maintenance (Alaloul *et al.,* 2021). The widespread adoption of Digital Twins across various industries highlights their potential for enhancing efficiency, optimising processes, and reducing costs, making them an essential tool for businesses in the digital era.

Digital twin for construction progress monitoring

In construction projects, monitoring and review are crucial for identifying progress discrepancies between the as-planned and as-built status and addressing issues promptly. Time and cost overruns in construction projects can be attributed to two primary factors: efficient and accurate progress monitoring. The benefits of achieving precise tracking results using automation for construction projects include time savings, surveillance systems, cost-effectiveness, and risk monitoring of high-rise buildings. According to (Wang *et al.,* 2021), BIM has additional advantages and can provide insights and integrate with virtually any data collection and detection technology.

A ground-breaking framework introduced by Opoku *et al. (*2021) incorporates modern computer vision algorithms to enable automatic monitoring of precast walls, a critical component in precast construction. Efficient and optimal construction activity observation is vital to construction management. This framework uses object detection, instance segmentation, and multiple objects tracking to gather location and time information about precast walls from surveillance footage captured during construction (Opoku *et al.,* 2021). The obtained status data is stored in a JavaScript object notation (JSON) file, which is then used to synchronise the wall components in a corresponding BIM. The scalability, accessibility, and effectiveness of this vision-based framework are demonstrated. However, the proposed framework has three limitations: (a) Movement and viewing distance of video surveillance can impact its effectiveness due to poor lighting and camera shaking; (b) The computer vision techniques employed necessitate high-performance technology, potentially raising overall project costs, and (c) The study's primary focus is on precast wall elements, neglecting other crucial building components needed for comprehensive progress monitoring.

While BIM provides an intelligent 3D model-based process for planning, designing, constructing, and managing buildings and infrastructure, digital twins can extend this utility by offering real-time data integration, simulation, and analysis capabilities (Alisadehsalehi *et al.,* 2020). Similarly, computer vision algorithms can be beneficial for object detection and recognition, but their application can be further enhanced by integrating with digital twins for more complex tasks such as predictive analytics or real-time decision-making (Wang *et al.,* 2021).It is essential to explore innovative solutions that can address the limitations of existing construction progress monitoring technologies and expand the scope of Digital Twins to encompass various construction processes and components. By doing so, the construction industry can leverage the full potential of Digital Twins for more efficient, data-driven, and responsive project management, and this will improve cost-effectiveness, risk management, and overall project outcomes.

METHOD

This hybrid study uses an exploratory approach for data collection and combines literature review, interviews, and a questionnaire survey. This methodological design is divided into three distinct phases, each aiding in forming and validating a proposed Digital Twin framework for progress monitoring.

Phase 1: Systematic Literature Review

The first phase involves conducting a systematic literature review that spans from 2015 to 2022. Sources of secondary data include journal articles, conference papers, university research findings, government organisation reviews, company records, and industry-specific research guides. This step's objective is to analyse and summarise the current state of Digital Twin research, which forms the foundation of the framework proposed later (Krishnaswamy *et al.,* 2006).

Phase 2: Framework Development

Based on the insights derived from the literature review, a framework for utilising Digital Twins in progress monitoring is designed. This framework is shaped by the strengths, limitations, and opportunities identified in the literature concerning existing technologies and the emerging potentials of Digital Twins.

Phase 3: Experts' Evaluation of the Framework

The third phase of this research includes the evaluation of the proposed framework through expert consultations. The experts are professionals from various sectors, including site management, building operations and maintenance, facility management, and BIM. Two methods of consultation are adopted - semi-structured telephone interviews designed to foster detailed discussions and a Google Forms-based questionnaire to gather broader insights. A total of 35 professionals were contacted via LinkedIn, and 22 responses were collected after two weeks, yielding a response rate of 62.8% (Chen *et al.,* 2021).

This comprehensive methodology ensures that the proposed framework is grounded in academic literature and validated by industry professionals.

Digital Twin Framework for Progress Monitoring

This framework proposes a digital twin model for construction project monitoring that incorporates wearable IoT technology and various other elements. While the framework's scope is broader than wearable technologies, these devices are pivotal, facilitating an enhanced interactive experience and efficient communication within the construction project. The framework for digital twin implementation for progress monitoring in construction projects can be applied as follows:

(a) Ideation: At this initial stage, the core idea of integrating smart construction site sensors, IoT technologies, cloud-based BIM design models, and augmented reality (AR) into a cohesive framework for digital twin implementation in construction projects are conceived. The idea considers the potential of these technologies to revolutionise construction project monitoring by providing real-time updates, data-driven insights, and enhanced interactivity. Existing literature and technological advancements offer insights into this ideation process (Al-Ali *et al.,* 2020).

(b) Development: During the development phase, the proposed system components - smart construction site sensors, IoT data management technologies, cloud-based BIM design models, and AR glasses - are carefully selected and designed to fulfill the goal of creating an effective digital twin framework. The system architecture and operational logistics are developed, considering best practices from various studies (VanDerHorn and Mahadevan, 2021).

(c) Implementation: This stage involves the actual application and integration of the proposed system in a real-world construction project setting. Smart sensors and IoT technologies are deployed for real-time data collection, the cloud-based BIM models are uploaded and made accessible via Autodesk Forge, and the AR glasses are linked to the digital twin system to provide real-time updates and interactions. The effectiveness and efficiency of the digital twin framework are evaluated and fine-tuned during this phase.

(d) Diffusion: After successful implementation and validation, the developed digital twin framework is disseminated or diffused across the wider construction industry. This diffusion is facilitated through industry forums, seminars, publications, and collaborations. As the framework is adopted by more construction projects, the resultant data and feedback can be used to enhance the system further, thereby creating a continuous loop of improvement and innovation (Gbadamosi *et al.,* 2021).

The proposed framework is designed to provide a comprehensive solution for progress monitoring in construction projects by integrating advanced technologies for data collection, processing, analysis, and visualisation. By leveraging wearable IoT devices and augmented reality, the framework aims to enhance decision-making, facilitate collaboration, and reduce construction errors on site. The proposed framework offers numerous benefits and opportunities for managing construction sites, automation, enhanced performance, safety, and tracking of activities and workers: (a) Improved Decision-Making: Real-time data collection and analytics enable stakeholders to make informed decisions based on accurate and up-to-date information, leading to better planning, scheduling, and resource allocation; (b) Enhanced Performance Monitoring: By continuously tracking construction progress and comparing it to the digital twin, discrepancies and deviations can be detected early, allowing for prompt corrective actions and improved overall performance; (c) Increased Automation: The framework supports integrating innovative construction technologies, such as automated cranes and robotic equipment, reducing reliance on manual labour and increasing efficiency; (d) Improved Safety: Continuous monitoring of construction site conditions, equipment usage, and worker activities helps identify potential safety hazards and address them proactively. This can reduce accidents, protect workers, and minimise project delays due to safety incidents; (e) Real-time Activity and Worker Tracking: By employing IoT and wearable technologies, the framework allows for seamless tracking of workers and activities on-site, leading to better coordination, task allocation, and productivity; (f) Enhanced Collaboration: The cloud-based BIM collaborative environment facilitates real-time information sharing and coordination among various stakeholders, such as architects, engineers, and construction managers, resulting in better collaboration and streamlined workflows; (g) Cost and Time Savings: By identifying potential issues early, minimising errors, and improving overall efficiency, the framework can lead to high cost and time savings throughout the construction process.

Despite the numerous benefits of the proposed framework, several barriers must be addressed to ensure successful implementation: (a) Connectivity: Reliable and high-speed connectivity is essential for real-time data transfer and communication between various components in the framework. Construction sites may face challenges in establishing consistent and robust connectivity, especially in remote or densely built areas; (b)3D Model Requirement: Creating and maintaining accurate and up-to-date 3D models for digital twins can be time-consuming and resource intensive. This may pose a challenge for smaller projects or organisations with limited resources; (c) Data Security: As the framework relies on cloud-based data storage and communication, ensuring data security and privacy becomes crucial. There is a risk of unauthorised access or data breaches, which can have severe implications for project stakeholders; (d) Holistic Transformation of Digital Infrastructure: The adoption of the framework requires a complete transformation of the existing digital infrastructure, which can be a significant challenge for organisations with traditional construction methods and systems. The transition may be resource-intensive and require extensive planning and coordination; (e) Hardware Requirements: Implementing the framework may necessitate significant investments in hardware, such as sensors, wearable devices, and other IoT components. This can be a financial barrier for smaller organisations or projects with tight budgets; (f) Expertise: The successful implementation and management of the framework require a skilled workforce with expertise in various technologies, such as IoT, BIM, data analytics, and AI. There may be a need for more qualified professionals in the industry, or additional training may be required for the existing workforce, and (g) AI Ethics: The use of AI and machine learning within the framework raises ethical concerns, such as algorithmic bias and transparency in decision-making processes. Ensuring ethical AI practices and addressing potential biases in the algorithms are essential to avoid unintended consequences and maintain trust among stakeholders.

Experts' Evaluation

The key advantages and disadvantages of implementing digital twin technology in the construction sector were identified in previous literature. To gain further insights from industry professionals, a questionnaire survey was conducted with 22 participants, all providing valid responses. This sample size was deemed suitable for balancing time constraints and the need for reliable data. Participants' construction experience varied from one to over ten years, and their roles included Facility/Project Manager, BIM Specialist, Civil Engineer, Architectural Design Consultant, and Research Engineer, among others.

Of the 22 participants, 40.9% (9 individuals) demonstrated a level 3 familiarity with digital twins. Most respondents believed that digital twin technology could benefit the construction industry by enhancing work management efficiency, automating progress monitoring, improving performance, simulating scenarios, and ensuring safety. These factors received a 59% approval rating. In comparison, the remaining 41% of participants agreed that digital twins could assist in real-time data management, reducing operational and construction costs and optimising asset performance.

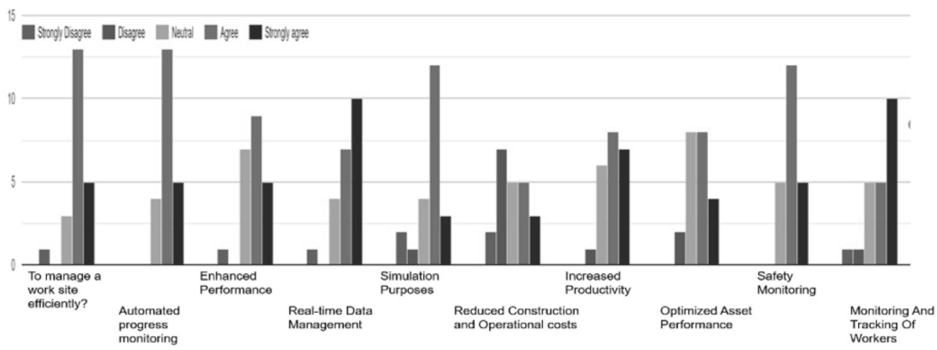

Figure 1: Opportunities of Using Digital Twin for Progress Monitoring

Only one participant disagreed that digital twins could help with simulations, increased productivity and collaboration, and worker monitoring and tracking. Regarding optimal asset performance and sustainability, 36.36% of respondents remained neutral, and 31.81% stayed neutral for improved operational performance, as depicted in Figure 2.

Participants acknowledged the drawbacks of employing digital twin technology in the construction industry. Ethical concerns were identified as a significant disadvantage, with 45% of participants strongly agreeing on this issue, as shown in Figure 3.

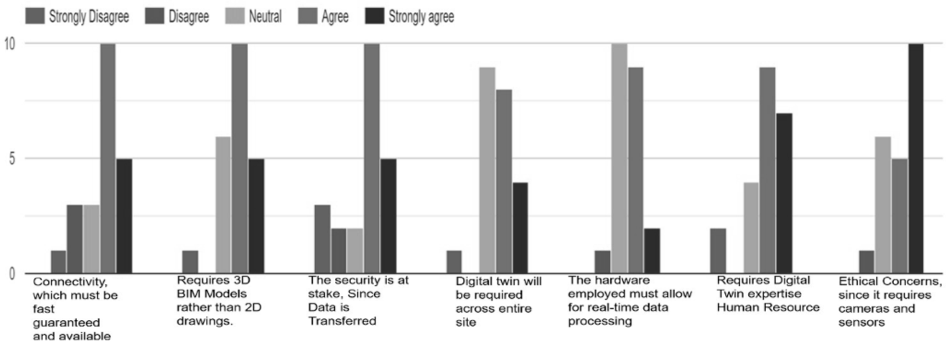

Figure 2: Barriers for Digital Twin Implementation

An expert validation was also conducted with interviewees familiar with the Digital Twin framework and who had experience in IoT-based construction projects, providing valuable insights into the framework's potential impact on construction site management. They emphasized the importance of reliable data collection, using advanced sensors like optical fibre detectors for real-time monitoring. They also highlighted the benefits of AR training for improved site management and worker response. The interviewees noted that implementing the Digital Twin framework could lead to significant cost savings and better synchronisation of design models across disciplines using Autodesk Forge API and the Forge platform. Additionally, they mentioned that supply chain segmentation based on construction stages is crucial for effective planning and execution.

CONCLUSIONS

This study developed a Digital Twin framework to enhance construction progress monitoring by incorporating wearable Augmented Reality (AR) technology. The framework combined various technologies to address the construction site tracking challenges faced by the AEC industry. By offering continuous access to real-time as-planned and as-built model simulations, the Digital Twin architecture allows decision-makers to monitor project status effectively.

The framework integrates BIM, GIS, UWB, WSN, and AR technologies, translating complex information into an intuitive AR visualisation platform for improved monitoring and decision-making. Advanced analytic technologies like AI and ML enable better prediction and response to potential challenges.

The framework streamlines and improves time-consuming management activities by efficiently acquiring data, virtualising construction activities, updating project documentation instantly, displaying information on a relative scale, and redistributing findings and operations to the cloud. Based on the input from industry professionals, the validation process demonstrated that the framework benefits management, interoperability, remote judgment, automation, and collaborative effectiveness.

In conclusion, this study explored and promoted using Digital Twin applications in combination with AR glasses to collect data and monitor construction site progress. The framework, integrating BIM, multiple reality capture methods, Digital Twin, and wearable AR technology, offers a comprehensive approach to creating, recording, synthesising, interpreting, managing, and visualising construction progress analytics and information. Using a quantitative questionnaire survey, the advantages, and disadvantages of using digital twins in the construction industry were also examined.

The Digital Twin framework is crucial in project management, simulation, analysis, and alignment with organisational goals and requirements.

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BIM-A AND BIM-VR SYSTEMS FOR CONSTRUCTION WORKER'S SAFETY COGNITION DEVELOPMENT

Oluseye Olugboyega[1], Obuks Ejohwomu[2] and Emmanuel Dele Omopariola [3]

[1] *Department of building/construction management, Obafemi Awolowo University, Ile-Ife, Osun-State, Nigeria*

[2] *Department of Engineering Management, School of Engineering, The University of Manchester, MECD Campus, Manchester, M13 9PL, UK*

[3] *Department of Building Technology, Kogi State Polytechnic, Lokoja, 260001, Nigeria*

The creation of a system capable of recognizing the reciprocal interactions between psychological, behavioural, and situational variables of safety management is a viable solution to safety cognition development. Thus, this research suggests a qualitatively validated conceptual model of BIM-animation and virtual reality-system for improving construction workers' safety cognition. Combining BIM technologies with safety cognition components and choosing two BIM technologies that are beneficial for fostering and enhancing workers' safety cognition led to the creation of the system. Workers will only follow safety rules and regulations if they have mental models of safety knowledge that are relevant to the laws and regulations, according to the study.

Keywords: BIM; BIM-A; BIM-VR; safety management; cognition development

INTRODUCTION

The construction industry is a socio-technical setting in which a safety management system must convince employees and managers to display specific safety behaviours to achieve a safe climate (Pousette *et al.,* 2008). This demonstrates that the apex of the safety management system is the development of construction worker safety policies, rules, and regulations. Unfortunately, studies indicate that workers do not always adhere to safety laws while on the job (Dekker, 2003). Hence, the most effective method of safety management is to assist construction workers in adapting safety information to their actions by strengthening their safety cognition (Dekker, 2003). By doing so, the burden on construction workers to comply with safety standards and procedures will be alleviated.

As well, it will increase their knowledge of safety issues. In addition to the fact that a safety management system cannot guarantee safety climate in the absence of safety behaviour, safety climate (a representation of workers' and managers' safety practices within a sociotechnical setting) is dependent on attitude and risk perception, which are characteristics of safety behaviour (Goncalves and Waterson, 2018). In essence, safety behaviour represents the difference between safety rules and practices. This

[1] oolugboyega@oauife.edu.ng

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claim is corroborated by Gherardi *et al.,* (2008), who claimed that safety behaviour is instinctual and the most crucial aspect of safety culture (Gherardi *et al.,* 2008).

The five parts of safety behaviour are safety training and education, safe work methods, management's commitment to safety, accident investigation and disaster management, and safety performance. Among these safety behaviour components, safety training and education are the most significant (Goh and Sa'adon, 2015; Pousette *et al.,* 2008). This is because safety behaviour is innate, and its essence is safety cognition, but safety cognition is primarily the result of safety training and instruction (Shin *et al.,* 2014). Safety cognition development through safety training and education is important due to the degree of exposure of construction workers to risks and hazards (Biggs *et al.,* 2013), the high rate of safety-related human errors and the need to heighten construction workers' sensitivity to risks, and the high exposure of construction workers to risks and hazards (Saurin *et al.,* 2008; Li *et al.,* 2012).

Zhang *et al.,* (2015) say that during the planning and design phases of a project, technological opportunities must be used to remove work hazards and put in place safety standards and best practices. Park and Kim (2012) also said that construction workers need to be better at recognizing risks, that managers and workers need to be able to talk to each other in real time, that latent safety risks need to be found, that a proper and consistent safety management process needs to be put in place, that safety information needs to reflect the real construction work environment, and that visual-based safety education needs to be put in place.

A visual safety training and education system will make sure that safety measurement in the construction industry can move forward in a way that is useful for safety stakeholders (Chouldry *et al.,* 2007). Also, it will make sure that a safety management system is made that can see how psychological, behavioural, and situational aspects of safety management and measurement affect each other. This study therefore presents and validates a conceptual building information modelling—animation (BIM-A) and virtual reality (BIM-VR)—system for enhancing the safety cognition of construction workers. It is anticipated that interactive BIM technologies such as the BIM-A and BIM-VR systems will promote visual-based safety training and instruction by interacting with the mind of the worker (Guo *et al.,* 2012; Olugboyega and Windapo, 2019). This is predicated on the fact that virtual-based training has yielded comparable results in the fields of rehabilitation (Rutkowski *et al.,* 2020), orthopaedic surgery (Vaughan *et al.,* 2016), and mechatronics (Kamińska *et al.,* 2021).

LITERATURE REVIEW

The Concept of Safety Cognition

Goh and Sa'adon (2015) defined safety cognition as the mental models of safety that control the conduct of employees through the mind. Shin *et al.,* (2014) defined safety cognition as the capacity to be aware and conscious of workplace safety issues. Goh and Sa'adon's (2015) and Shin et al.'s (2014) definitions of safety cognition are complementary since they include the same safety cognition characteristics (attitude, concentration/mindfulness, situational awareness, and risk perception). It is necessary to synthesize the proposed dimensions of safety cognition to apply them to construction safety and provide a more comprehensive description of safety cognition.

A summary of the data in Table 1 reveals five primary elements of safety cognition associated with construction (attention, situational awareness, concentration/mindfulness, task prioritizing and adjustment, and risk perception).

Four of these five dimensions are associated with mental models of safety knowledge, as specified by safety policies, rules, and regulations (Goh and Sa'adon, 2015). This reclassifies construction-related safety cognition dimensions as mental models of safety knowledge (attention, situational awareness, concentration/mindfulness, task prioritizing, and modification) and risk perception.

Based on the construction-related aspects of safety knowledge that have been found, a full definition of safety knowledge for the construction industry can be made. Therefore, safety cognition in the construction industry is the mental process of safe behaviour that comes from being able to recognize construction safety risks and apply mental models of safety knowledge (safety policies, safety rules, safety regulations, and safe work procedures) to construction activities. This definition of safety cognition puts safety behaviour first, just like safety culture puts safety behaviour first (Saurin *et al.,* 2008).

Table 1: A summary of the dimensions of safety cognition

References	Dimensions of safety cognition
Stanton *et al.,* (2001)	Reflection on the situation, orientation to the situation, development of knowledge and mental models, perception, and representation
Saurin *et al.,* (2008)	Knowledge models of self, knowledge models of the environment, task modification
Wallace and Chen (2011)	Perception, memory, motor function
Sacks *et al.,* (2013)	Attention, concentration
Pires, (2005); Tan *et al.,* (2015)	Attention, awareness
Goh and Sa'adon, (2015)	Attitude, perceived behavioural control, subjective norms
Shin *et al.,* (2014)	Risk perception, attitude, intention, behaviour, outcome
Fang *et al.,* (2016)	Obtaining information, understanding information, perceiving responses, selecting a response, taking actions

Use of interactive BIM technologies for safety cognition development of construction workers

According to Guo *et al.,* (2012), the most effective technique to enhance safety training and instruction is to employ interactive BIM technologies, which can connect with the workers' thoughts. Virtual reality and animation have been highlighted as interactive BIM technologies beneficial for construction worker safety training (Guo *et al.,* 2013; Zhao and Lucas, 2015; Li *et al.,* 2012; Le *et al.,* 2015; Sacks *et al.,* 2013; Pires, 2005; Tan *et al.,* 2015; Guo *et al.,* 2012). Sacks *et al.,* (2013) investigated what would happen if virtual reality was used to teach construction workers about safety. Before and after the virtual reality-based safety training, the workers were tested on how well they followed directions and paid attention to their work. The study showed that workers' attention and ability to focus got better after they learned about safety using virtual reality.

Guo *et al.,* (2012) did a case study on safety training for construction plant operators. They did this by using animation technology. The study concluded that animation-based safety training and education enhanced plant operators' risk perception. In another animation-based safety training and education study, Pires (2005) replicated the cognitive behaviour of humans during fire evacuation emergencies. As a result of animation-based simulations of fire emergency evacuation scenarios, the study uncovered a higher degree of attention to uncertainties and a heightened awareness of risks. These studies show that BIM-based virtual reality and animation-based safety training and instruction can help construction workers become more aware of safety issues. Unfortunately, the BIM literature doesn't have many useful steps for making BIM-A and BIM-VR systems to help construction workers learn more about safety. Also, existing approaches to the use of virtual reality and animation in safety management have focused on safety training for specific job tasks, with little or no consideration for safety cognition development. This paper proposes a strategy for incorporating virtual reality and animation into BIM-based procedures for the development of safety cognition. As discussed by Guo *et al.,* (2013), Zhao and Lucas (2015), and Pires (2005), safety cognition is a mental process that involves more than attention to instructions, concentration on work, and danger awareness. This paper argues that the focus of BIM-based safety training must be expanded to include the enhancement of workers' level of attention to instructions and uncertainties, situational awareness, level of concentration to work, ability to modify and prioritize tasks, and risk perception to adequately improve the safety cognition of construction workers and utilize interactive BIM technologies. The overall benefit of this kind of safety training is that it helps construction workers learn more about safety and creates a culture of safety in any construction environment.

METHOD

This study employs interview-based quantitative research. A quantitative research interview is a standardized discussion in which the researcher and respondents discuss industry-specific references such as terminologies, theories, and models (Frels and Onwuegbuzie, 2013). The interview method is ideal for collecting data from a representative sample in quantitative research. Dworkin (2012) recommends a sample size of 5-50 participants for an interview. Therefore, a handy sample of three BIM professionals and two safety experts was chosen as a representative sample for this research. The BIM specialists are men with around three years of BIM experience and ten years of construction experience. There is one male and one female safety expert.

The female participant has accumulated eight years of expertise in construction safety management, while the male safety expert has accumulated more than ten years of experience. Conceptual models of the BIM-A and BIM-VR systems were used to come up with the interview questions. By determining the methods for utilising BIM-animation and BIM-virtual reality technologies, the model was created. The stages at which safety cognition aspects may be handled were identified in the procedures. The model was produced by outlining the methods and combining similar BIM-animation and virtual reality procedures. The questions were shared with the participants on a Google Doc. Participants were asked to assign a number indicating whether they agreed (1) or disagreed (0) with the model's concepts. The relevance of the concepts was determined using the frequency distribution and percentage of the obtained data. The significance threshold was set at 50 percent.

FINDINGS

BIM-A and BIM-VR System for Construction Workers' Safety Cognition Development

Figure 1 presents a conceptual model of the BIM-A and BIM-VR systems for the development of construction workers' safety cognition. The model's theoretical foundation is based on the link between animation and virtual reality as interactive

BIM technologies. This association is illustrated in Figure 1. The basics of Figure 1 are to show how safety managers can produce a realistic three-dimensional image or environment, as well as an illusion of motion and shape change that workers can perceive as real and learn safety procedures from. As depicted in Figure 1, the model investigates the integration of BIM technologies with the components of safety cognition by finding two BIM technologies that are effective for developing and enhancing workers' safety cognition. All the safety cognition components (risk perception, attention to work, situation awareness, heightened focus, and knowledge-based task prioritization and modification) influence safety cognition.

Safety training that does not include all these components will not result in the formation of safety cognition. To make sure that safety training covers all aspects of safety knowledge, each scenario must successfully model all of them. The BIM-A and BIM-VR systems are organized into four process operations (see Figure 1). The initial two phases are applicable to both BIM-A and BIM-VR (outline the objectives of the safety training and develop the scripts for safety cognition). This suggests that either of the technologies may be utilized to cultivate safety cognition. Yet, the level of interactivity afforded by the technologies is distinct. BIM-VR provides an interactive space that simulates the real world, as well as the flexibility to employ a variety of animation techniques. The figure also displayed the two separate processes that are unique to BIM-A and BIM-VR. With BIM-A, it is necessary to create a visual representation of the scripts to simulate the scripts' scenarios.

Modelling 3D animation for each simulated scenario utilizing BIM animation technologies such as Autodesk Maya and 3DS is the second critical step. In addition to recommending suitable animation tools, the BIM-A system identifies 3D animation as the most suitable animation type for BIM-based safety cognition development. Because it promotes practical solutions and realistic methods, 3D animation was suggested. The specific procedures for BIM-VR are to create a fully immersive virtual reality of the scripts and build a 3D virtual environment for the fully immersive simulated scenarios utilizing BIM virtual reality technologies. Fully immersive simulations were recommended as the optimal virtual reality technique for the BIM-VR system because they facilitate the creation of a more credible and realistic experience.

Figure 1 presents ten concepts drawn from the BIM-A and BIM-VR systems suggested. The concepts were given to the participants as statements for them to indicate whether they agreed or disagreed with them. Table 1 contains an analysis and presentation of their responses. As demonstrated in Table 1, most participants (>50%) felt that virtual reality and animation are beneficial for creating and enhancing construction workers' mental models of safety knowledge and risk perception. The majority also agreed with the BIM-A and BIM-VR safety cognition system development approaches. This validates that the BIM-A safety cognition system should be designed as a sequence of animations that illustrate the objects and concepts necessary for the development of mental models of safety knowledge and risk perception.

By incorporating BIM-A technologies into safety training, construction workers will be able to personalize their learning experiences and advance at their own speed. They will receive precise information from the system. This will successfully accelerate training sessions because participants will spend less time visualizing and comprehending complicated concepts or procedures. Additionally, the BIM-A system will aid in their retention by making material more memorable and delivering it in both auditory and visual formats. The results of the study show that BIM-VR can simulate dangerous situations without putting safety at risk. With the BIM-VR system, workspaces and jobs can be duplicated in a realistic virtual space. This lets construction workers do hands-on training without having to worry about getting hurt. This implies workers can make mistakes without risk and gain knowledge through practice.

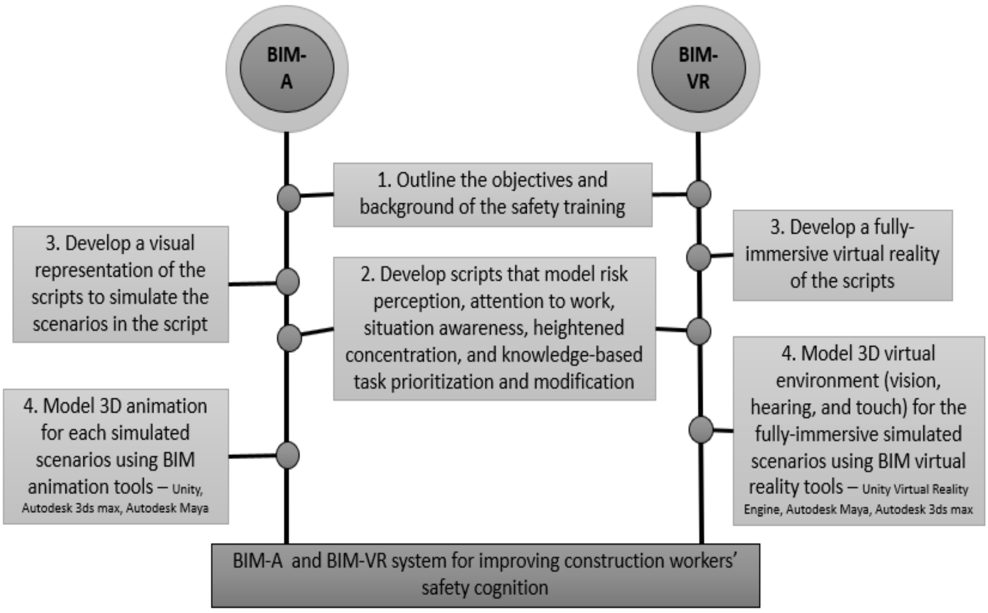

Figure 1: BIM-A and BIM-VR system for improving construction workers' safety cognition

Qualitative Validation of the BIM-A and BIM-VR System for Construction Workers' Safety Cognition Development

The purpose of safety cognition is to remove the load of safety rules and regulations from the minds of construction workers and make them second nature. With standard safety training and teaching, this has proved impossible to do (Li *et al.,* 2012). The BIM-A and BIM-VR systems enable construction employees to practice and perfect safety procedures. The systems are also useful in empowering construction workers to make safe and independent decisions when confronted with hazards, to have a better understanding of safety policies and regulations, to be able to relate to conditions and regulations that have a life-or-death significance, and to have a well-developed risk perception (the capacity to visualize invisible dangers and choose the appropriate responses based on knowledge and experience) (Zhao and Lucas, 2015).

CONCLUSIONS

Working in a construction setting can be dangerous, and the key to minimizing safety risks is a highly skilled and trained staff. Yet, a dangerous environment is not the best place to teach important safety skills, especially for people who work in high-risk jobs. Based on the nature and requirements of construction work, BIM-based safety cognition training is required for safety training that is suitable for each work purpose and scenario. This study suggests a BIM-A and BIM-VR system as a BIM-based safety cognition training system that would help construction workers quickly learn visual safety training content. The study concluded that the system is a great way for construction workers to improve their working memory, learn about safety management in an interesting and effective way, and practice and perfect safety rules and norms.

Table 2: Level of agreement with the BIM-A and BIM-VR system for construction workers' safety cognition development

Concepts from the model	Agreed	Disagreed
The objectives of the safety training should be outlined in the BIM-A and BIM-VR system	4 (80%)	1 (20%)
BIM-A and BIM-VR model should include risk perception as mental models of safety	4 (80%)	1 (20%)
BIM-A and BIM-VR model should include attention to work as mental models of safety	5 (100%)	0 (0%)
BIM-A and BIM-VR model should include situation awareness as mental models of safety	4 (80%)	1 (20%)
BIM-A and BIM-VR model should include heightened concentration as mental models of safety	5 (100%)	0 (0%)
BIM-A and BIM-VR model should include knowledge-based task prioritization and modification as mental models of safety	5 (100%)	0 (0%)
The scenarios in the BIM-A model should be simulated virtually	4 (80%)	1 (20%)
BIM-VR model is best developed as a fully immersive virtual reality	4 (80%)	1 (20%)
3D animation in BIM animation tool is appropriate to develop BIM-A safety cognition model	5 (100%)	0 (0%)
3D virtual environment in BIM virtual reality tool is appropriate to develop BIM-VR safety cognition model	5 (100%)	0 (0%)

The study's conclusion is that workers' safety cognition can be improved by helping them pay more attention to their work, be more aware of their surroundings, focus more, change, and prioritize tasks based on their knowledge, and understand risks. The parts of safety cognition that were found were these parts of mental models of safety knowledge. The study additionally finds that workers will only follow safety rules and regulations if they have mental models of safety knowledge that are relevant to the rules and regulations. This has ramifications for construction site safety management approaches. The study shows that when workers' safety cognition is developed, they will be able to use safety information in their work and be able to spot safety risks while doing their jobs. The study also says that construction and safety managers should use relevant BIM technology to improve safety awareness in the construction sites where they work.

To comprehend safety laws and regulations, workers require safety training and instruction. The relevance of these models in relation to safety training and education is that the use of BIM technologies makes safety training and education meaningful and effective. Workers must make mental models of safety knowledge before they can follow safety policies, rules, and regulations at work. This study will also help construction and safety managers see that workers need to learn how to think about safety. The models will also be valuable for construction managers in developing the most efficient safety management system to achieve safety targets within a predetermined timeframe. This study offers a novel approach to achieving safety awareness in the construction setting. The system should not be used on the job site to help with safety compliance or safety management. The system is suitable in real-life scenarios for worker safety training on work procedures and technologies prior to on-site operations. The system can be used in training sessions and safety education activities. Future research should study the relationship between better worker safety awareness and construction site performance. Additionally, the effect of BIM integration on the development of safety cognition should be examined.

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EXPERT VERIFICATION OF INFORMATION REQUIREMENTS FOR INTEGRATING BUILDING INFORMATION MODELLING WITH OPERATION AND MAINTENANCE

Dania Abideen[1], Akilu Yunusa-Kaltungo[2], Patrick Manu[3] and Clara Cheung[4]

[1, 2 &4] *Department of Engineering Management, School of Engineering, The University of Manchester, MECD Campus, Manchester, M13 9PL, UK*

[3] *School of Architecture and Environment, University of the West of England, Frenchay Campus, Coldharbour Lane, Bristol BS16 1QY, UK*

Despite the successful project delivery for BIM in facilities management, limited investigations have focused on BIM and Operation and Maintenance (O&M) integration. Although this phase accounts for approximately 60% of total life cycle costs, making it crucial for realising good return on investment (ROI). It was found that one of the main reasons for slow adoption of BIM in O&M is the absence of clear information requirements, making it challenging to create asset registers. Therefore, the purpose of this work is to identify the information requirements for integrating BIM with O&M. This research deploys a combination of a systematic literature review (SLR) and expert verification (via questionnaire) to identify the information requirements. The combination of the information extracted from the SLR with their validation by 21 experts resulted in identifying 21 information requirements (IRs) grouped into five categories: general IRs, strategic IRs, operational IRs, commercial IRs and continuous improvement IRs. These IRs provide a fundamental framework for O&M practitioners and researchers to promote the implementation of BIM in O&M.

Keywords: BIM; operations; maintenance; integration; reliability

INTRODUCTION

Building information modelling (BIM) has provided designers and builders with opportunities for successful project delivery, at a higher quality and a lower cost (Suprun *et al.,* 2022). While the design-to-construction phases typically account for 2-5 years, the operations and maintenance (O&M) phase usually takes up to 20 years and even beyond, which makes it crucial to the realisation of a good return on investment (ROI). This implies that there is a possibility for huge cost savings with BIM in O&M. One crucial pillar to this integration, is information management (Chan *et al.,* 2016; Ma *et al.,* 2020). The application of clearly defined asset information needs is therefore a vital element to the success of BIM and O&M integration (Chan *et al.,* 2016; Ma *et al.,* 2020). However, BIM adoption and

[2] Akilu.kaltungo@manchester.ac.uk

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utilisation during the O&M phase remains slow, owing to several justifications. Firstly, the absence of clear information needs that support the use of BIM in the O&M phase makes it difficult to support the integration. Secondly, the compatibility between BIM and the different systems used during the building life cycle (e.g., CMMS, CAFM and BAS) is complex. Thirdly, since assessing the performance of the integration is critical to its success, the absence of key metrics can further hinder the process. For these reasons, BIM integrations within the O&M phase remain slow and their applications are limited. This necessitated a state-of-the-art review to capture and identify what information requirements are crucial to facilitate the adoption for BIM in O&M. Therefore, the purpose of this work is to identify the information requirements for integrating BIM with O&M.

METHOD

The first phase of this research was the systematic literature review SLR. The second phase was a quantitative method approach (survey) to show the extent of alignment between theory and practice. Therefore, a combination of both approaches was used to answer the following research questions: RQ1.What is the current state of art of BIM integration with O&M and what are the research gaps? RQ2. What are the key information requirements that are needed to support the integration of BIM in O&M in construction sector?

The key research questions and the research phenomenon under investigation is influenced by the type of philosophical worldview (Creswell, 2017). To address the research questions, particularly RQ2, the information requirement for BIM-O&M integration was viewed as a single reality (in other words, there are specific, precise set of information requirements) that needed to be identified. In this of view, the study adopted the positivist world view which considers reality to be single, existing independently of the researcher and thus being able to be objectively assessed.

Review of Related Literature

The literature review methodology deployed for this study was based on preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) (Petrosino and Lavenberg, 2007). A comprehensive protocol from (Okoli, 2015; Iheukwumere-Esotu and Yunusa-Kaltungo, 2020; Qiao, Yunusa-Kaltungo and Edwards, 2021) was adapted. The three databases were Scopus, Web of Science and Engineering Village. The selection of these databases was due to their efficient, easy, and advanced searching options, as well as their reliable and comprehensive academic information in the specified area of this research. The methodology consists of 5 main stages, namely, scoping, identification, screening, eligibility, and final records. In the second stage, the advanced keywords searching option was used with the following phrases ((“Building information model *” OR “building model *” OR “BIM”) AND (“operation and maintenance” OR “asset management” OR “facility * management” OR “maintenance information management” OR “maintenance management *” OR “computeri * maintenance management *”)). The total number of returned results were 669 articles which was further refined based on the inclusion criteria which were: (1) All available articles on BIM integration within the O&M phase of construction and infrastructure domains; (2) All available articles that address drivers and barriers to BIM-O&M integration; (3) only journal papers were included ; (4) The SLR was not constrained by a time frame so as to ensure a more encompassing approach to information tracking and data capturing; (5) Articles written in English. In the third stage, the unrelated articles were excluded through title and abstract assessments. The penultimate stage entailed establishing the eligibility of the remaining articles based on full-text availability. Finally, 196 articles were included in the review. Full details of the SLR can be found at (Abideen *et al.,* 2021, 2022).

Many efforts have been devoted towards the definition of information requirements that can better drive the integration of BIM into O&M FM. For instance, A 7-step handover framework based on owner requirements for educational institutions was developed by Thabet and Lucas (2017). However, further grouping of the proposed data would improve the quality of the integration. Sadeghi *et al. (*2019) proposed a taxonomy of information requirements under: location, specifications, warranty, maintenance instructions, and construction specifications.

However, the proposed model is considered inflexible and requires further customization. (William East, Nisbet and Liebich, 2013) grouped information requirements into either geometric related or asset related. Mayo and Issa (2016) addressed the non-geometric information needs using Delphi method. The study did not provide sufficient details regarding which O&M systems relate to the identified information needs. Most of these studies lacked demonstration of actual benefits in maintenance tasks and had little focus on O&M. Even though each organization is different and has diversion in their business nature, there is a research gap in generalising the requirements and information needs with respect to the asset's operational performance.

Experts' Verification Process

Though the literature review addressed some information requirements for BIM, it has also revealed that these information requirements do not capture clear information needs in the operation and maintenance phase of the building/construction project. In addition, it was found that these information requirements are not clearly outlined with respect to O&M. For that reason, experts' verification of the potential information requirement for BIM in O&M was necessitated. The verification process was conducted to (1) verify the appropriateness and comprehensiveness of identified categories of information requirements for inclusion into the BIM-O&M framework, and to (2) identify additional key requirements that might have been missed or not reported by the literature.

The philosophical worldview adopted in this study further informed the research strategy and research method to be a quantitative research method (Creswell, 2017). Therefore, the verification process was done through a quantitative method (survey) to gather objective evidence of the relevance of the information requirements to the BIM and O&M integration. The survey was remotely deployed and was not constrained by geographical location. Hence, participants were drawn from several countries e.g., United Kingdom, Saudi Arabia, etc. Several studies have proposed frameworks or examined information needs through the application of quantitative approaches like questionnaires /surveys in and around BIM and O&M. Lin et al., (2016) used questionnaires to develop a BIM framework with seven core elements. Tucker and Masuri (2018) developed a framework with three main areas: the drivers, the barriers, and RIBA plan of work. Nguyen et al., (2017) identified the needed information for FM staff from the hand-over data for high rise buildings. Liu and Issa (2016) used surveys to understand the requirements of facility managers and the type of maintainability problems.

To achieve an effective verification process, a panel of experts was constituted. The selection guidelines were adapted from the guidance of (Hallowell and Gambatese,

2009) in selecting experts for expert group techniques. At least three of the following requirements should be met; (1) Minimum of five years of professional experience in BIM or O&M or other related domains like facilities management in the construction industry ;(2) Minimum educational qualification of a bachelor's degree in relevant fields; (3) At least one professional qualification relevant to BIM, O&M or FM; (4) An academic who has carried out research in areas of BIM applications in the O&M phase.

Verification of Information Requirements

The systematic literature review revealed 21 information requirements that are crucial to the support of BIM in O&M. These 21 information requirements were used to design a simple questionnaire. The main task put before the experts was to determine the suitability of the initially identified information requirements from the literature. Therefore, the questionnaire requested the experts to review and indicate the relevance of the 21 information requirements to the support of BIM and O&M integration for building projects. The experts were asked to select from the list of the information requirements the ones they consider to be relevant. The questionnaire also asked experts to identify other suitable information requirements that may have been missed.

The level of agreement and acceptability of each information requirement was determined using percentages. The results are presented in Figure 1 A total of 21 out of the 32 experts responded to the questionnaire: thereby, reflecting around 67% response rate.

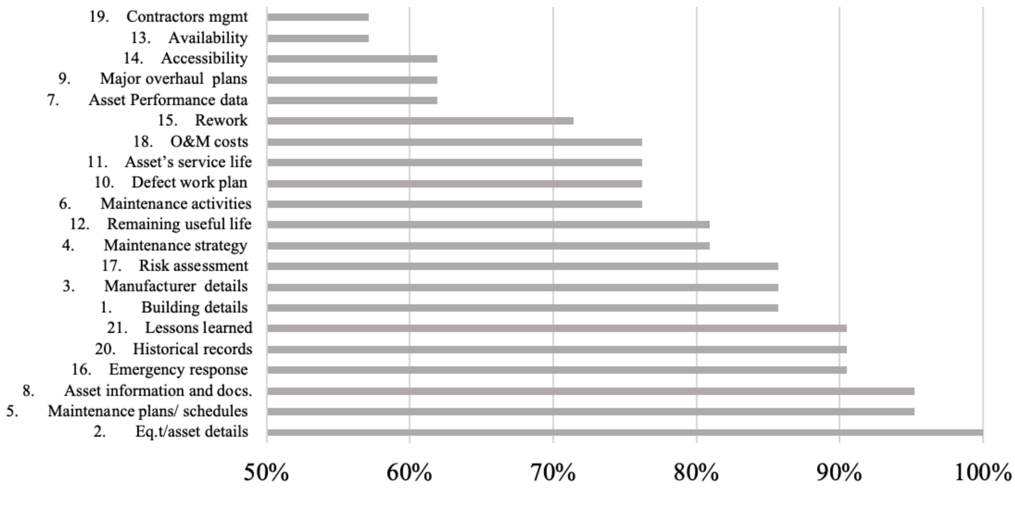

Figure 1: Results on expert survey

For each of the information requirements over half of the experts (i.e., a simple majority- 50%) agreed that it is relevant to the integration of BIM and O&M in building projects. Also, the experts did not suggest any new information requirements. In the end, the 21 information requirements were verified to include in the BIM and O&M integration framework. Based on these 21 information requirements and the PDCA management cycle, an integrated BIM and O&M framework was established. It involves planning, implementation, checking, and reviewing phases which consist of processes and procedures that help in the continuous improvement of BIM and O&M.

Detailed descriptions of the thematic categories namely, general IRs which capture the general information for the building, asset and manufacturer details. Strategic IRs which capture high level strategic plans and information that an organisation requires to maintain their assets effectively. Operational IRs which capture technical information that an organisation requires to evaluate design, operational and maintenance performance limits of their assets. Commercial IRs which capture commercial information that supports the monitoring and validation of key financial and contracting performance management, and continuous improvement which capture the historical maintenance related information to facilitate the concepts of learning from successes and failures, as well as developing feedback loops for an improved and sustainable maintenance regime. The various information requirements within and their corresponding PDCA phase are presented in the Table1.

Table 1: Verified categories and sub-categories of information requirements (IR) to facilitate BIM and O&M integration

Category	Proposed information requirements	Description
General	1. Building details	General building information
	2. Equipment/asset details	General equipment information
	3. Manufacturer and warranty details	General manufacturer information and warranty details
Strategic (PLAN)	4. Maintenance strategy	Existence of a clear maintenance strategy that identifies the vision, mission, constrains and required resources
	5. Maintenance plans and schedules	Existence of clear maintenance plans that show how maintenance will be conducted, including schedules that show start-up and shutdown information for each activity as well as their sequence
	6. Maintenance activities/task	Each asset/component has a clear description of the required maintenance activity
	7. Asset Performance data collection/data handling	The means for data collection and sampling for O&M activities used to assess the performance of the asset
	8. Asset information and documentation	Clear O&M documentation (that is updated regularly with all the required information), data retrieval, and recovery.
	9. Major overhaul plans	Major overhaul plans (if needed) that are required during plant/ asset's shutdown/disassembly to carry out maintenance
	10. Defect work plan	Clear rectifying measures to handle components defects
Operational (DO and CHECK)	11. Asset's service life	The service life of the component
	12. Asset's remaining useful life	The approximate number of years that an asset or system is estimated to be able to function as planned prior to warranting replacements
	13. Availability	The duration of time a particular asset can perform its intended task
	14. Accessibility	Means to access the component for maintenance works
	15. Rework	Repair work done on previously maintained equipment
	16. Emergency response	Emergency response protocols for urgent / late maintenance works
	17. Risk assessment	Efforts to identify and analyse potential hazards
Commercial (DO and CHECK)	18. Operational and Maintenance costs	Records and means to calculate potential associated costs
	19. Contractors management	Strategy of outsourced O&M activities and contractors selection criteria
Continuous improvement (ACT)	20. Historical maintenance records	Maintenance history and status of components
	21. Lessons learned/ feedback loops	Documented lessons learned of previous maintenance interventions and plans of feedback loops

DISCUSSION

The analysis identified five main thematic categories that are relevant to the integration of BIM with O&M. Regarding the ranking of each information requirements, all the participants agreed that equipment/asset details are the topmost important set of information needed to facilitate the support of BIM in O&M with 100% agreement level. Ultimately, 86% of experts believe other general asset's information requirements should be available from the very first stage to facilitate the integration.

BIM and O&M Integration Framework

Plan

In the first phase (Plan), the grouped list of strategic IRs helps in setting the strategic maintenance objectives as well as the means and methods of reaching these targets. To ensure an effective planning of the integration between BIM and O&M, establishing a clear maintenance strategy that identifies the vision, mission, constrains and required resources for the maintenance organisation as well as clear rectifying measures to handle components defects is a main pillar in optimizing maintenance and crucial to the preparedness and readiness of the integration (Liu and Gao, 2017b; Heaton, Parlikad and Schooling, 2019). 81% of experts emphasised this fact. Also, it is unsurprising that 95% of participants agreed on the relevance of maintenance plans and schedules that show start-up and shutdown information to the success of this integration. This will decrease the total maintenance costs through saving human labour and time (Liu and Gao, 2017a; Lu *et al.,* 2018).

Ultimately, 76% of experts approve that defining a clear description of the required maintenance activity/task for each asset, will help in maximizing equipment operating time and reducing asset's failures (Cavka, Staub-French and Poirier, 2017; Liu and Gao, 2017a; Farghaly *et al.,* 2018; Lu *et al.,* 2018; Heaton, Parlikad and Schooling, 2019). On the other hand, 95% of experts agree that identifying the means to document asset information from the planning phase helps in better tracking of maintenance history at later phases, thus allowing for continuous improvement by learning from failures (Cavka, Staub-French and Poirier, 2017, 2018; Liu and Gao, 2017a; Lu *et al.,* 2018). Also, defining major overhaul plans (if needed) that are required during plant/ asset's shutdown/disassembly to carry out maintenance saves breakdown costs and can be more profitable in the long term than immanent repair (Shou *et al.,* 2020).

Do and Check

In the second and third phase (Do and Check), the operational and commercial IRs presented, work as a guide by presenting the operational data needed, tools to collect and analyse these data and performance indicators. In the operating phase of the PDCA cycle, measuring asset's operational performance through key performance indicators can give an indication regarding equipment's health and understanding its patterns. Therefore, it is unsurprising that asset's remaining useful life became of equal performance to maintenance strategy followed by asset's service life.

Moreover, 71% of experts agree that rework rate and 62% and 57% of experts agree that asset's accessibility and availability allow breakdowns to decrease, resulting in higher asset's reliability (Shou *et al.,* 2020). The importance of such information requirement was reported in literature in various building types like Institutional, Infrastructure, healthcare, industrial and residential buildings as well as HVAC systems as seen in (Cavka, Staub-French and Poirier, 2017; Liu and Gao, 2017a; Lu *et al.,* 2018; Heaton, Parlikad and Schooling, 2019; Dias and Ergan, 2020). Also, very few studies considered accessibility.

One study did consider equipment accessibility but did not explain the later relation to O&M and the maintainability design requirements (Cavka, Staub-French and Poirier, 2018). Similarly, the higher the time between the failure, the more reliable the asset. On the other hand, Mean time to repair (MTTR) is considered an important metric that gives indications about asset's efficiency. Examples are seen in healthcare, industrial, and residential buildings as well as HVAC systems as in (Cavka, Staub-French and Poirier, 2017; Dias and Ergan, 2020).

Establishing an emergency response which covers the response protocols for urgent / late maintenance works reduces asset's interruption chances and enhances compliance with health and safety regulations (Shou *et al.,* 2020). 86% of experts believe that proper risk management and effective safeguarding protocols are vital to protect the workforce from injuries (Lu *et al.,* 2018). To improve monitoring and constant checking of the BIM and O&M integration 76% of experts agree that tracking asset's costs history allows to optimise budgeting.

While (Cavka, Staub-French and Poirier, 2017; Heaton, Parlikad and Schooling, 2019) was among the very few studies who focused on maintenance costs, this study details the associate costs with respect to O&M systems in by giving insights of different cost categories that tailored to specific O&M requirements. Moreover, 57% of expert agree that contractor's management plan (price list, point of contact) helps in mitigating risks and avoiding loss in time and money due to pre-defined collaboration strategies (Dias and Ergan, 2020).

Act

In the final phase (Act), efforts and adjustments to sustain and standardise the integration process are established. 90% of experts chose the historical maintenance records and Lessons learned/ feedback loops as necessary information requirements. Capturing such information to facilitate the concepts of learning from successes and failures, as well as developing feedback loops allows tracking of equipment's performance and demonstrating its compliance, helps in better budget planning. Thus, the amount of redundant maintenance works is decreased. These information requirements are in line of what was reported in previous efforts of integrating BIM in O&M as seen in (Cavka, Staub-French and Poirier, 2017; Liu and Gao, 2017a; Lu *et al.,* 2018; Heaton, Parlikad and Schooling, 2019)

CONCLUSION

It can be concluded that although BIM asset delivery is now well developed to globally recognised and accepted standards, some drawbacks hinder the adoption of BIM in O&M. We aim to address these deficiencies through the proposed framework. The current study proposes an integration framework for BIM and O&M and contributes to the existing body of knowledge by identifying clear information requirements from the perspective of a reliability information management to support BIM integration with O&M phase. It provides a means to categorise, and priorities the required information needs based on their importance and relevance to the integration of BIM in O&M and standardising the integration process between BIM and O&M through the adoption of the PDCA cycle.

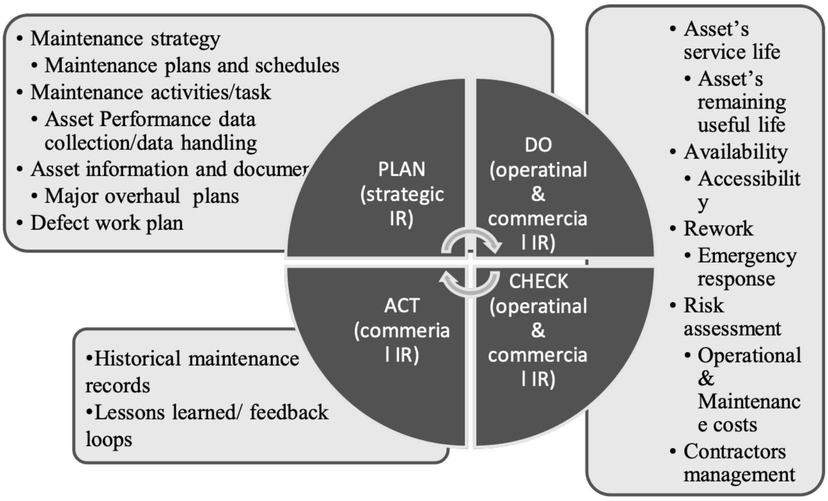

Figure 2 Integration framework between BIM and O&M based on the PDCA cycle

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DIGITAL INNOVATION AND INTRA-ORGANISATIONAL CHANGE: A CHALLENGE FOR THE CONSTRUCTION INDUSTRY

Sam Zulu[1], Ali Saad[2], Neema Kavishe[3] and Maria Unuigbe[4]

[1,2,3] School of Built Environment, Engineering and Computing, Leeds Beckett University, Leeds, LS2 8AG, UK

[2] School of Engineering, University of Central Lancashire, Preston, PR1 2XQ, UK

Studies have examined the benefits of broader use of digitalisation on the construction industry. However, there has been limited empirical explorations of the challenges of intra-organisational change due to digitalisation. A review of general change management literature shows that studies on organisation change have broadly focused on the reasons and the impact of the organisational change. This study is based on a qualitative methodology using semi-structured interviews with industry leaders and uses the McKinsey 7S model as a theoretical lens to examine digitalisation-led intra-organisational change. Qualitative data from seven participants has been analysed both thematically and deductively, leading to the identification of the recurring patterns that align with the adopted theoretical framework. Findings include key challenges in achieving a common meaning of relative values, organisational structuring, leaders' strategies and style, and the readiness of employees to change. The study provides further insights into the challenges associated with digitalisation at an organisational level, offering coherence on these challenges and enabling more informed decisions that are vital for an effective transformation.

Keywords: digitalisation; innovation; intra-organisational; organisational theory

INTRODUCTION

The shift towards digitalisation has driven industries to a fundamental change. However, the construction sector, as is often the case, is among the last to embrace innovations, and digitalisation is not an exception. Nonetheless, the benefits of using digitalisation have led to a 'digital era' (Shah, 2022), and in turn, the changing digital environment is forcing construction organisations to apply unprecedented changes as an unavoidable need to cope with the transformation (Zulu and Khosrowshahi, 2021). Generally, challenges undermining broader technological change have been linked to people, organisations, and strategies (Li *et al.,* 2019). It has been contended that multiple changes at an organisational level are critical for achieving alignment with an external changing environment (By, 2005). Such organisational change has been described as 'multifaceted', due to requiring new, and most often complex ways of

[1] s.zulu@leedsbeckett.ac.uk

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thinking (Thakhathi *et al.,* 2019). The emergence of digitalisation, hence, demands an increasing need for construction organisations to alter their conventional processes and establish a more ready and reinforced environment that can drive change. Introducing digitalisation to the construction narrative demands a level of adaptation among organisations in relation to their internal processes to effectively leverage the benefits of digital technologies.

In the context of organisational change, non-technical inhibitors are seen as equally important to the technical inhibitors, and these vary to include issues influencing the confidentiality of data (Aghimien *et al.,* 2022); such as forcing organisations to take measures against cyberattacks (García de Soto *et al.,* 2022), complexity of the relative supply chain networks (Lavikka *et al.,* 2018); such as forcing organisations to depend on non-local and foreign expertise (Ayat *et al.,* 2022), and lack of knowledge and information (Berlak *et al.,* 2021); such as forcing organisations to assess the level of their employees' digital literacy (Zulu *et al.,* 2023). This implies that a shift to embrace digitalisation is associated non-conventional challenges that are believed to demand organisational change (Grybauskas *et al.,* 2022). Thus, it is here assumed that neglecting the intra-organisational changes may be undermining broader digitalisation among construction organisations. Overall, research efforts in construction management research seem scarce when illuminating how these challenges are influencing organisational change in the construction context (Nagy *et al.,* 2021), nonetheless, this in turn present an opportunity to explore an unfulfilled knowledge gap. Mainly, digitalisation is seen from the lens of negativism (Svensson, 2022), rather than the highly needed optimistic stance that is vital for driving innovation adoption (He *et al.,* 2022). Therefore, it is imperative to explore the non-technical inhibitors and their role in undermining effective change.

One of the popular models created to help comprehend the needed internal changes is the McKinsey 7-S Framework, which looks at external changes as accompanied with internal changes predominantly in seven key areas of Shared values, Structure, Strategy, Systems, Style, Skills, and Staff (Waterman *et al.,* 1980). The model conceptualises that an organisational change may initiate alterations in the seven organisational factors, imposing plausible challenges for organisations to reinvent the old and traditional processes. The drive behind this choice is the limited use of this model in construction management research compared to other research areas such as healthcare (Scerri and Resident, 2020), education (Paquibut and Naamany, 2020), and automotive (Kukkamalla *et al.,* 2021). McKinsey 7-S has been described as one of the most popular change management frameworks that is highly effective in simplifying the challenges of change, to components that are more manageable (Mulholland, 2021). Thus, its use in this paper offers perceiving the relative challenges associated with digitalisation in construction organisations from a different angle. Therefore, the aim of this study is to examine digitalisation-led intra-organisational challenges. due to adapting to broader digitalisation.

LITERATURE REVIEW

The review of literature suggests the complications associated with adapting to digitalisation at the intra-organisational levels of construction firms. For example, Aghimien *et al.* (2020) argue that the low adoption rates are linked to the lack of trust of construction organisations with their digital partners supplying the digital systems. This crystalises the importance of collaboration with digital advocates to achieve a common meaning and better implement digitalisation in an effective manner

(Aghimien *et al.,* 2022). Moreover, Säynäjoki *et al. (*2017) raise an important realisation that areas where digitalisation is expanding are most often in pursuit of data without necessarily comprehending the different setting of the construction industry, and thus, such an approach is undermining the values expected from digitalisation. This aligns with Lasarte *et al. (*2021), who call for the need for accessible value chains and information relative to construction processes. Without doing so, Berlak *et al. (*2021) warn about the loss of information, and most importantly, the loss of value from digitalisation due to the lack of veracity. Hence, it here becomes clear that the implicit inferred in previous research efforts demands the need to better understand the challenges of organisational changes as a key prerequisite to drive effective digitalisation.

Challenges may be linked to the social system of the organisation, which concerns employees' skill sets and knowledge. Grybauskas *et al. (*2022) emphasise that digitalisation is 'worsening' employees' divergence in digital literacy, since skill sets are varied, those who often are digitally advanced are so because of their environment rather their own willingness. This interesting proposition touches on the issue of skills and competency in the digital era. Nonetheless, the increasing use of digitalisation in the industry is imposing threats on these organisations to take on board the transformation and seek the skills necessary, which is argued to be achieved through the "mutually constitutive relationships" (Morgan, 2019, 415), which are relationships nurtured by close monitoring by organisations' leaders. Another challenge imposing complications to the wider use of digitalisation in construction firms is the technological 'revitalisation', as Hewavitharana *et al. (*2021) reveal that the changing and non-static nature of technologies challenges developing a specific set of skills. The study calls resolving such an issue by having standard digital tools for the different construction purposes. Therefore, an interoperability challenge exists among the existing digital tools and is in turn influencing the overall competency of employees (Lasarte *et al.,* 2021). Hence, there is a need to better understand the nature of skills required by staff as a key prerequisite for an effective adoption.

The fear of associated challenges is widely stated in the existing body of knowledge (Sanchez-Riofrio *et al.,* 2021). Literature reflects that those who are favouring digitalisation may be holding an unreasonable belief that achieving efficiency in imminent and conclusive (Zheng *et al.,* 2021). Such perception may not always be the situation with the adoption of digitalisation in construction organisations (Bazán *et al.,* 2021). This aligns with Aghimien *et al. (*2021, 274), who state "the question is not about whether to adopt technology, but how to go about it", as construction organisations are seen as 'too blunt' to accelerate digitalisation in the sector (Sezer *et al.,* 2021). This aligns with Jacobsson and Linderoth (2021), who argue the lack of the sense of urgency in construction organisations as forces that are needed to drive fundamental change. Additionally, Zulu and Khosrowshahi (2021) describe that this issue is linked to the uncoordinated and poor management in construction organisations. These non-technical inhibitors are driven by the vagueness of the benefits and added values associated with digitalisation in the construction context (Demirkesen and Tezel, 2022). Overall, these studies imply issues related to the intra-organisational challenges that need better consideration upon broader digitalisation, which align with Lindblad and Gustavsson (2021, 33), who emphasise that digitalisation advocates "have to take the intra-organisational change process into account". Intra-organisational change is described to take multiple forms that includes skills, policy, procedures, staff, and other aspects seen as the pillars of an organisation

(Walker *et al.,* 2004). Hence, digitalisation can be seen to impose challenges at an intra-organisational level and seeking more coherence on these challenges present a knowledge gap that remains ill-researched in the existing literature.

METHOD

The aim of this study is to explore the challenges facing construction organisations in their quest to cope with broader digitalisation. Due to the lack of studies with a similar aim (Statsenko *et al.,* 2022), the authors' choice of the research method implies an exploratory stance (Hoepfl, 1997). To achieve this, the paper adopts a qualitative method through semi-structured interviews that can capture perceptions, and by that, achieving improved comprehension of the relative social phenomenon (Eisenhardt, 1989). The use of interviews promotes the actor-observer paradigm and equips research with the interpretations that emerge from viewpoints of those living the experience (Motro and Sullivan, 2022).

The study adopts a purposive sampling strategy based on the selection of participants best suited to the purpose of the study (Unuigbe *et al.,* 2020). Such a sampling approach is believed to align with the context of this study by enabling a targeted selection of interviewees of whom have the appropriate expertise and knowledge to provide an in-depth view of the intra-organisational challenges when adapting to digitalisation. The sample includes organisational leaders from industry (see Table 1) recruited through a knowledge-exchange construction event. Seven organisational leaders participated in the study which was deemed suitable due to the focus on quality of data (insight) (Patton, 1982) and saturation (O'Reilly and Parker, 2013), both of which are key criteria for qualitative methods. The average time of each interview was 30 minutes, and participants were asked about the challenges facing their organisations, staff, and decision-makers as well as the strategies utilised to overcome these challenges. Moreover, questions also promoted discussions to include the values of digitalisation and its adoption.

Data has been analysed thematically and deductively based on pre-determined constructs. Firstly, a thematic analysis employing the procedures outlined by Braun and Clarke (2012), initiated by data familiarisation, followed by data generation and alignment, prior to final reporting. Themes are then deductively formed to fit in constructs of prior knowledge (Thakhathi *et al.,* 2019), which are based on the seven classifications relative to organisational change in the McKinsey 7-S framework (Waterman *et al.,* 1980). Hence, recurring viewpoints by the participants have been grounded within the framework's constructs as the study's theoretical underpinning.

Table 1: Interviewees' roles and experience

#Interviewee	Organisation type	Role	Years of Experience
Participant 1	Consultancy	BIM Manager	Over 20 years
Participant 2	Contracting	CDM Co-ordinator	Over 10 years
Participant 3	Consultancy	Associate Director	Over 10 years
Participant 4	Consultancy	Senior Quantity Surveyor	Over 15 years
Participant 5	Consultancy	Director	Over 10 years
Participant 6	Consultancy	Equity Partner	Over 20 years
Participant 7	Contracting	Director	Over 20 years

FINDINGS

The recurring viewpoints from the interviewees have been fitted into the seven McKinsey 7-S framework's constructs to help explain the intra-organisational challenges due to changes in the shared values, structure, strategy, systems, style, skills, and staff. The framework has been described by Paquibut and Naamany (2020, 783), as one "of the most popular approaches used for their ability to breakdown the change process into more manageable components".

Shared values

Achieving a common meaning among all the members of an organisation is driven by having a shared value (Lavikka *et al.,* 2018). One of the values is 'control' stated by Participant 1 (P01); "It's easier to control, because you're all working on the same platform", as control promotes the ability to communicate. Additionally, the same participant argues that digitalisation enables meeting clients' needs and wants; "the client can see what it's actually going to get", aligning with P05 who states, "we're able to influence the way that clients define what they want". Achieving a shared value with clients, however, has been described as problematic; "client will want it but don't want to pay any money, regardless of it would save money further down the line. They just want it but don't want cost." (P02). The matter of shared value relevant to digitalisation has been described as critical in the construction context, as Lindblad and Gustavsson (2021, 32) state; "the client has to accept the change before they may exert their influence on external actors". Shared value, in this context, is encouraged to comprise a lifetime perspective, and not otherwise; "All the real benefits of that lifetime cycle are going to be for them rather than short-term things." (P06). Despite of the internal advantages, achieving a common value with external customers to justify digitalisation is seen as a challenge that hinders broader adoption. It is here important to note the successes associated with achieving a common value, however, the process of driving such shared perception between the actors is a complex and problematic process.

Structure

The specialisations and the diversified levels and roles in a firm shape the structure of the organisation (Li *et al.,* 2019). One of the key levels described by the participants is the middle managers, whom have an influence on the decision-making; "middle management that's been really hard work. In a battle with them, they're the ones that's been holding me back." (P01). This aligns with P03 who states that, "the way we've been doing it has sort of been a bottom-up approach. So, people at the mid and junior levels trying to push up the business". These arguments inform that the willingness and knowledge are the key characteristics driving decision-making as exemplified by P06, stating, "I could see that you would have information director/manager. But on other projects that are a lot smaller, they'll need somebody who's got management knowledge, whether they can only have it part-time to do it right by a director". Hence, a structure of an organisation is challenged to emphasise the role of middle managers as a key approach to promoting a robust hierarchy that includes effective digital advocates (Zulu *et al.,* 2022).

Strategy

Having the right strategy is a key condition for an effective digital transformation in construction organisations (Shojaei *et al.,* 2022). Participants show a consensus on the challenging nature of developing the correct strategy that embraces digital change by phasing out traditional habits and practices; "how do you send out a document, people do it electronically now, but a lot of people still like a paper copy and paper drawings, well how do you send out a BIM model in that format" (P06). To achieve this, P01 states; "we don't do one process for one project, and another process for another, so we've done it across the board. And that has sort of helped as well." (P01). Moreover, developing a strategy that welcomes innovations is much cheaper than one that is reluctant; “it's cheaper and easier to accommodate something before you've built it than trying to prevent something afterwards.” (P02). Such arguments align with Beddewela *et al.* (2021, 2793), who state that “change process at the intra-organisational level, it is equally likely to face restrictions and problems, such as individual resistance and disagreement”. Hence, traditional strategies are believed to be challenged into a new paradigm that requires looking at change from a new lens of innovation (Hsu *et al.,* 2019).

Systems

The systems of an organisation are the adopted procedural and operational means based on supporting the organisational strategy (Lundberg *et al.,* 2021). Participants agree that having a procedure in place would facilitate adoption; “it makes our job easier if we've got a proper BIM scheme” (P02). Additionally, the lack of a system in place has as well been flagged as a potential inhibitor undermining digitalisation; “we don't have the facility to gather that kind of information or store that kind of information. It's so humongous.” (P04). These arguments align with P05, who stresses the need for a system that can drive and foster adoption; “if you don't have some sort of framework around them and a framework around the whole team, making them work together, I think that it actually complicates what is already quite a complicated process.” Therefore, having a rigorous set of procedures to comprise an effective system is a key organisational challenge associated with digital transformation (Wernicke *et al.,* 2021).

Style

An organisational style is referred to the way of thinking relative to managerial influences, forming its culture (Zulu and Khosrowshahi, 2021). Namely, a style that leads to helping others is seen as highly important; “helps the rest of us out with this” (P01). Moreover, higher management advocating change is also seen as important in the transformation; “Some of the guys that we have in the business, the senior directors, they are well into their fifties, and they are the BIM evangelists.” (P03). In contrast, a way of thinking that aims to avoid change is also present among construction organisations; “they don't want to admit that there's something new out there that can improve things, because they don't want to be left behind” (P02). For instance, late adopters who take a conservative stance when looking at change; “we're just going to see how it affects the trade, the construction industry, as a whole, and then we'll adapt to that.” (P04). P07 proposes a style that is believed to embrace change, stating; “We look at different ways of doing things.”. Hence, adopting a style that can discard the old and conventional ways of doing things to a new way of thinking is another challenge associated with change at an intra-organisational level (Burke and Clark, 2016).

Skills

Having the right skills enables individuals belonging to the organisation to perform and carry out the activities needed to deliver the main objectives, which defines its competitiveness in the market (Horbach and Rammer, 2022). Construction organisations may face a substantial challenge when training large number of employees to align with that expected from broader digitalisation; “training was one big issue, especially when you've got 400 people” (P01). The issue has been described as beyond the learning curve itself; “It's not so much a learning curve in terms of being able to do, but it's more a mind thing, whether they'll lock it together.” (P06), aligning with P07, who states, “They know what their systems will do, but they can't advise of what is best or fit for purpose for that individual project, because they don't know the whole picture.". This reality makes it challenging for construction organisations and imposes the need to search for new skills amidst an already scarce and shortage of skills in the industry; "We've recognised that we need people that are certainly more technology-competent." (P07). Hence, identifying and employing skill sets among an organisation is another key challenge accompanied with their organisational changes in pursuit of digitalisation (Helsper and Eynon, 2013).

Staff

Staff refers to the characteristics of the human resources within an organisation and how these align with the organisation's main objectives (Folkestad and Gonzalez, 2010). The staff of construction organisations have been described as varying between those unwilling to change and others who are more open to it; "getting the user to move out the comfort zone into something new. Some people, they want to do it. Others are happy in their own little comfort zone." (P01). Arguably, this has been linked to the demography of staff; "older guys are sometimes more reluctant to do that" (P02). The challenge herewith is seen to be mainly larger than awareness itself; "A lot more people, maybe 90%, know about BIM, but they're not comfortable to really work in that environment." (P03), despite that digitalisation is fairly ensuring a more convenient work environment; "They're not running between office and site anymore, wasting their time." (P07). Hence, the nature and characteristics of the employed staff within construction organisations impose another challenge for effective change (Jacobsson and Linderoth, 2021).

CONCLUSIONS

Authors of this paper follow a research agenda that aims to set out some of the challenges facing construction organisations amidst change towards broader digitalisation. To explore these challenges, the study adopts the Mackenzie 7-S model that explains and classifies these changes into seven organisational factors. Overall, the viewpoints of seven participants have been explored in pursuit for better understanding of these challenges. This study illuminates the organisational situated challenges that are of a non-technical nature but are nevertheless believed to inhibit broader digitalisation in the construction sector. Across the seven organisational clusters forming the model, several challenges emerge to undermine the transformation. Firstly, there is a challenge to achieve a common meaning among all members of the social system of organisations, as justifications for change remain vague despite the demonstrated benefits of digitalisation. In the organisational structure, the role of middle managers to bridge the gap between higher management and digital advocates is presented as a key attribute for change. Moreover, the findings suggest that change is dependent on leaders to create and adopt strategies, procedures, and styles that can create and reinforce the transformation early and adequately, whereas any lag in the creation and reinforcements of any of these factors is believed to drive an ineffective change process. Finally, the study suggests the problematic nature of the skill sets needed to achieve digital transformation, an aspect that is echoed by vast literature reiterating the issue of skill shortages in the industry. This realisation becomes more complicated with the extensive need to upskill existing staff, an aspect that places more pressure on leaders to operationalise approaches that can promote knowledge and training. Overall, the study offers managerial insights to decision-makers on the challenges of broader digitalisation at an intra-organisational level. This study therefore provides an opportunity for future quantitative studies focusing on digital-led intra-organisational changes.

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DISASTER MANAGEMENT AND RESILIENCE

UNDERSTANDING HOW BUILDING IS ADAPTED UNDER CHANGING SCENARIOS FROM A USER' PERSPECTIVE

Jiajing Feng[1], Dragana Nikolić and Ian Ewart

School of Built Environment, University of Reading, Whiteknights, Reading, RG6 6AH, UK

How a building is adapted has been studied mostly from its design stage in terms of improving its physical attributes to benefit the future. While this process is also influenced by other social aspects, such as how building users make decisions to adapt to changing situations or the actual practice after building has been constructed. During this stage, heterogeneous network of human or non-human actors will play their part, especially in public buildings where diverse adaptations are made. Different users also have different authorities or power to make changes. This research, therefore, invites the lens of actor-network theory (ANT) to view this process. Using ethnographic observation method in a public building to identify building adaptation incidents in daily, planned, and emergency scenarios. Semi-structured interview is then used to follow these incidents and track related users involved. The translation process from ANT is mainly used to analyse comparatively the three scenarios. Expected contribution will be in the theoretical and methodological exploration of building adaptation area and investigation of its social aspect.

Keywords: Actor-network theory; building adaptation; scenarios; translation; users

INTRODUCTION

The recent outbreak of coronavirus (COVID-19) has brought us more thinking about the built environment we live in, and how we can provide a safe environment under different situations. Today's rapidly changing world gives the places where we live more challenges that they need to be adapted in response to these changes swiftly and in an appropriate way. The 'building' where we spend most of the time living, working, studying, or conducting other activities is the unit from which we can start to explore this adaptation process. Within the building, we encounter its physical attributes surrounding us, or in another way, we are communicating with the people who designed, constructed, or are using, adapting it continuously. These elements unfold the complicated adaptation process that we are still not clear about, and this is the starting point of this research.

Building adaptation or building adaptability is the main concept discussed in this area. When a building is designed, it is impossible and unnecessary to make all the predictions about how it will be used in the future (Rockow *et al.,* 2019). Therefore, building adaptation is unavoidable after the building has been constructed. It can

[1] jiajing.feng@pgr.reading.ac.uk

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mitigate the mismatch between the supply (what buildings provide) and demand (what users need) under different situations afterwards (Gosling *et al.,* 2013). Accordingly, building adaptability is the capacity for a building to make adaptations effectively under changing demands. Most of the studies explored how to increase such adaptability through the design stage by improving the building's physical attributes such as its openness, height, etc. (Wilkinson 2011). Nevertheless, there still lacks the understanding of how buildings make adaptations. Furthermore, it has been pointed out by some researchers that the existing studies neglected the involvement of users and other relevant stakeholders during the actual building adaptation process (Heidrich *et al.,* 2017). Beyond the discussion of building's physical attributes in making adaptations, there is still a gap in understanding the impact from users, and relevant stakeholders during this process. The focus of this study, therefore, is not to provide more strategies for improving building adaptability from the perspective of the building's physical attributes but aim to understand the building adaptation practice under changing scenarios from a social perspective that involves the users or relevant stakeholders. Specifically, actor-network theory (ANT) is used as the lens. Only by understanding the building adaptation can find the issues and then provide suggestions to improve building adaptability in the future. Since one of the problems in the building industry is limited learning from existing buildings' use and operation (Jensen 2012).

LITERATURE REVIEW

Adaptation of Existing Building

Building adaptation is any work to a building over and above maintenance to change its capacity, function, or performance (Douglas 2006). While maintenance work only maintains the existing state of a building without improving or increasing any capacity, building adaptations adjust, reuse, upgrade or extend the useful life of a building to suit new conditions. But why building needs to adapt? Changes in building use are key drivers for adaptation. The stimuli of changes may be factors such as legislation, sustainability concerns or user demands, and these will cause mismatch between the user expectation, actual use and building performance. In different situations, the mismatch varies at different levels and building adaptation helps manage it to balance the relationship between the building and users (Blakstad 2001). Nowadays, with increasing new situations, rapidly changing user or organisation demands, buildings are always facing different scenarios that they need to adapt to.

Instead of focusing on the design stage, the long time after building has been built is neglected when considering of making adaptations. The construction of a building is only the beginning of the process but not the end as it will interact with users, adapt to their needs, support their intervention with the surroundings. Nevertheless, this long-term stage after construction has not received enough attention. Very few studies revisit buildings beyond five years after the physical completion of the building (Patel and Tutt 2018). Therefore, it is significant to receive such feedback to understand how buildings adapt in practice. This ultimately helps improve the building adaptability for changes in the future (Ilesanmi 2010).

Different Building Adaptation Scales

In terms of the different types of building adaptation, it can be classified according to different scales as small (minor improvement such as wall re-rendering, furniture replacement, signage improvement), medium (major upgrading such as removal or insertion of walls, new air-conditioning system) and large (extensive changes such as restoration of a ruinous building, major extension of buildings) (Douglas 2006: 6). Table 1 also shows other categorisations in literature (Heidrich *et al.,* 2017): Adjustable, flexible, refit-able, convertible, scalable and moveable. However, these ways of categorising are not clear enough and there seems to be no accurate and commonly agreed categorisation of building adaptation. This may also confuse who should be assigned to the adaptation work and how. Clarification of building adaptation and its different scales is needed.

Table 1: Dimensions of building adaptation

Adaptation Main type	Decision level	Adaptation dimension	Meaning
User-driven adaptations	Users	Adjust-able	Change of tasks by users daily or monthly
	User	Flexible	Change of space and location of services, furniture, and equipment by users daily or monthly
Adaptations to the fabric	User or owner	Refit-able	Change of performance of some components without replacing the whole system
	User or owner	Convertible	Change of function (space or services)
	Owner	Scalable	Change of size of the building (e.g., expansion of buildings)
	Owner	Movable	Change of location of fabric (e.g., reusing rather than demolishing)

Therefore, another layer of soul was mentioned by Brand (1997) and Blakstad (2001) explained that souls represent every end-user of the building and the organisation's needs. End users usually interact with the stuff and space layers, and the organisations can interact with slower layers beyond. The recent discussion also added the level: body (of the user), with its changing speed goes even in minutes. Nevertheless, the elaboration of how the soul or body layer interacts with other layers is limited and no empirical studies have been conducted for understanding this layer's impact on building adaptation yet. Much exploration is needed. Here, user minor building adaptation includes the layers of soul, stuff, and space. This type of adaptation involves the decision-making usually done by 'users' in Table 1, e.g., the daily or monthly changes of furniture, signs, space, etc. Minor building adaptation has not been studied much especially in a systematic way. This area is fragmentary in various disciplines like architecture, building space, environmental psychology, organisational management, etc. However, it has close interaction with the building users' daily life and presents the building performance directly.

Users' Involvement in Building Adaptation

Users and stakeholders of different types of buildings have different motivations, autonomy, and interaction with building adaptation. However, the main tension between the buildings' architectural or physical features with its user, stakeholder, or organisational management is similar. The prior studies paid a lot of attention to the buildings' design or architectural attributes' impact on the building's adaptation in responding to changing scenarios (Herthogs *et al.,* 2019). Nevertheless, few have been investigated in the user, stakeholder, or organisation's aspect and these two aspects should not be considered separately.

User adaptation links to how users adapt their buildings, since how a building can be adapted does not only depend on the building's capacity, but also on people's (users or owners) or the organisation's capacity to adapt (Schmidt III *et al.,* 2010). According to Heidrich *et al.,* (2017)'s dimensions of building adaptability, they classified two dimensions of user adaptation that do not affect the building fabric and the other four dimensions that make adaptations to the fabric as Table 1. Schmidt III *et al.,* (2010) further added the decision level of each adaptation dimension (the second column of Table 1), showing the different autonomy levels of them. This makes this process more complicated, dynamic, and never stops (Blakstad 2001).

In terms of different types of buildings, the users have different autonomy accordingly. Residential building users usually have higher autonomy than public buildings. However, at the same time, the public building users are also using their own way to adapt and communicate their needs, though implicitly to some degree. It is important to understand how they adapt the building as this matters to large groups of users with their satisfaction, safety of use or other potential aspects. In such public buildings, there is also a complex separation between decision-making by different stakeholders of how buildings should be adapted and how actually it is adapted.

Actor-Network Theory

Although this discussion shows the importance of considering user impact during building adaptation, it cannot be considered separately from the physical attributes of the building. This brings about the question of how to link these factors together. Instead of understanding building adaptation in terms of shearing layers, nowadays, with the ever-changing circumstances from external and internal, there should be a more fluid theory or mechanism to understand how buildings respond to the changing situation and their interaction with human behaviour. This discloses that this process is not a unilateral and rigid process but bidirectional and dynamic adjusting system. This system requires further consideration of users' interaction with building, the stakeholders' involvement, and more factors. As Holland (2012) mentioned that 'ecosystems, governments, biological cells, markets, and complex adaptive systems in general are characterised by intricate hierarchal arrangements of boundaries and signals.' Understanding the origins and effects of signal and boundary interactions wherever they occur in different contexts is important. In the case of a building, how it reacts to different 'signals and boundaries' by external and internal changes and actors, keeping the balance is still not clear.

The view of social material that the building, stuff, users are ever unfolding and entangled will help refresh the rooted problem in conceptualising building as solely material and static. Sociomateriality is also practice-based which matches this research's aim to understand the building adaptation from practice. It attempts to understand the interaction between social (human-related factors) and material (e.g., objects, spatial arrangement, technology, etc.) in everyday organisational life. And the social and material elements are shaping or are shaped by each other (Orlikowski, 2016). There are many theories under the umbrella of sociomateriality, such as activity theory, complexity theory, practice theory or actor-network theory (ANT). ANT does not emphasize like activity theory that human beings are the main actor to plan and interact with other human and nonhuman actors consciously. Instead, ANT contends that both are equal. This helps balance the two sides this study focuses on. Also different from complexity theory that considers more on the interactions between the actors and the outcome, ANT considers more of the minor details of the actors or actants in the network development. This is more suitable for the minor adaptation studies. Practice theory is also used for understanding everyday activities in a socially structured way, but ANT has more strengths in offering both theoretical and methodological guidelines. In this explorative study, ANT provides more possibilities for flexible investigations.

ANT is a theory developed in the 1980s and is mostly associated with its key authors: Bruno Latour, Michel Callon and John Law. Its basic idea is to understand how human and nonhuman actors are brought together in networks. And by tracing the transformation of these heterogeneous networks, ANT explores how these actors' or actants' relations are forged, negotiated, or maintained in networks and compete with other networks (Law, 1992) (Tatnall and Gilding, 1999). Tracing such heterogeneous and dynamic interactions between different actors of building can help unfold how actually building is being adapted. ANT is argued that it does not define terms (Mol, Annemarie, 2010). The following concepts' introduction only wants to provide the basic platform to be enacted by these concepts but not to define or make them rigid.

Actor-network

Usually, many studies use actor to refer to the human and actant as the non-human that is involved in the activity studied. The dividing of human and nonhuman is argued as inevitable only because of the labour of division (Ruming, 2009). For an entity to be an actor, it is not required to have contentful mental states, but to be able to perform actions as intended. If an actor makes no difference, it's not an actor, showing the effects is important (Mol, Annemarie, 2010). During this process, some of the actors are treated as the focal ones that initiate the actor-network formulation, some may be made to act, but none of them acts alone. All actors form networks and work by the relational effect with other actors and such effect is also continually forming themselves (Latour, 2005). They may also relate to other existing networks. And network is fluid, they may be stable for some time, but they may falter eventually.

Translation

Translation is a process to understand how networks emerge, being transformed the interest to various actors. This is an ongoing process, never completed and may fail. There are four stages of translation: problematisation, interessement, enrolment and mobilisation. Problematisation is the stage in which a key actor attempts to frame the nature of the problem in their own terms and starts to involve several actors (human or non-human) in to initial problem-solving network. Also, it is suggested that the problems would be resolved if the actors negotiated and pass the 'obligatory passage point' (OPP) of the problem. OPP is the crucial point that forms the actors into a system of associations. The second stage, interessement is where the actors seek to lock other actors into the roles that had been proposed for them. However, the interessement does not ensure success, so the next stage, enrolment is where actors seek to define and interrelate with other actors. This may include negotiations, trails of strength or tricks to enable the success. The final stage, mobilisation is to use methods to assure that supposed actors properly finish their roles (Callon, 1984) (Law, 1992).

Black box and punctualisation

When the translation process finally gets a single-point actor, it is black-boxed or punctualised. So, these two concepts are about simplification. A black box can be a car or a computer or any other entity that have their complex operations inside but is invisible to us (Cressman, 2009). Punctualisation is a process by which complex actor-networks are black-boxed and linked with other networks to create larger actor-networks. Currently, the whole networks are greater than the single parts. Therefore, this process transfers an entire network into a single point or node in another network (Tatnall and Gilding, 1999). But new actor can still enter and open the black box.

Power and control
ANT is also about power as an effect rather than a set of causes. Those who wish to exercise control over others need to create an actor-network. When an actor-network forms, there are certain entities that control others (Law, 1992). To study this, Latour proposes 'following actors' to trace the associations (Latour, 2005).

METHOD

Mixed qualitative methods are used to trace how different actors mobilised different materials to adapt the building and achieve specific goals under changing scenarios. How they interpret the situation, initiate actions, and collaborate with different people are investigated. ANT guided the data collection with its main principle of 'following the actors'. And with the ethnographic methodology used, the data collection and analysis are conducted in a parallel and interlinked way, which separates them into several phases (O'Reilly, 2012). One specific building, Building S is used as the unit to conduct this study. Building S is a building where a university School A is in the UK. It started to be used since 2017 and was designed to facilitate a sense of community, enable teaching, research activities that reflect collaborative working in industry. It has two floors, with the ground floor as central classroom for the whole university and the first floor as home of School A. The first floor has two teaching and research labs, social break-out spaces, academic offices, and a resource room as its main facilities.

Firstly, the participant observation is conducted for around 8 months mainly in the public area and some offices. Observations are made to identify the initial adaptation incidents happening in this building with the role of building user. The main categories of different scenarios are then identified as the daily, planned and emergency. Initial data mapping is used to plan for the next stage data collection. In phase two, semi-structured interview is used to investigate further. 12 interviews have been conducted. Specifically, to better trace what the actors did, photo-elicitation skills are used to help remind them the incidents of what they did and how did they do with the collaboration from whom or more details. The next phase of data collection was to follow further the actors these interviewees mentioned. During this process, parallel analysis of collected data helps compare and determine who and what are really needed to achieve the research aim and objectives. Setting the boundary and interpreting with the chosen theoretical framework is important to make sure the data collected are relevant enough. For analysis, compared with content analysis and constant comparative method that used a lot in qualitative analysis, a better way is to understand the data with researcher's experience as an ethnographer (Chow, 2016). Getting more familiar with the data and then starting categorising and developing themes based on the theoretical framework during the data collection will better suit this study. The social network mapping is used only for showing the relationship between different actors visually.

FINDINGS

The initial findings will show some vignettes as example incidents. Here a resource room in Building S will be used to illustrate its adaptation under three scenarios.

Daily Vignette: Various Functions

The resource room is one room that belongs to the School A on the first floor in Building S. Therefore, it is different from the classrooms on the ground floor that are centrally bookable for the whole university. The resource room's main function is to provide School A's students with study space and other resources like books and relevant facilities. In a daily context, this room may also be altered for other uses. Such as Figure1 and 2 show, 'Resource room is booked for interviews today until 3 pm' and 'Risk workshop till 12:00, please do not disturb, thank you'. When these things happen, the room would be set up accordingly. Usually, the interview would invite staff in School A and Human resources staff at university level to come. The executive team would work with them and book the room by updating the timetabling frame on the door as well as putting up the temporary signage. This is a routine problematisation phase in ANT's translation moments to frame the nature of this interview activity. And this relies on existing network of different staff and room space to complete.

Figure 1: Interview notice

Figure 2: Workshop notice

The temporary signage can also be understood as the interessment phase that existing actors wish to invite other actors (e.g., students who usually use this room) to agree with the interview activity going on and do not disturb. This is also an ongoing translation until the interview is finished and temporary signage is removed. Similarly, in Figure 2, the academic staff also went to the executive team to book the room and used the temporary signage to make it clearer for students. The flip chart was also borrowed from the post room to show the work of students and is convenient for discussion. The tables in resources room are reassemble and easy to move when more space is needed. They can also be put back after all these activities are finished. These nonhuman actors were enrolled and mobilised to help finish the translation along with the existing actors.

Compared with daily context, the less happening but more planned vignette is from the open day. It is open to potential students and their parents interested in studying at the university to come and visit. This is a university operating event that there is a central open day team under the Department of Marketing, Communications and Engagement to organise. The central open day team gives general guidance and then each school has their own team to arrange the 'show' for the visitors in the building specifically. It is usually planned four months in advance. For the resource room, the existing table, and chairs for students to study should be moved out to make space for visitors and staff to drink and have conversations.

Planned Vignette: The Open Day Room Arrangement

Firstly, such decision was made by School A's open day team since School A moved to Building S in 2017. At that time, the school director of teaching and learning told the executive team how the resource should be set up with the drawing (Figure 3). And through many years, they just found it useful, and they know how it works for the visitors by their experience. Secondly, how to set up the space. The resource room is not a central classroom, so School A can directly book the room through its executive team. The date and time were given by the central open day team. The setting up includes the rearrangement of tables and chairs as an outcomr (Figure 4).

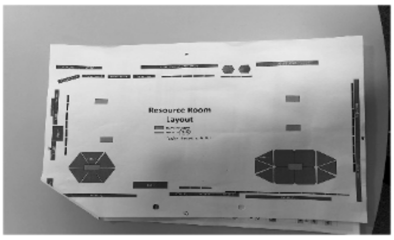

Figure 3: Drawing for the reset

Figure 4: Resource room after reset

This is done by the university campus service, part of the Estates department. The executive team needs to request the service through the online platform at least one week before. The booking information will be received by the porters showing how and when they should set up the resource room, with drawings attached. Basically, the porters just know how to set up the room. They may still have the layout at hand to follow when I observed how they set up the room, but they have done this a lot and they can rely on their own understanding, common sense, experience, communication with the school's executive team, etc. After the open day, they will put everything back. Apart from this, the executive team also need to book the catering for drinks and food, print the brochures and register form for visitors.

The whole process all shows that they already have much experience of doing this and the translation phases went smoothly in terms of they know what and how to do it. Such planned case involves more actors and networks like more staff from higher level of the university, online platform, brochures, drinks and food, existing working relationships, etc. All these actors make this event happen and the visitors will also be part of it.

Emergency Vignette: Signage and One-Way System

Under the situation of Covid-19, the whole Building A needs to be adapted under changing policies and decisions made by the university. This is a long process with numerous people's effort, and this is not a usual case. Use the resource room as an example, firstly, users approach the resource room through only one-way system. During the early stage, the whole building was closed that only staff who had applied could enter. When people slowly returned to the building, the resource room's capacity had been recalculated that only limited number of users can stay at the same time and keep distance. They were also provided with sanitiser and wipes. Signages were also used to remind people about the encouraged behaviours. How did these happen?

These were done by the university's major incident team (MIT) with their interpretation of the government rules. The university set up the MIT to respond to the COVID-19 with many important, high-level people such as the chancellor, heads of school, Health and Safety director, the Estates director, Communication and Marketing director, etc. They had a lot of meetings and discussions to establish the one-way system on campus buildings. Specifically, the local buildings designed the plan for each building, done by each building's health and safety coordinator under the line of technical service. They designed it based on their familiarity with the building, building users and generated the updated floor plan. The university's Creative and Print Services (CPS) team designed the signage. All these signages were put on by the people appointed by the MIT. The same as other decisions of room capacity or sanitiser, they are also from the decision making from MIT and then interpreted locally. Compared with the prior two scenarios, each phase of the translation was much more difficult to achieve. And there were many tensions when so many actors were involved.

These three vignettes from three scenarios have shown part of the findings. Comparatively, the daily vignette has more stable network with the user as focal actor to initiate. The planned vignette requires existing and larger teams from the university level to achieve specific goals. Usually, more stuff are mobilised by both school and university teams' collaboration and is usually planned long time in advance. While the emergency scenario requires more, even outsourcing actors to achieve the goals and should respond in short time. The focal actor is not the building user anymore, but more from the top-down policy. This network is not stable but very flux and dynamic with many trials. Various materials, digital technology played their roles as intermediaries to help.

The findings open the black box of building's minor adaptation, which is rather hidden and invisible before investigation. How the building space use is changed under different scenarios is not simple, but involves various human and non-human actors collaborating, networks forming and adjusting. Unfolding this process helps identify and clarify what or who are needed when planning for future adaptations. The minor but not minor adaptations behind is playing important roles influencing other layers of buildings.

CONCLUSION

This study attempts to explore how building's adaptations are made in practice from the lens of ANT. The minor adaptations in a public building are investigated with ethnography observation and semi-structured interviews following the different actors involved. Building's minor adaptations are made by different human and nonhuman actors with networks initiated, motivated, formed, worked, or ended. Identified daily, planned and emergency scenarios have different patterns of actor- networks. The main contribution will be mainly in the new perspective to view building adaptation under changing situations. Understanding this process will help prepare future cases and solve the current conflicts. Somethings that we view as common sense, may have its different mechanisms to work.

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ENABLERS OF COMMUNITY-INCLUSIVE DECISION-MAKING FOR RISK-SENSITIVE URBAN PLANNING: A TISM AND MICMAC ANALYSIS

Devindi Geekiyanage[1], Terrence Fernando and Kaushal Keraminiyage

School of Science, Engineering and Environment, University of Salford, 43 Crescent, Salford, M5 4WT, UK

Risk-sensitive urban planning (RSUP) is a novel approach to achieving sustainability in urban construction by bridging the gaps between silo approaches to disaster risk reduction, climate change adaptation and city planning. Community engagement is essential for achieving social sustainability in RSUP. However, existing approaches fail to promote supportive factors for community-driven decision-making, which impedes fostering of an inclusive planning approach in many emerging economies. This study, therefore, developed an interpretive model of enablers of community engagement in RSUP through interviews with industry and community participants in Sri Lanka. 19 enablers and 33 pair-wise links were identified, and total interpretive structural modelling (TISM) was used to develop a five-layer model with digital telecommunication infrastructure at the highest level. MICMAC analysis identified 5 driving enablers: digital telecommunication, field workers' support, communities' lived experience, international collaboration, and NGOs. Practitioners can benefit from the prioritised list of enablers, while policymakers can develop regulations to promote inclusive development. These factors can be incorporated into planning and decision-making to ensure that construction projects are designed, implemented, and managed in inclusive and responsive ways.

Keywords: participation; structural modelling; sustainability; developing countries

INTRODUCTION

Urban construction focuses on achieving sustainability via diversified approaches. For instance, sustainable construction management, such as resilient building designs and technologies, collaborative governance, and community engagement, are inevitably considered (Akotia and Opoku 2018, Liu *et al.,* 2021). Effective construction management also plays a critical role in urban regeneration projects ensuring that projects are completed to the desired quality and functional standards of both clients and neighbourhoods (Wang 2014). In addition, Janné and Fredriksson (2019) emphasize the need for developing governance mechanisms considering different stakeholder perspectives, including locals, on organising construction logistics in urban development projects. The ultimate focus of these construction approaches is to achieve sustainable, safe, and resilient cities and communities.

[1] d.geekiyanage@salford.ac.uk

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Risk-sensitive urban planning (RSUP) is an innovative planning and development approach that can transform the way cities are constructed to face the uncertainties that arise from climate-induced disaster risks (UNDP 2022). Scholars posit that the transition toward RSUP requires more inclusive governance, community-based collaboration, collective actions, locally accountable leadership, and participatory risk assessment and monitoring (Leck *et al.,* 2018; Thomalla *et al.,* 2018). Although many studies have pointed out the need for community-driven approaches to building safe, resilient, and equitable cities and have highlighted the barriers to inclusive decision-making (Geekiyanage *et al.,* 2020), their studies have not been extended to understanding the salient factors that drive community entry and consistent involvement in RSUP.

The enabling factors of engaging communities in neighbourhood planning and development are shaped not only by a country's governance, economy, and political characteristics but also by the community context. Given the highly contextual nature of community engagement, this study aims to explore the enablers of inclusive decision-making for planning, development, and adaptation to transition from typical sustainable development to risk-sensitive and equitable cities taking Sri Lanka as its focus.

LITERATURE REVIEW

Based on a selection of worldwide inclusive projects, the literature highlights some apparent enabling factors, for mainstreaming community actions into urban construction initiatives. It should be mentioned that related work, however, does not purely apply to RSUP but focuses on either community-based Disaster Risk Reduction (DRR), city-making, or social sustainability in construction.

Community Context Enablers

To achieve inclusive and equitable urban planning, it is important to recognise and harness the collective efforts of local communities. Scholars have highlighted the value of the knowledge and experiences of communities in assessing risks, planning land use, and responding to disasters (Perrone *et al.,* 2020; Thomalla *et al.,* 2018). Therefore, decision-makers and implementors should learn from communities and incorporate their tacit knowledge and lived experiences into agency-led plans. Community leaders, who have a deep understanding of their neighbourhoods, play an important role in driving change and action. They often form community committees and engage with NGOs or local authorities to address local issues (Deshpande *et al.,* 2019; Thomalla *et al.,* 2018). In addition, community-based organisations (CBOs) have a crucial role in promoting citizen voices and ensuring that public needs and values are incorporated into local government decision-making (Rafique and Khoo 2018). Therefore, recognising and building on the strengths and capacities of local communities is a key factor in constructing disaster-risk-responsive cities.

Institutional Enablers

Inclusive urban planning can be enabled through institutional mechanisms involving both public and private agencies. While bottom-up governance has been recognised as a valuable approach to achieving inclusive urban design (Dias *et al.,* 2018), this may not always be feasible, especially with large-scale projects. Critics have argued that a bottom-up approach may reduce planners' and designers' control and decrease the efficiency of the urban planning process. Nevertheless, stakeholder collaboration has been identified as a critical factor in achieving sustainable and inclusive outcomes.

Although the multi-level stakeholder collaborative planning process can be time-consuming and challenging, it allows for meeting individual as well as collective needs in city planning (Gupta and Vegelin 2016). Successful bottom-up governance and stakeholder collaboration can increase a community's capacity to manage their environment and lead to inclusive and equitable urban planning (Kirshen *et al.,* 2018).

Relational Enablers

Relational enablers include the factors that synergise the community and institutional contexts. The most prominent relational enabler is committed field workers because they build community trust over time (Kirshen *et al.,* 2018). Community trust building relates to the skills of field workers in having the time and expertise to understand every aspect of the complex community landscape upon which the development is trying to impact. Volunteer workforces, including NGOs, are another prominent enabler in any domain of participatory work who act as intermediaries between communities and local governing bodies (Deshpande *et al.,* 2019). NGOs associated with humanitarian actions and environmental sustainability often make significant efforts to mitigate the negative social and environmental impacts of urban sprawl through inclusive DRR and land use planning (Gupta and Vegelin 2016)

Legal and Policy Enablers

Regulatory frameworks and political factors can be both a driver as well as factors against inclusive development. Christiansen and Loftsgarden (2011) argued that although several factors act as driving forces, in the end, it is the public authorities that decide how land development should be managed. Therefore, adequate planning and political control are critical in preventing or limiting unsustainable development. For instance, European countries, including Denmark, Britain and the Netherlands, have different policy provisions and regulatory frameworks to enforce and control inclusive development (Tosics *et al.,* 2010) (e.g., the Localism Act (2011) in England and Section 15 of the Local Government in Scotland Act (2003). However, this is less evident in most developing economies due to political instability and corruption (Geekiyanage *et al.,* 2020).

Resource Enablers

Resource mobilisation is necessary for inclusive initiatives, with finance and expert knowledge being vital resources. Inter-governmental organisations (IGOs) such as the World Bank and UN entities like UN-Habitat and UNDP fund most DRR and humanitarian-related works and provide the necessary administration and technical expertise (United Nations 2016; Walters 2018). Social media has opened up unprecedented possibilities for engaging the public in government work, and many scholars argue that it should be considered as a critical infrastructure, given its demonstrated use in DRR, emergency management, and community development (Lindenau and Böhler-Baedeker 2014).

METHOD

Initially, a literature review was conducted to identify the enablers from the global perspective and synthesized. The decision to adopt the constructivist grounded theory (GT) of qualitative inquiry is based on the vacuum in the existing literature on the enablers of inclusive RSUP and due to the highly contextual nature of the study focus (Charmaz 2014). Thick-quality data were gleaned through in-depth interviews. The study participants were purposively chosen adhering to the theoretical sampling of the GT strategy. Given that inclusive development is a collective effort, the study sample comprised industry experts and community members. Initially, 11 expert interviews were conducted to identify the enablers of community engagement in RSUP and their interrelationships, followed by 6 interviews to validate the transitive links. Simultaneously, 7 focus group discussions, including 27 community participants, were conducted to include community perspectives. A summary profile of the study participants is presented in Figure 1.

In the data analysis, initially, the transcribed interview scripts were open coded to examine the salient data, and the resulting codes were subsequently revisited and organised through focused coding.

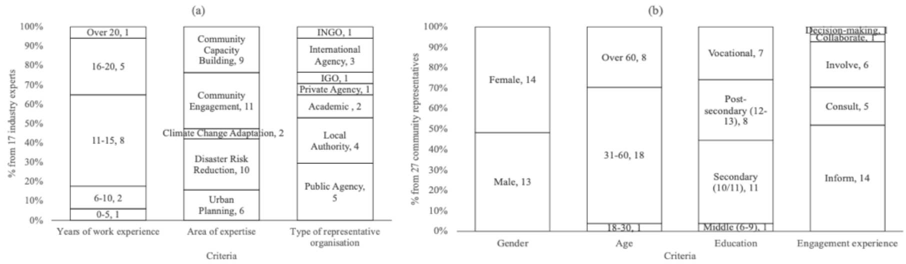

Figure 1: Profile of the study participants: (a) Experts, (b) Community participants

Then, theoretical coding was conducted to generate enabler themes by combining and categorising the structured data. Secondly, TISM, an enhancement of interpretive structural modelling (ISM), was used to model the enablers by analysing their contextual pair-wise relationships. While ISM focuses on understanding the "what" and "how" of research, TISM delves deeper by incorporating the understanding of "why" factors as well (Sushil 2012). Thus, TISM surpasses ISM in 2 ways by (1) providing interpretations to all the links; (2) retaining significant transitive links that have meaningful interpretations. Thirdly, a MICMAC analysis was conducted to distinguish the enabler themes that drive the model in various classes (Mathivathanan *et al.,* 2021).

FINDINGS

The data garnered through inductive coding shed light on 19 themes of enablers of community entry and engagement in RSUP, as defined in Table 1. TISM Analysis of the Enablers of Community-Inclusive RSUP in Sri Lanka

The pair-wise contextual relationships identified between the 19 enablers were input to a Structural Self-Interaction Matrix (SSIM) of i19 x j19 (Figure 2(a)). Next, the SSIM was converted into the Initial Reachability Matrix (IRM) by substituting V, A, X and O with 1 and 0. Subsequently, the transitivity concept was introduced so that some of the cells of the IRM were filled by inference. Transitivity can be explained by the following example: if ‘a’ relates to ‘b’ and ‘b’ relates to ‘c’, then transitivity implies ‘a’ relates to ‘c’. Thereby the Final Reachability Matrix (FRM) was developed that consists of original entries of pair-wise comparisons and some inferred entries (1*). The only difference between the IRM and the FRM is inferred entries; thus, Figure 2(b) provides the FRM. As observed from Figure 2(a), for example, CBOs (E3) are instigated by communities’ lived experience (E1) and community committees (E4), whereas each other influences community committees and community leaders (E5). From Figure 2(b), for example, E1 and E4 are linked transitively because of the direct link between E1 and E5.

The FRM was subsequently converted into the level-wise placement of enablers. Accordingly, the reachability, antecedent, and intersection sets were computed for each enabler to establish their partition levels. The enabler for which the intersection set is the same as the reachability set was designated the top-most level (Level 1), and the Level 1 enablers were removed from the entire set for the next iteration. This process was continued until each enabler was assigned its corresponding levels. After 5 iterations, all the enablers were assigned to their levels, and the outcome of this iterative process is shown in Figure 3.

Table 1: Enablers of community-inclusive risk-sensitive urban planning in Sri Lanka

	Code	Enabling factors	Description	No.	%
Community-context	E1	Communities' lived experience	Locals' tacit knowledge and hands-on experience in coping with hazards and disaster events in their locality.	42	95
	E2	Community literacy	Locals' ability to read, write, speak, and listen in a way that lets them communicate effectively.	12	27
	E3	Community-based organisations	Organisations aimed at making desired improvements to a community's social health, well-being, and functioning.	18	41
	E4	Community committees	Representative bodies established as intermediaries between the government and the residents of a particular area.	18	41
	E5	Community leaders	A person widely perceived to represent a community.	12	27
	E6	Monitoring and feedback received from communities	Using community members to monitor implementations and their feedback on participatory initiatives helps to revise future plans and actions effectively.	36	82
Relational	E7	Support from field workers	Field officers' commitment to building rapport and engaging with locals.	12	27
	E8	Technical experts	The country is rich in technical experts who can provide tech-based solutions.	12	27
	E9	Impact research	Research studies that have an effect beyond academia: research influences an individual, a community, a development of policy, or the creation of a new product/service.	6	14
	E10	Trust built with communities	Trust that industry practitioners have already established with locals from previous participatory projects.	12	27
Resource	E11	External funds	Funds originate from a source outside the government /corporation to aid inclusive efforts.	12	27
	E12	Incentives to financially vulnerable groups	Financial giveaways to poor locals to motivate and attract them to engage in development activities or to appreciate their contribution.	24	55
	E13	Social media	The means of interactions among people in which they create and share information and ideas in virtual networks.	24	55
	E14	Digital telecommunication infrastructure	The country has good internet coverage and mobile penetration to support distance communication.	6	14
Legal and policy	E15	Administration system to the village level	Sri Lanka is one of the few countries, presumably with an administrative structure that reaches the village level, where several administrative officers govern each small area.	6	14
	E16	Right to information (RTI) policy	Sri Lanka's RTI Act comes into effect by bringing a promise of open government, inclusivity in governance, and accountability to the country's people.	12	27
	E17	Divisional level act	Community engagement provisions in divisional level acts.	24	55
External enablers	E18	International collaboration	Administrative and financial assistance received from urban development, DRR and humanitarian-related organisations in other countries.	6	14
	E19	NGOs	Voluntarily formed non-profit entities to execute welfare projects to address various concerns and issues prevailing within the society.	24	55

Enabler Theme	E1	E2	E3	E4	E5	E6	E7	E8	E9	E 10	E 11	E 12	E 13	E 14	E 15	E 16	E 17	E 18	E 19
E1		O	V	O	V	V	O	O	O	O	O	O	O	O	O	O	O	O	O
E2			O	O	O	V	O	O	O	O	O	O	O	O	O	O	O	O	O
E3				A	A	O	A	O	O	O	O	O	O	O	O	O	O	O	O
E4					X	V	A	O	O	O	O	O	O	O	O	O	O	O	O
E5						V	O	O	O	O	O	O	O	O	O	O	O	O	O
E6							O	O	O	O	O	O	A	A	O	O	O	O	O
E7								O	V	V	O	O	O	O	O	O	O	O	O
E8									V	O	O	O	O	O	O	O	O	O	O
E9										V	A	O	O	O	O	O	O	A	O
E10											O	A	O	O	A	O	O	O	O
E11												V	O	O	O	O	O	A	A
E12													O	O	O	O	O	O	A
E13														A	O	O	O	O	O
E14															O	O	O	V	O
E15																O	O	O	O
E16																	O	O	O
E17																		O	O
E18																			O
E19																			

V: 'i' leads to 'j' but not vice versa
A: 'j' leads to 'i' but not vice versa
X: mutual influence of 'i' and 'j'
O: no association

(The symbols 'i' and 'j' represent the row and column variables, respectively, and are used to indicate the direction between two nodes in the matrix.)

Enabler Theme	E1	E2	E3	E4	E5	E6	E7	E8	E9	E 10	E 11	E 12	E 13	E 14	E 15	E 16	E 17	E 18	E 19
E1	1	0	1	1*	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
E2	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
E3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E4	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
E5	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
E6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
E7	0	0	1	1	1*	1*	1	0	1	1	0	0	0	0	0	0	0	0	0
E8	0	0	0	0	0	0	0	1	1	1*	0	0	0	0	0	0	0	0	0
E9	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
E10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
E11	0	0	0	0	0	0	0	0	1	1*	1	1	0	0	0	0	0	0	0
E12	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
E13	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
E14	0	0	0	0	0	1	0	0	1*	1*	1*	1*	1	1	0	0	0	1	0
E15	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
E16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
E17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
E18	0	0	0	0	0	0	0	0	1	1*	1	1*	0	0	0	0	0	1	0
E19	0	0	0	0	0	0	0	0	1*	1*	1	1	0	0	0	0	0	0	1

The substitution of 1s and 0s are as per the following rules:

- if the (I, j) entry in the SSIM is V, the (I, j) entry in the IRM becomes 1 and the (j, i) entry becomes 0
- if the (I, j) entry in the SSIM is A, the (I, j) entry in the IRM becomes 0 and the (j, i) entry becomes 1
- if the (I, j) entry in the SSIM is X, the (I, j) entry in the IRM becomes 1 and the (j, i) entry also becomes 1
- if the (I, j) entry in the SSIM is O, the (I, j) entry in the IRM becomes 0 and the (i, i) entry also becomes 0

Figure 2: Pair-wise contextual relationships between the enablers: (a) SSIM and (b) FRM

Enabler (Mi)	Reachability Set R(Mi)	Antecedent Set A(Ni)	Intersection Set R(Mi)⌒A(Ni)	Level
E3	3	1, 3, 4, 5, 7	3	1
E6	6	1, 2, 4, 5, 6, 7, 13, 14	6	1
E10	10	7, 8, 9, 10, 11, 12, 14, 15, 18, 19	10	1
E16	16	16	16	1
E17	17	17	17	1
E2	2	2	2	2
E4	4, 5	1, 4, 5, 7	4, 5	2
E5	4, 5	1, 4, 5, 7	4, 5	2
E9	9	7, 8, 9, 11, 14, 18, 19	9	2
E12	12	11, 12, 14, 18, 19	12	2
E13	13	13, 14	13	2
E15	15	15	15	2
E1	1	1	1	3
E7	7	7	7	3
E8	8	8	8	3
E11	11	11, 14, 18, 19	11	3
E18	18	14, 18	18	4
E19	19	19	19	4
E14	14	14	14	5

- Reachability set: the enablers affected by other enablers and themselves (rows)
- Antecedent set: the enablers that affect the other enablers and themselves (columns)
- Intersection set: enablers common to both the reachability and antecedent sets

Figure 3: Level partitioning of enablers

The resulting 5 levels produced the basis for the TISM model. Next, the transitive links identified in the FRM were discussed with the experts involved in the phase 2 data collection to establish their validity. The experts found only 5 (E1-E4, E7-E5, E14-E9, E14-E11, E18-E12) out of the 13 transitive links are satisfying while eliminating 8 transitive links. Finally, the TISM model was developed to represent the hierarchy of enablers of community engagement in RSUP in Sri Lanka (Figure 4).

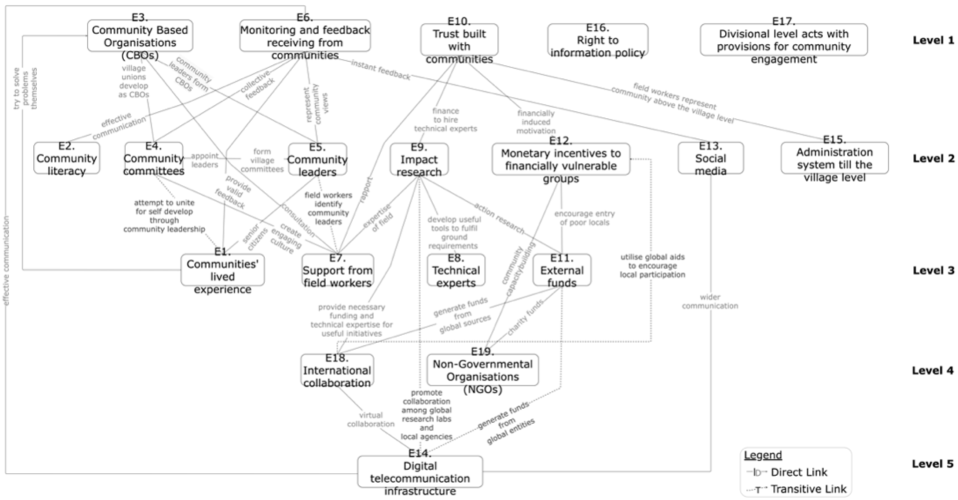

Figure 4: TISM of enablers of community inclusive RSUP in Sri Lanka

The 19 enabler themes were placed in respective positions on the hierarchy based on their levels determined in Figure 3, and the links between the enablers are symbolised with arrows referring to the binary interaction presented in the FRM in Figure 2(b). In this hierarchy, the most vital enablers are placed at the bottom, whereas insignificant enablers are at the top. Thus, digital telecommunication infrastructure (E14) is the key driving enabler in this case. E14 promotes international collaboration (E18), which is at the 4th level. Experts established this link by stating that uninterrupted communication networks facilitate virtual collaboration, especially with global agencies. E14 and E18 further enable collaboration with international educational institutes that brings opportunities for impactful research to implement actions on the ground. These 2 enablers attract global funds, either through research grants or humanitarian aid. NGOs (E19), placed at level 4, are not driven by any other enabler but support generating external funds (E11) and provide monetary incentives to financially vulnerable groups (E12). NGOs donate their charity funds to support locals in rebuilding, especially during disaster events, thus, encouraging locals to participate in development decision-making. Additionally, the factors in the 3rd and 4th layers influence and are influenced by other enablers. The topmost layer of the hierarchy includes 5 enablers. Amongst them, CBOs (E3), community monitoring and feedback (E6), and trust built with communities (E10) are highly, but differently, supported by other enablers. However, there are 2 enablers: the right to information policy (E16) and divisional level acts with community engagement provisions (E17) which are not dependent on, or driven by, other enablers, thus placed isolated within the model.

MICMAC Analysis of the Enablers of Community-Inclusive RSUP in Sri Lanka

A MICMAC analysis was performed to classify the identified enablers into 4 quadrants based on their dependence (x-axis) and driving power (y-axis). The driving and dependence powers for each enabler were calculated by summating rows and columns in the FRM, excluding rejected transitive links. A position coordinates matrix was developed for the enablers and is displayed in a scatter plot, as shown in Figure 5.

Code	Driving Power	Dependence Power
E1	5	1
E2	2	1
E3	1	5
E4	4	4
E5	4	4
E6	1	7
E7	6	1
E8	2	1
E9	2	5
E10	1	6
E11	3	4
E12	2	4
E13	2	2
E14	6	1
E15	2	1
E16	1	1
E17	1	1
E18	4	2
E19	3	1

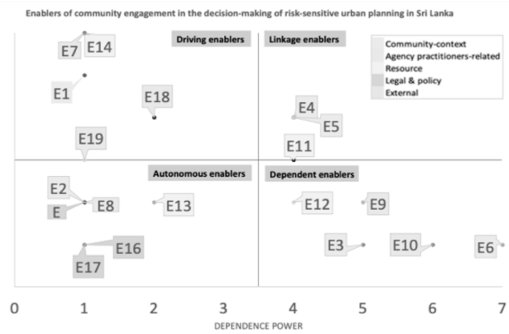

Figure 5: Cluster diagram of enablers of community inclusive RSUP in Sri Lanka

The scatter plot obtained was further divided into 4 quadrants. 5 out of the 19 enablers have resulted as driving enablers with high driving power and poor dependence. Hence, these are the most significant enablers which drive the process of inclusive RSUP. This implies that community participation in RSUP can be intensified through an improved digital telecommunication infrastructure (E14), supportive field workers (E7), incorporation of communities' lived experience (E1), international collaborations (E18), and NGOs (E19). Only 3 enablers: community committees (E4), community leaders (E5), and external funds (E11) have been classified as linking enablers. Linking enablers provide stability to the system; thus, ignoring these will disrupt the system (Mathivathanan *et al.,* 2021). There are 4 dependent enablers which have high dependence and poor driving power. It can be inferred that monitoring and feedback from communities (E6), trust built with communities (E10), CBOs (E3), impact research (E9), and monetary incentives to vulnerable groups (E12) have a high dependence on other enablers. Autonomous enablers are those isolated from other enablers due to poor dependence and driving power. The enablers included in this category are of less significance to the entire system; thus, strengthening these enablers will not do much to facilitate inclusive RSUP.

CONCLUSIONS

The study provides a comprehensive analysis of the factors that promote community engagement in RSUP. The findings support previous arguments that suggest the public has more supportive factors than constraints to inclusive development (Leck *et al.,* 2018; Thomalla *et al.,* 2018) and that community leaders and committees act as intermediaries between locals and agencies (Deshpande *et al.,* 2019; Rafique and Khoo 2018). The study also identified previously unexplored enabling factors, such as digital telecommunication and the RTI policy. However, the study did not identify any institutional enablers in the Sri Lankan context, with fewer legal and policy enablers that could reflect in similar developing contexts. The study highlights digital telecommunication infrastructure, supportive field workers, incorporation of communities' lived experience, international collaboration, and NGOs as the most critical enablers that drive inclusive RSUP towards achieving social sustainability in urban construction.

The contextualised interpretive links established between the enablers offer a tailored tool for urban planners and construction industry practitioners in Sri Lanka to assess the impact of various factors on inclusive development. By understanding the interdependencies among these factors, decision-makers can prioritise their efforts and allocate resources effectively to leverage the driving enablers to enhance community engagement. This detailed analysis of community-context enablers helps to identify and address structural inequalities and power imbalances within communities for equitable decision-making. This can help to ensure that the voices of marginalised communities are heard and considered in urban construction. This study further recommends regular monitoring of community feedback and if any issues are identified, appropriate actions should be taken to mitigate any impact. Impact research should be promoted through international collaboration and a mechanism to report grounded results to policy formation institutes in the country/region should be devised to formalise inclusive construction. NGOs should be welcomed to attract more funds, knowledge, and technical support to overcome resource constraints, particularly in public-led construction projects aimed at social sustainability.

In the broader construction management discipline, community-inclusive urban planning interlinks with the construction industry, particularly in architectural design. For instance, in accessible and inclusive design, communities' lived experiences should integrate within construction designs to foster a sense of ownership and accountability among the community members towards the project. Furthermore, identifying the unique needs and preferences of the local community can result in more effective and sustainable construction projects that meet the needs of the community and have a positive impact on the local economy and environment. When the community is involved in the planning process, they are more likely to be aware of the potential impact of the construction project on their daily lives, and this can help reduce disputes. Thus, can improve the public perception of the construction industry and create a positive impact on the community. Overall, both the urban development and construction sectors can incorporate the enabling factors discussed in this study into their planning and decision-making processes to ensure that construction projects are designed, implemented, and managed in a way that promotes inclusive and sustainable development while minimising risks and vulnerabilities.

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EQUALITY, DIVERSITY AND INCLUSION

EXPLORING SOURCES OF CONSENSUS AND DISAFFECTION IN ALTERNATIVE PROVISION PROVIDED BY THE CONSTRUCTION INDUSTRY IN THE UK

Jemma Bridgeman[1] and Martin Loosemore[2]

[1] *WISERD, Cardiff University, sbarc/spark, Maindy Road, Cardiff, CF24 4HQ, UK*

[2] *School of Built Environment, University of Technology Sydney, Sydney, NSW 2007, Australia*

Alternative provision (AP) is where young people at risk of exclusion because of their behaviour are removed from mainstream education into alternative forms of education. This research explores construction AP delivered by five organisations, using the work of Basil Bernstein as the theoretical approach on the sources of consensus and disaffection in education. Disaffection arises when students cannot or will not accept the expressive order (conduct, behaviour) and/or the instrumental order (knowledge, skills) of the school. Drawing on interviews with construction trainers and social value teams working in construction AP, this research makes an important new contribution to construction education research by showing how training young people on a live construction site encourages improvements in behaviour as young people learn the appropriate behaviours for working in the industry. In addition to improving behaviour and gaining the skills and qualifications needed to access employment opportunities in the construction industry, young people can continue to learn mainstream academic subjects such as maths. It is concluded that Bernstein's theoretical approach is useful for understanding the construction industry's contribution to educating young people at risk of exclusion.

Keywords: alternative provision; Bernstein; education; schools; exclusion

INTRODUCTION

Despite the unprecedented challenges of the COVID-19 pandemic and the subsequent economic downturn, the construction industry continues growing and faces severe skills shortages in many countries. For example, the UK construction industry must recruit 45,000 people per year over the next five years to meet the expected output in the UK because of an ageing workforce, a decreasing number of new entrants to the industry and competition internationally for skilled workers worsened by BREXIT (CITB, 2023, Brooks and McIlwaine, 2021). In Australia, in 2023, labour demand is projected to grow by 42,000 to a peak of 442,000, more than double the projected available labour supply (Infrastructure Australia 2022). Chan and Connolly (2006) suggest that the industry's poor image affects recruitment and makes it challenging to recruit the workforce needed to deliver the growing output of the UK. Brooks and

[1] BridgemanJ1@cardiff.ac.uk

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McIlwaine (2021) suggest that it is time the industry tells a better story of the prospects available, given its negative public image around its relatively poor health and safety (H&S) record, masculinised and exclusionary culture, long working hours, insecure work, poor mental health and well-being and a poor working environment.

Workforce diversification is recognised as one way the construction industry can address its skills shortage challenges and poor public image (Infrastructure Australia, 2021). In most countries, it is one of the largest employing sectors. It offers a wide range of jobs for an equally wide variety of people, from professional managers to tradespeople to manual labourers (Michielsens, 2016). It is also a significant potential source of employment for many non-traditional groups who can help address skills shortages, such as people with a disability; migrants and refugees; Indigenous people; young people at risk; and ex-offenders, although many face discrimination in the industry (Loosemore *et al.,* 2020; Bailey *et al.,* 2022). While the pathways for entry into the construction industry for many of these groups have been explored, one group which has received relatively little attention are children and young people in school. Even less attention has been paid to those school students who are at risk of failing and disengagement from education because they struggle with traditional classroom-based education. However, in many countries, school leavers are encouraged to pursue academic pathways in preference to trade qualifications despite the latter providing important pathways into work for such students (Callanan and Perri 2020, Australian Government 2018). Although a few studies have examined the difference school-based interventions can make in encouraging young people to consider a career in construction, this tends to be in mainstream education settings and on career guidance rather than alternative provision (AP) (see, for example, Chan and Connolly, 2006). Conversely, research in America has found that school pre-apprenticeship programmes are instrumental in supporting socio-economically disadvantaged groups into the industry (Bruno *et al.,* 2016). Furthermore, in Australia, Taylor (2004) examined a school-based vocational construction programme and found it beneficial in preparing students for transitions from school to work by giving them practical training and work experience in a real working environment. In the UK, Loosemore and Bridgeman (2017) examined a construction industry-led school engagement programme where school pupils, in mainstream education, interacted with construction industry professionals, visited sites and completed individual and team assignments to learn about various roles in the industry. Loosemore and Bridgeman's (2017) study examined what motivated professionals from the industry to volunteer on the programme and found that volunteers derived many benefits including reinforcing existing skills and developing stronger internal and external relationships. In contrast, this research explores construction interventions delivered to young people in AP and how young people in AP can be helped to overcome barriers and meet the future skills needs of industry, constructing for the future.

Despite these encouraging albeit limited insights into the potentially positive impacts of exposing school students to construction work as part of their formal education, the role that 'alternative provision' can play in recruiting people to work in the construction industry has yet to receive any research attention. The term alternative provision (AP) describes the wide range of interventions where pupils at risk of disengagement from education are provided with a range of complementary vocational, academic, life skills, therapeutic, work skills, work experience, environmental and creative education (Trotman *et al.,* 2018; Thomson and Russell, 2009). Children and young people suited to AP are likely to have struggled to cope with mainstream education and be at risk of or have been permanently excluded from school. In research on AP in Australia, McGregor and Mills (2012, p. 858) found that students in AP valued practical and vocational AP approach as it was 'real life, hands-on and connected', especially if these courses could help with employment; Research has found that practical AP programmes can captivate students' interest and new ways of learning can have a positive impact on students 'experiences of learning and can lead to improved behaviour (Hickey *et al.,* 2020).

However, concerns have been raised that while AP programmes may have valuable outcomes for some young people, they seldom lead to a qualification, exacerbating later disadvantages (te Riele, 2007). The literature on AP points to a messy landscape of alternative provision, a need for more evidence of effectiveness and insufficient research on the longitudinal outcomes of young people in such programmes (Thomson and Russell, 2009; Malcolm, 2018). It is essential to examine AP because its use needs to be clarified, particularly when compared to the focus of both policy and research on exclusions (Malcolm, 2018). While some AP programmes offer construction training, work-based vocational skills, and work experience there needs to be research into these programmes' nature, implementation and value. This paper aims to address this gap in research by utilising Bernstein's (2003) theory of consensus and disaffection in education to explore the following research questions:

1. What different types of AP does the construction industry deliver?
2. How is construction training delivered to young people who have struggled with behaviour (the expressive order) in school in a highly regulated industry?
3. What skills and knowledge can construction training offer young people who have struggled with academic learning (the instrumental order)?

By addressing these questions, this research contributes new theoretical and practical insights into the role of the construction industry in delivering AP, how the industry can widen its recruitment based to address skills shortages and how it meets growing requirements to provide employment and training opportunities for disadvantaged people in the communities in which it builds (Raiden *et al.,* 2019). Furthermore, this research contributes to the advancement of Bernstein's (2003) theories which have hitherto been restricted to examining the trajectories of academically able students (Power *et al.,* 1998) and examining inequalities in higher education (Donnelly, 2018).

Theory

Bernstein's (2003) theory of consensus and disaffection in education provides a new theoretical lens to understand the potential of AP to help address the construction industry's skills shortages. Bernstein (2003) explains that the sources of consensus and disaffection should be understood by exploring the relationship between the school's culture and the orientation of the family to that culture. However, there is more to consider than just the relationship between families and schools; there is also the culture of the school to consider. Bernstein identifies two distinct but interrelated kinds of behaviour that are present in schools: the expressive order and the instrumental order (Bernstein, 2003). The expressive order involves pupils' conduct, character, and manner; this concerns the appropriateness of conduct in school, where compliance is necessary (Bernstein, 2003). The instrumental order involves acquiring specific skills and knowledge and captures acquiring educational qualifications (Bernstein, 2003). Bernstein (2003) explains that disaffection arises when students cannot or will not accept the expressive and instrumental order within a school environment and consensus occurs when pupils accept both the expressive and instrumental orders. Bernstein (2003) also explains that there can be tension between instrumental and expressive orders within schools. For example, in the instrumental order, when students are placed in groups and defined by their ability level to develop some specific skills, divisions can be created between pupils and between pupils and teachers. Nevertheless, at the same time, the expressive order is expected to be conveyed by the whole school in terms of its externally perceived image, internal codes of conduct, character and the 'moral order' (Bernstein, 2003, p. 34). Bernstein (2003) also argues that pupils who are weakly involved in the instrumental order are less likely to be receptive to the moral order of the school.

By highlighting the tensions between the two orders in schools, Bernstein's (2003) theory represents a potentially valuable approach to examining construction AP because the highly regulated, high-risk, and highly skilled and process-driven nature of construction work requires compliance with both instrumental and expressive orders. For example, Bernstein's (2003) theory helps examine whether pupils who had challenges following school rules in school (the expressive order) will be able to follow the many regulations (such as Occupational Health and Safety) which require workers to behave appropriately on a construction site. While compliance is considered necessary in schools, it is considered critical and potentially lifesaving in the construction industry. Construction work is also practical and hands-on. Previous AP research has found that young people prefer this learning environment and can help reengage them in education (for example, see Hickey *et al.,* 2020). So, while there may be tensions between the expressive and instrumental orders in a school environment, young people might behave appropriately on a construction site because of the regulatory requirement to do so and the risk to themselves and others if they do not and because they enjoy hands-on learning.

METHOD

Following an interpretative phenomenology approach (Neubauer *et al.,* 2019), data was collected via semi-structured interviews with professionals implementing five construction AP programmes in the UK. Programs were selected because they delivered construction training where school pupils were removed from a classroom in a mainstream school or a pupil referral unit (PRU). A PRU is a type of school for young people who cannot cope with the demands of mainstream education. The interviews were undertaken between December 2021 and July 2022 and undertaken by a team of researchers from construction and education backgrounds. Informed by Bernstein's (2003) theoretical concepts of consensus and disaffection, the interviews aimed to explore the culture of construction AP particularly concerning the expressive and instrumental orders described in Bernstein's sources of consensus and disaffection. Interviews lasted one to two hours, and questions focussed on exploring how they worked with children and young people; what their intervention involved; what they did differently than schools or PRUs and what were the outputs and outcomes for children and young people.

Semi-structured interviews were valuable in collecting data because they generated 'information-rich' depth insights into the particularly concerning the expressive and instrumental orders in each AP program. This 'exploratory' approach was also sympathetic to the uncertain and evolving nature of the construction AP, the interpretivist nature of our research and the lack of priori research in this area, which prevented a positivist hypothesis-testing approach. This required an approach which respected respondents' individual AP experiences and enabled respondents to express these in their own terms. All interviews were audio-recorded and transcribed verbatim and analysed using thematic analysis following protocols by Guest *et al.,* (2012). Our analytic starting points were our research questions and Bernstein's (2003) theoretical concepts of consensus and disaffection. The first step involved researchers immersing themselves in the data by repeatedly reading the interview transcripts to obtain a high level of familiarity with the data. Second, researchers conducted open (inductive) and directed (deductive) coding (based on Bernstein's (2003) theoretical concepts of consensus and disaffection), organising and generating an initial list of items/codes (first-order coding) from the data set that had a reoccurring pattern. Third, researchers searched for recurring patterns, linkages, categories, and subcategories within the first-order codes relating to each research question. Forth, researchers examined how codes combined to form overreaching themes relating to the research questions. In the fifth and final stages, emergent themes were further refined by continued searches for data that supported or refuted the initial themes, allowing further expansion and connections between overlapping themes. This process continued in parallel with data collection until theoretical saturation occurred, and no other themes emerged. Any instances of disagreement were resolved through discussion, which continued until 100% inter-rater agreement was achieved, providing a high level of 'fit' with the data and confidence in the theoretical validity of the emergent themes.

Table 1: The Sample

Participant	Position	Organisation	AP Intervention delivered
1	Apprenticeship Coordinator	Housing Maintenance	Practical construction workshops delivered using an industry toolkit to pupils struggling in mainstream education.
2	Business Development Manager	Construction Training Company	Groundworks training, including driving construction vehicles on a live construction site to pupils from a local PRU.
3	Social Value Manager	Construction Company	Careers advice and practical construction workshops delivered on live construction sites to pupils from a local PRU.
4	Training Manager	Environmental organisation	Providing a full-time timetable of AP, including plumbing, carpentry, photography, cookery, and bike maintenance.
5	Head of pre-16 Training	Vocational training organisation	A range of vocational options, including bricklaying, carpentry and painting and decorating.

FINDINGS

Regarding research question one about the different types of construction, AP delivered in the UK. All five organisations delivered different types of AP in different settings. Participant 1 worked for the housing maintenance organisation and worked in schools where 'pupils lacked opportunities' as part of their social value commitments, explaining, 'we have got to give back to our communities and tackle skills shortages because there is such a shortage of tradespeople.' They delivered workshops from an industry toolkit designed to complement the school curriculum, including plumbing, electrical, painting and decorating and carpentry workshops for pupils struggling in mainstream education. Participant 2 worked for a commercial construction training organisation that aimed to tackle skills shortages explaining that 'construction is always carpentry, plastering, blockwork, brickwork plumbing, and electrical. Those routes get promoted, not necessarily the plant or the groundworks.' They worked with learners from a local PRU. They were refurbishing an old colliery site explaining that pupils were not just learning; they were 'building the classrooms, clearing all the grounds and contributing to the work on the site itself.' Their scheme of work included 'manual handling, first aid, dumper truck training and H&S training.'

Participant 3 worked for a construction company building an extension for a PRU; they were 'lucky to be on site', which made engagement easier. They could provide pupils with practical taster sessions, including bricklaying, tiling, plastering and carpentry. They also delivered employability sessions, including careers advice, mock interviews, and CV workshops. Participant 4 worked for an environmental organisation that delivered 'plumbing, cookery, carpentry art and photography.' Pupils came to them if they were 'having difficulties in school' They had purpose-built classrooms in the environmental organisation's factory. Participant 5 worked for a vocational training provider; they had developed a pre-16 AP provision. Because when 16-year-olds came to them, it was too late. They had the 'skill set, but they weren't able to progress because their English and maths were weak.' They had tutors from 'real life industry backgrounds' delivering a range of vocational options. In construction, they covered bricklaying, carpentry and painting and decorating.

In answering research question two to explore how the construction industry worked with pupils who have struggled with behaviour (the expressive order) in a highly regulated industry, participant 1 and participant 3, had concerns about behaviour from an H&S point of view. Participant 1 explained that because they worked with 'groups that were not in the mainstream classroom', they kept 'numbers at a minimum for workshops' so they could 'control the situation.' Participant 3 reflected that the pupils in the PRU they were working in had previously not engaged with employers because they were 'deemed as unemployable' and 'struggled with any career support.' Participant 3 initially tried a careers talk, but 'pupils were a bit naughty; they did not want to be there.' Instead, they delivered practical sessions, including 'bricklaying, plastering and tiling.' Conversely, participant 2 explained that because 'they do a different type of engagement, in a real-working environment,' they had 'tight control measures.' They explained to pupils, 'your behaviours need to be this way because of this.' It is all about 'raised awareness', which is 'specific to the construction sector. But that's who we are; that is what we are.'

Both participants 1 and 3 reflected that although there were some issues, the practical construction workshops had worked well. Participant 1 explained that when pupils 'were busy doing something not classed as a classroom subject, you saw a completely different side to them; they were enthusiastic, and they were quite happy to get hands-on and get messy with the grout and the paints.' This led to an increase in confidence 'when they saw the results of what they did.' Participant 1 continued, 'teachers' response was positive because they couldn't get over how well-behaved they were and how polite they were, how they responded to doing something different, which was good.' Participant 3 explained that their practical workshops went well despite initial concerns about behaviour:

> *It was fab. They were busy; they were hands-on. They were able to do something that wasn't in a classroom, and they were somewhere new; they were very well behaved, which we were concerned about what they might be like, when they're in that environment, from a Health and Safety, point of view. They did a really good job, and the bricklayers were impressed with their skills.*

Participant 4 explained that they teach the 'hardest to teach.' In terms of behaviour, they also described the satisfaction they felt when they 'succeeded.' They attributed improvements in behaviour to a student-teacher ratio of one to six and a hands-on alternative curriculum. Moreover, they had a robust induction process because of the factory setting and the practical nature of the construction training. Participant 5 described the common theme for all their learners: 'they've all been kicked out from school' with some having a 'complexity of need.' Nonetheless, they explained that their 'starter is to rebuild their faith in adults and education and then build rapport and then teach them.' If they got them in time, they 'could see a complete change' in behaviour. Explaining that staff had 'different approaches' including staff from the construction sector, which 'really helped.'

In answering research question three about the skills and knowledge the construction industry could offer young people struggling with academic learning (the instrumental order), practical construction workshops had been designed to contextualise the national curriculum; the practical construction activities were a carrot for more practical experience and when giving careers advice people in the industry explained why academic subjects such as maths were vital if they wanted to progress into a construction career. Participant 1 explained to pupils that construction was not just about 'the tiling and the wallpapering; you've got to have the academic side as well.' Explaining that the workshops were "part of the curriculum. So, they're learning without realising. Doing a bit of science.' Although they did not offer qualifications, they did offer work experience opportunities and the chance for pupils to progress to an apprenticeship when they left school.

Participant 2 explained that although most of their work was on a live construction site, they did 'classroom-based stuff and then went out and drove the machines. They hate doing maths; they hate writing. The machines are the carrot. They love the machines.' Participant 2 continued that they aimed to give pupils a head start when they were old enough to secure construction employment:

> *They learn how to drive the machines correctly. The dumper, the rights and the wrongs, this is how they should be driven up a hill. When digging trenches, how near can you go to the trench. So, we're instilling all the safety aspects of construction, so when they are 16, they've got qualifications and can go for interviews.*

Participant 4 delivered work-based accreditations and qualifications in 'plumbing, cookery, carpentry art and photography.' They explained that they 'embed maths and English into everything we do.' They re-engage pupils with learning through vocational education. They explained 'it does work.' Some of the young people they worked with could return to mainstream education, and others had progressed into apprenticeships. Participant 5 explained that their aim was for the learner to gain 'five to nine GCSE or equivalents' and that learners would progress into 'something that they're interested in and would maintain.'

DISCUSSION

This research examined the construction AP delivered to children and young people who had struggled to cope in a mainstream setting and were at risk of disengaging from education, utilising Bernstein's sources of consensus and disaffection, which has been predominantly used to explore the culture of mainstream education settings. Research question one asked what type of construction AP was delivered. Reflecting on the literature on skills shortages, participants delivered training to address the industry's skills shortages (CITB, 2003, Brooks and Mcllwaine, 2021). The literature on AP explains that there needs to be more research into the nature, implementation, and value of AP programmes (Thompson and Russell, 2009; Trotman *et al.,* 2018). The limited literature on school-based construction training suggests it can support socio-economically disadvantaged groups into the industry and give them valuable work experience (Bruno *et al.,* 2016; Taylor, 2004). The literature also acknowledges that workforce diversification might be one way to meet the skills shortage in the industry (Infrastructure Australia, 2021). Participants from industry explained that they needed to give something back to communities; they recognised that the pupils they worked with lacked opportunities. However, they also explained that they were aiming to tackle skills shortages because there needed to be more tradespeople. Participants delivered a range of practical hands-on training, including plumbing, painting, and decorating, plastering, carpentry and brickwork.' Conversely, one of the participants explained that it was these more traditional routes that got promoted and had developed a programme of plant and groundworks training. Future research could explore whether construction AP is being planned with the skills needs of the industry in mind and where there is potential to address skills gaps.

Research question two was informed by Bernstein's expressive order to examine how construction training in a high-risk environment was delivered to pupils who had struggled with behaviour in mainstream education. The literature on AP explains that students in AP will have struggled with mainstream education and be at risk of disengagement from education whilst the construction literature explains that construction is a highly regulated and high-risk environment (Trotman *et al.,* 2018; Thomson and Russell, 2009; Loosemore and Bridgeman, 2017). Reflecting the literature participants explained that they did have concerns about behaviour from an H&S point of view. Participants acknowledged that whilst they had tight control measures in place, they felt what made a difference was that learners were doing something hands-on, they were not in the classroom, they were incredibly well-behaved and construction staff were impressed with their skills. This demonstrates that pupils were not anti-education and were open to learning in a more practical hands-on environment. There is scope to explore how this type of vocational learning can help re-engage pupils struggling with mainstream education.

In answering research question three, the instrumental order explored the knowledge, skills, or qualifications participants could offer pupils in AP. The previous literature has focused on academically able students considering trade and vocational routes instead of academic pathways (Callanan and Perri, 2020). The practical activities had been designed to complement the national curriculum. Participants were clear with pupils of the need for academic ability in construction and that it was not just about practical skills; they also needed the academic side, particularly maths. Bernstein (2003) explained that there could be tension in schools between the expressive and instrumental orders where pupils who are less involved in the instrumental order are less inclined to follow the expressive order of the school. The findings of this research suggest that pupils who had challenges following school rules (the expressive order) were able to follow the many regulations (such as Occupational H&S). This could be because, in construction training, H&S is part of the skills and knowledge gained (the instrumental order). As the construction trainer explained, what was specific to the construction sector, was the need to raise awareness and because 'your behaviours need to be this way', but it could also be because young people enjoyed the hands-on learning. Given the industry's focus on supporting disadvantaged people, future research could explore whether construction training could help young people educated in AP secure apprenticeship and employment opportunities, as this group is known to face barriers to employment (Trotman *et al.,* 2018).

CONCLUSIONS

It is concluded that Bernstein's theoretical approach is helpful in exploring how construction AP is delivered to pupils at risk of disengaging from education. There is scant research on construction AP and limited research on all types of AP, unsurprisingly, as there is a messy landscape of provision and a lack of information on how it is used (Thomson and Russell, 2009; Malcolm, 2018). There is scope to explore how construction learning can re-engage young people with education. However, the findings of this research demonstrate that construction AP can have a role in constructing for the future and has a role in meeting the future skills needs of the industry whilst meeting requirements for training people from disadvantaged communities. Participants were mindful of the need to meet skills shortages and promoted both traditional routes, such as carpentry and plastering but were also able to tackle skills shortages in less promoted routes, such as plant and groundworks. This shows the potential for construction AP to meet future and perhaps the less traditionally promoted skills needed by the industry. Additionally, Bernstein's theoretical approach was helpful in exploring construction AP. Firstly, in the expressive order, participants described how pupils who had struggled with behaviour in a mainstream setting had been incredibly well-behaved when they were doing something hands-on and were impressed with their skills. Secondly, in the instrumental order, young people could develop skills and knowledge in construction AP. Participants described how activities had been designed to promote the national curriculum and were clear with pupils of the need for academic qualifications, particularly maths. The findings of this research suggest that construction AP can have a role in re-engaging some pupils in education and in meeting the skills needs of industry.

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FORMAL INSTITUTIONAL BARRIERS TO FINDING MEANINGFUL EMPLOYMENT IN THE AUSTRALIAN CONSTRUCTION INDUSTRY: A REFUGEE AND MIGRANT PERSPECTIVE

Suhair Alkilani[1], Martin Loosemore[2] and Hammad Ahmed[3]

[1,2] School of Built Environment, University of Technology Sydney, Sydney, NSW 2007, Australia

[3] School of the Built Environment, University of New South Wales, Sydney, NSW 2515, Australia

As numbers of refugees and migrants grow, their integration into host countries is becoming a growing international challenge. Finding meaningful employment is critical to successful integration and globally the construction industry represents an important source of potential employment for both migrants and refugees. However numerous barriers exist which prevent refugees and migrants finding meaningful work. This research addresses a major gap in research into the barriers which formal government employment support systems present for refugees and migrants in finding meaningful work in construction. We report the results of an anonymous online survey of 40 refugees and migrants seeking work in the Australian construction industry. Findings highlight many barriers to employment in construction with the top three being: Employers not understanding the challenges migrants and refugees face; Government employment agencies not understanding migrant and refugee challenges; and Lack of help to navigate the government employment system. It is concluded that these are the main areas where refugee and migrant integration policies should focus.

Keywords: barriers; employment; formal institutions; migrants; refugees

INTRODUCTION

A refugee is a person who has fled their home country due to a well-founded fear of persecution, external aggression, occupation, foreign domination or events seriously disturbing public order (UN 1951). Every refugee begins as an asylum seeker (a person seeking refugee status) but not all asylum seekers are granted refugee status. A migrant is someone who voluntarily choses to change their country of residence for a range of reasons, the most common being the search for work (UNHCR 2018). As numbers of refugees and migrants grow, their integration into host countries is becoming a growing international challenge (International Organization for Migration 2018). Finding meaningful employment is critical to successful integration (Lee *et al.,* 2020). In many countries, asylum seekers face restrictions or limitations on their right to work during the initial stages of their asylum application process. This is

[2] martin.loosemore@uts.edu.au

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often due to the need for their refugee status to be determined and for administrative procedures to be completed (OECD- UNHCR 2016). While people seeking asylum in Australia, especially people who come by sea are denied consistent access to work rights (AHRC 2023), some types of bridging visa granted for asylum seekers allow them to work in Australia while their case is being considered. If a person is classed as a refugee, they are granted a temporary or permanent visa which provides full access to work rights, healthcare, and employment support services.

Globally, the construction industry represents an important source of potential employment for both migrants and refugees due to the large numbers and varieties of skilled and unskilled jobs it provides for migrants and refugees (Hedwards *et al.,* 2017). Yet the very limited research into refugee and migrant job seeking experiences in the field of construction shows that the industry poses peculiar work integration challenges for refugees and migrants, related to its unique culture, norms, and practices. Key issues identified include: high productivity pressures; strong pre-conceived notions of an 'ideal' construction worker; work-related acculturation, skills and qualifications recognition; social networks and informal hiring practices; stereotype perceptions of risk to productivity, quality and safety; and discrimination and bias in work and recruitment practices (Fozdar and Torezani 2008, Dunn *et al.,* 2011, Chancellor and Abbott 2015, Buckley *et al.,* 2016, Hajro *et al.,* 2019, Loosemore *et al.,* 2020, 2021a, 2021b). While this research has been useful in exposing the types of barriers which refugees and migrants may face in finding meaningful and sustainable employment in construction, it has focussed on the 'internal barriers' posed by the industry itself. In contrast, there has been little research into the barriers posed by the formal government employment services provided by many countries, which many refugees and migrants rely on to find work. As discussed, these formal systems of support have been found to be problematic in many countries such as Australia (Commonwealth of Australia 2019). The aim of this paper is to address this gap in research by reporting the results of a survey of refugees and migrants seeking work in the Australian construction industry.

Government Employment Support for Asylum Seekers, Refugees and Migrants in Australia

Faced with the immediate need to support themselves research shows that asylum seekers, refugees and migrants are highly resilient and creative in finding employment (Torezani *et al.,* 2008). While informal networks can be very important in finding work in industries like construction Loosemore *et al. (*2021b), this can often result in low quality, insecure and poorly paid survival jobs in the grey economy (Arian *et al.,* 2021). Government employment systems are meant to minimise these risks by providing access to important 'linking social capital' which can result in higher quality jobs which prevent exploitation (Torezani *et al.,* 2008).

Research across a wide range of countries shows that government employment systems are ineffective in helping refugees and migrants' secure work. In Australia, this system has been widely criticised for: commoditising job seekers; being overly complex and burdensome for both job seekers and employers; for producing generalist employment services which do not understand refugee and migrant unique challenges and histories; poor quality services to both job seekers and employers; poor connections with employers; for perverse incentives which keep job seekers in insecure work and pointless training which de-skills them over time; and poor matching of jobseeker's skills and experience and employers' needs etc.

(Commonwealth of Australia 2019). Arian *et al.* (2021) found that refugees have difficulty understanding how the formal employment system works and the very limited and highly generalized support provided leaves refugees to fend for them themselves. Industry has also complained about the complexity of this system, meaning that less than 4% of employers in Australia use it for recruitment (Parliamentary Inquiry 2022). The overall impression is of a system which commodifies refugees and migrants (and other job seekers) in a 'work first' model, which focuses on low-paid, casualised, part-time and/or temporary low-quality jobs (Henriques-Gomes 2022). Consequently, Legrain (2017) report that refugees and migrants are left at high risk of exploitation in industries like construction and experience employment as a form of entrapment in their host countries rather than an opportunity for a new life.

METHOD

Our research design was trust-building, culturally sensitive and respectful of the potential vulnerability and complex lives of our respondents. Data was collected via an anonymous online and face-to-face survey of refugees and migrants who had sought work in the Australian construction industry (successfully and unsuccessfully) with the assistance of a not-for-profit community-based refugee support organisation which help to broker access to suitable respondents. A survey was used on the advice of this support organisation because it afforded more anonymity than other methods and helped to maximise responses from a geographically dispersed population of people with complex demanding lives. The survey was translated into several languages (English, Farsi, Urdu and Arabic) and administered and analysed in accordance with the Australian Code for the Responsible Conduct of Research (2018); and other relevant research into refugee and migrant methodologies such as Saad *et al.* (2022) by a multicultural research team which included a refugee working in the construction industry who also provided fluency in several languages spoken by our respondents. Following Olmos-Veha *et al.* (2022) we also ensured analytical reflexivity by ensuring the multicultural research team constantly communicated about potential cultural assumptions around findings as they emerged.

Guided by our research question, the on-line survey comprised four sections comprising a range of categorial, open-ended and Likert scale questions. The first section asked general demographic information such as: gender; age; language competency; country of origin; qualifications; years lived in Australia, construction industry experience, and visa status. The second section explored the specific experiences of respondents in seeking work in construction (successfully and unsuccessfully) including: types of work found; length of time looking for work; numbers of jobs applied for; ease of finding work; and satisfaction with current work; whether salary. The third section explored field-specific barriers to employment derived from an extensive literature review of potential barriers to employment facing asylum seekers, refuges and migrants seeking work in construction as discussed. Barriers to employment were assessed on a five-point Likert scale ranging from 1 = "not a problem" to 5 = "huge problem" and informed a detailed literature review. The final section explored how respondents had overcome these barriers through interactions with various institutions, both formal and informal: friends; family; charities, formal government employment agencies, not-for-profits and community-based organisations; industry organisations; education providers; private labour hire companies etc. The survey questions were tested and refined in a pilot study with a small representative sample of respondents before being administered to the broader population, who were asked to distribute it to fellow refugees and migrants working in construction.

Data was analysed using a variety of descriptive and inferential non-parametric tests, following pre-testing for Kurtosis and Skewness which showed that the data are exceeding the recommended range by Hair *et al.,* (2013) of greater than +1 and less than −1, which indicates a not normally distributed dataset. A Kolmogorov-Smirnov (KS) test was also conducted to re-affirm the non-normal distribution nature of our data. A Relative Importance Indexing (RII) method (Holt 2014) was used to rank the responses of respondents against the barriers and challenges faced by the respondents in finding meaningful and secure work in the construction industry. A higher RII indicates that an item is more prevalent than other items with relatively lower RIIs. One-Sample Wilcoxon Signed Rank Test. was used to find if there was an agreement among the respondents in ranking the barriers and challenges faced by them in finding meaningful and secure work in the Australia construction industry. The adopted significance level was 5%. Also, Exploratory Factor Analysis (EFA) with factor loading of at least 0.7 was used to classify the barriers/challenges the respondents faced in finding meaningful and secure work in the construction industry.

The survey resulted in a large volume of data and following section reports the results regarding the formal institutional barriers that refugees and migrants experience when searching for work in the construction industry.

FINDINGS

Given the online nature of the survey and the snowball sampling approach, it is not possible to provide an accurate response rate. However, the sampling and recruitment process resulted in a sample of 40 respondents (Table 1) which is assumed to be representative of the refugee and migrant population seeking working in the Australian construction industry.

Table 1: Sample characteristics

Characteristics	Frequency	Percentage %	Characteristics	Frequency	Percentage %
Gender			Language		
Male	32	80	Arabic (First language)	18	47.4
Female	8	20	English (Second language)	23	62.2
Age			Years stayed in Australia		
15 - 29 years	22	55	0 - 4 years	18	45
30 - 39 years	9	22.5	More than 4 years	22	55
40 - 49 years	6	15	Entry Visa to Australia		
Over 50 years	3	7.5	Asylum seeker	5	12.8
Years worked in Construction industry			Humanitarian Refugee	19	48.7
0-4 years	25	62.5	Skilled migrant	7	17.9
more than 4 years	15	37.5	Other	8	20.5

The results of One-Sample Wilcoxon Signed Rank Test in Table 2 show that there was strong agreement among all the respondents in ranking the barriers/challenges they faced in finding meaningful and secure work in the construction industry. Table 2, Mean and RII results also show that the respondents perceived the first ten barriers as 'critical' (Takim *et al.,* 2008) with Mean and RII values ranging from 3 to 3.425, and 0.6 to 0.685 for the first ten barriers.

Table 2: Means, RIIs and Ranks of the barriers that faced the respondents in finding meaningful and secure work in the construction industry

Barriers/ Challenges	Mean	RII	Rank	One-Sample Wilcoxon Signed Rank Test (sig at 0.05)
Employers not understanding the challenges migrants and refugees face	3.425	0.685	1	0.085
Government employment agencies not understanding the challenges migrants and refugees face	3.35	0.67	2	0.08
Not enough jobs	3.275	0.655	3	0.157
Lack of help to get through the government employment system	3.125	0.625	3	0.503
Employers not recognizing my past skills, Qualifications, and experience	3.075	0.615	4	0.674
Hard to get relevant training	3.05	0.61	5	0.663
Access to information about job opportunities, careers in construction	3.05	0.61	5	0.797
Getting work experience in construction	3.05	0.61	5	0.803
Confusing laws and regulations to get work	3.025	0.605	6	0.742
Being forced to take low quality work	3	0.6	7	0.938
Discrimination by employers	2.925	0.585	8	0.823
Support to setup your own business	2.9	0.58	9	0.686
Discrimination by government agencies and providers	2.9	0.58	9	0.566
Access to training and new qualifications	2.9	0.58	9	0.725
Overly complex employment systems and procedures	2.875	0.575	10	0.574
Gaps in employment services	2.85	0.57	11	0.581
Pointless compliance requirements (pointless training etc.)	2.825	0.565	12	0.361
Not understanding my personal needs and challenges (no individual support)	2.8	0.56	13	0.283
Poor quality employment services	2.8	0.56	13	0.248
Poor communication between organizations in the employment system	2.775	0.555	14	0.25
Uncaring and impersonal employment services	2.775	0.555	14	0.232
Competition between organizations in the employment system	2.75	0.55	15	0.132
Assistance with applying for jobs, English language classes, writing CVs, Interview techniques etc	2.75	0.55	15	0.32
Transport to work	2.725	0.545	16	0.138
Support with resumes and interview skills	2.675	0.535	17	0.18
Availability of interpreters and lack of translated materials	2.65	0.53	18	0.068
Access to other government support services such as childcare etc.	2.55	0.51	19	0.028*

In Table 2, 'Employers not understanding the challenges that migrants and refugees face' was ranked the most important barrier (Mean= 3.425, RII= 0.685, Rank=1), followed by 'Government employment agencies not understanding the challenges migrants and refugees face' ' (Mean= 3.35, RII= 0.67, Rank=2), then 'Not enough jobs' and 'Lack of help to get through the government employment system' which were ranked third (Mean= 3.275, RII= 0.655, Rank=3). 'Use of technology to look for work' was ranked the least important barrier faced the respondents (Mean= 2.475, RII=0.495, Rank=20). 'Access to other government support services' such as childcare was also ranked very low (Mean= 2.55, RII=0.51, Rank=19) as was availability of interpreters and lack of translated materials (Mean= 2.65, RII=0.53, Rank 18). The lack of significant difference between refugee and migrant responses is interesting since numerous studies indicate that refugees and migrants face distinct challenges in finding employment (Legrain 2017). However, our findings align with Loosemore et al's (2021 a, b) analysis which also found that the barriers faced by refugees and migrants were broadly the same, albeit not in a formal institutional context as was the focus of our research. In this way, our results both confirm and extend Loosemore et al's (2021 a, b) results.

There were only two variables where the One-Sample Wilcoxon Signed Rank Test was significant at $p< 0.05$ indicating a lack of agreement between respondents: 'Access to other government support services' (such as childcare etc); and 'Use of technology to look for work'. These findings do not align with Irani *et al. (*2018) who found that refugees in general tend to struggle with technology in finding work in their host country. However, further analysis to explore where these differences lie, using a Mann-Whitney U Test and Kruskal-Wallis Test, offered no statistically significant differences across the sample demographics. This is therefore likely caused by the presence of outliers in the data (Voraprateep 2013). However, it was observed from the mean rank results that 'Use of technology to look for work' was the highest ranked (largest mean rank) by the age group of over 50 and least ranked (least mean rank) by the age group 15-29.

Exploratory factor analysis (EFA) results are presented in Table 3 offering a new categorisation of barriers to work facing migrants and refugees in construction. The EFA results arrange the variables into four groups based on similarities in the way that respondents answered these questions - indicating correlation between them. The first group includes four barriers which are broadly related to employment services (average mean and RII in Table 2 = 2.8 and 0.56). The second group includes six barriers which are related to lack of understanding of refugee and migrants needs by governments and employers (average mean and RII in Table 2 = 3.167 and 0.633). The third group of barriers are related to discrimination at work (average mean and RII in Table 2 = 2.91 and 0.583) and the fourth group are related to individual challenges and especially the technological resources to find and get to work (average mean and RII in Table 2 = 2.6 and 0.52). It is notable that these groups are quite different to the generic and unranked categorisations produced by Lee *et al. (*2020) which is as described previosuly.

This shows that older refugees will likely struggle more with recent changes to Australia's employment system which includes a new online service which relies on the digital maturity job seekers (Workforce Australia 2022).

Overall, given concerns about the increasing digitisation of government employment services in Australia (Ball 2022) the positive results around technological maturity are encouraging. As Borkert *et al.* (2018) found, technological ability contributes significantly to the integration of refugees into a host society. It is also interesting that access to interpreters is not seen as a major barrier to finding work in construction. Language problems are often cited as a major barrier to employment for refugees and migrants (Hiruy *et al.,* 2019) and our findings again align with Loosemore *et al.* (2021a) who ranked language problems very lowly in relation to the many other challenges faced in finding work.

Table 3: Exploratory Factor Analysis results

Rotated Component Matrix

	Component			
	1	2	3	4
Poor communication between organizations in the employment system		0.742		
Gaps in employment services		0.729		
Uncaring and impersonal employment services		0.8		
Poor quality employment services		0.793		
Lack of help to get through the government employment system	0.713			
Getting work experience in construction	0.776			
Hard to get relevant training	0.859			
Being forced to take low quality work	0.738			
Employers not understanding the challenges migrants and refugees face	0.763			
Government employment agencies not understanding the challenges migrants and refugees face	0.725			
Discrimination by employers				0.8
Discrimination by government agencies and providers				0.764
Use of technology to look for work			0.881	
Transport to work			0.713	

This may be explained the existence of cultural ghettos on construction sites (Dunn *et al.,* 2011), often associated with specific trades, which through cultural gatekeepers act to protect new members from the risks of poor language proficiency in the industry. The top three challenges are also interesting, especially the ranking of the construction employers above government employment agencies, despite all the criticisms the latter have received from many sources (Parliamentary Inquiry 2022). Our results indicate that despite its highly diverse workforce, there is much more that the industry can do to better understand the needs and challenges that migrants and refugees face in finding work. To inform such understanding, Loosemore *et al.* (2021a, b) found that challenges in securing work experience and recognition of past skills qualifications and experience, are the two most frustrating challenges facing migrants and refugees in finding work in construction. Loosemore *et al.* (2020) also found that subcontractors tend to perceive refugees and migrants as significant risks to cost, safety and productivity (the second highest of six groups compared). More broadly, research outside construction highlights many reasons for employers being reluctant to engage refugees and migrants (UNHCR 2017). These include confusion about work limitations and employment rights; additional costs of employment; unreliability; low productivity; safety risks; poor language skills; and lack of available information about how to manage refugees' complex needs. The new categorisation offered in this research about barriers to work facing migrants and refugees in construction provides a more nuanced insight for policymakers and managers into the broad types of barriers to employment faced by refugees and migrants seeking work in construction. For example, this information is important in the context of growing numbers of social procurement policies which target refugees and migrants in construction (Loosemore *et al.,* 2020).

CONCLUSION

This research took place within the context of an increasingly politicised and heated international debate about how to manage growing asylum seeker, refugee and migrant numbers. Given the relatively large employment opportunities offered to refugees and migrants by the construction industry in most countries, this paper argues that there is an associated responsibility to explore and address the barriers that may exist to potential employment in the sector. By explicitly exploring the barriers to employment for refugees and migrants presented by the Australian Government employment system, the findings make several important contributions to the very limited construction management research and debate in this area. First, while our results support previous research which criticise government systems for not meeting the employment needs of refugees and migrants, it appears that the construction industry is equally, if not guiltier. From the perspectives of refugees and migrants, the construction industry can do much more in several key areas which determine employment opportunities in the industry. These include providing relevant work experience; being more willing to recognise prior qualifications and experience where valid; addressing negative stereotypes in construction supply chains around risks to cost, safety and productivity; and better educating itself about the facts and the legal rights and opportunities offered by refugees and migrants. The research also offers a completely new categorisation of formal institutional barriers to employment for this group which can provide the basis for simplifying future government policy development and industry human resource management strategy in this complex area. This indicates that priority should be given first to better education about refugee and migrants needs and challenges, followed by addressing negative perceptions which could form the basis of discrimination, followed by addressing problems in formal government systems of employment support, followed by addressing deficiencies in the refugee and migrant population itself. Our results therefore challenge the current deficit approach to management strategy and policymaking in this contentious area of practice and research.

We recognise the limitations of this research. The results are presented entirely from a refugee and migrant's perspective and need to be balanced by further research from an industry perspective. Also, despite the challenges in undertaking research in this difficult area, we recognise that the sample is quite small. Therefore, further research is needed to validate our results using expanded samples and qualitative methods which can enable more detailed explorations into the experiences of various components within this diverse group.

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IS IT DIFFERENT ACROSS THE POND? EXPLORING GENDERED EXPERIENCES IN CIVIL ENGINEERING IN THE UK AND USA

Abi Brierley[1], Vikki Edmondson[2] and Fred Sherratt[3]

[1] Laing O'Rourke, Bridge Place, Anchor Boulevard, Crossways Dartford, Kent, DA2 6SN, UK

[2] Department of Mechanical and Construction Engineering, Northumbria University, Newcastle Upon Tyne, UK

[3] Construction Safety Research Alliance, University of Colorado at Boulder, UCB 428, Boulder, CO 80309-0428, USA

The construction industry continues to struggle to attract women into civil engineering. Despite drives for equality in both the UK and the US, women remain underrepresented on university courses, and thus also in the field. Increased understandings of this can inform and support positive change. A comparative study of the experiences of both male and female engineers at different stages of their careers in the UK and USA was undertaken. A purposive sample was selected which included students, graduates, and full-time engineers, with one male and one female participant at each experiential level. Interviews with n=10 UK and n=10 US engineers were held via Zoom, transcribed, and analysed to reveal the dominant themes therein. Findings reveal gendered differences in how the participants position themselves within the industry. Familiar problems also have long shadows; entry to the industry, general awareness, and perceptions of construction, as well challenges of bias, sexism and stereotypes all endure. This study updates understandings of why and how women continue to be underrepresented in civil engineering and using evidence from both countries makes suggestions to enhance gender equality in this space.

Keywords: comparative analysis; engineering; gender; women; USA; UK

INTRODUCTION

Although the language is the same, the UK and USA are very different countries, and when it comes to work-life balance Americans are often thought to be much worse off that their British counterparts. Differences highlighted by Ionescu (2021) include in the average salary of senior managers; in the USA they would be paid $104,940 and, in the UK, they would only be paid £52,000 which, accounting for conversion rates, is 50% less. Whereas British workers are entitled to 28 weeks of statutory sick pay, Americans are entitled to none. British workers are also legally entitled to 5.6 weeks of annual leave, whilst Americans are again legally entitled to none, with employers on average offering only 10 days. However, one similarity lies in the lack of women

[3] fred.sherratt@colorado.edu

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in civil engineering. In the UK, 18% of engineering graduates are women (Engineering UK 2023). In the USA, that statistic is slightly higher at 23% (ASCE 2022). Once in the workforce, these numbers drop to 9% and 14% in the UK and USA respectively (Engineering UK 2021; ASCE 2022).

This situation has not gone unrecognised, not least because diversity leads to better organisational performance and outcomes (McKinsey and Company 2022). The lack of gender equality within civil engineering is therefore not a novel subject for research (Navarro-Astor *et al.,* 2017) and is only becoming ever more important as the construction industry faces a significant skills shortage on a global stage, with civil engineering a named profession facing shortages in the long term (Chartered Institute of Building 2019). Indeed, the business case for increased equality and diversity within the construction industry has been established now for some time (Sang and Powell 2012). The construction industry is also keenly aware of this, with firms such as Balfour Beatty (2023) arguing that as well as encouraging more women to join the industry, actions must be taken to 'stop the flow of talented women leaving it'. The existing body of research has explored gender inequality within the construction industry from a variety of perspectives, including barriers to entry for women (Gurjao 2006; Powell *et al.,* 2010; Navarro-Astor *et al.,* 2017), the complexities of challenges they face when they secure professional roles (Aboagye-Nimo *et al.,* 2019), and why they often leave (Ayre *et al.,* 2013).

To add to the richness of detail to understandings of gender equality in the construction industry, and specifically within the profession of civil engineering, this study aimed to examine the experiences of both men and women working as professional civil engineers in the UK and USA at different stages of their careers. It sought to provide insights from localised gendered perspectives in both countries, thus potentially able to further support initiatives and interventions to better balance this specific workforce.

Context

Generating Awareness and Interest

It can be argued that the problem of the lack of women in engineering starts far earlier than in the workplace and earlier even than university. In fact, EngineeringUK (2019) found that whilst 30% of boys aged 11-19 knew quite a lot about what engineers do, only 18% of girls in the same age range could say the same. Research by Peixoto *et al. (*2018) argued that children, and their influencers, should be educated on the pathways into engineering which would allow them to envision their own potential career in the industry. They also lay importance on removing the unconscious bias in engineering as early as preschool age.

Strachan *et al. (*2020) suggest that the biggest influence on someone joining the construction industry, including making the choice to study civil engineering at university, comes from personally knowing someone who works or has worked in the industry. EngineeringUK (2019) found this to be broadly accurate, as 61% of young people would turn to their parents/carers for careers advice, but also found that 59% would ask a careers adviser and 56% would ask their teachers. In the USA, Blosser (2017:24) also found that school staff and '…faculty are influential figures who have been shown to play a central role in introducing students to the profession and can significantly impact students' experiences'.

There have been attempts to enhance the number of female students in engineering in both the UK and USA. Research has shown that there are very few differences in the factors that attract both male and female students to construction degree programs (Bigelow *et al.,* 2018), however their experiences can differ once there, and gender bias can become problematic for female students (King-Lewis 2021). In the USA at the University of Toledo, Franchetti (2012) developed a series of programmes that were implemented to retain students from freshman (first) year to sophomore (second) year. These programs included mentoring from older students, a focus on the society of women engineers and the 'Eberly Center for Women', employing female staff and including more practical elements and a design course for first years. These adjustments were monitored in groups of female engineering students over five years and compared against control groups that were not subjected to these changes. Findings confirmed that the programs implemented helped to significantly increase the retention of female engineers in education.

At the other end of the educational timeline, and to seek to counter ongoing preferences for hiring men (Navarro-Astor *et al.,* 2017), Strachan *et al.,* (2020) undertook a relatively small action research project involving a construction engineering careers event at Gateshead College aiming to increase diversity amongst the employers present, whilst also providing guidance to mitigate unconscious bias and any consequential recruitment decisions. As a result, there was an increase in the number of female applicants (from 8% to 19%) and a further increase in the number of successful applicants (8% to 23%). Such improved course outcomes could prove attractive to prospective female students, with clearer career paths demonstrable through the successes of previous graduates.

Experiences of Practice

Many women start their professional careers '…strongly believing in themselves as engineers, a belief that had endured despite the difficulties they encountered' (Ayre *et al.,* 2013). It is these 'difficulties' that have been identified by researchers over past decades, with seemingly little improvement in practice during that time. Ness and Green (2012:27) argued that '…the building site is one of the last bastions of a traditional working-class masculinity' and therefore a workplace where there is no obligation to be polite or “nice” to people. It is perceived to be a masculine, hostile, challenging, and dangerous environment (Galea *et al.,* 2015) resulting in a professional workplace where women are vulnerable to bias, discrimination, and harassment - which in turn become some of the root causes of the underrepresentation of women in civil engineering in the USA (National Academies 2020). More recently, the empirical work of Aboagye-Nimo *et al. (*2019) carried out in the UK found that the industry has a serious problem of women being treated unfairly, which not only discourages women from joining the industry but also negatively affects retention. Sexism remains a perpetual problem for the industry, felt to be a widely 'accepted practice' according to women who work there (Aboagye-Nimo *et al.,* 2019). Bagilhole *et al. (*2008:24) also argue that the industry largely sexualises women, with both men and women being guilty of this which often undermines qualified, professional women through the medium of ‘language, humour, style and appearance’.

Another key aspect for professional civil engineers is the lack of flexibility and thus accessibility to those wishing to have and care for family. This lack of flexibility reveals itself in the lack of respect for part-time roles, the long, unchanging working hours and issues surrounding maternity leave (Bagilhole *et al.,* 2008). Maternity leave can be particularly problematic, with Strachan *et al. (*2020) reporting cases of sexism in employers surrounding maternity leave. They highlight a quote from a male employer suggesting that between equally qualified male and female applicants, he would be more likely to hire the male because: '…if I think that Joe can do it rather than Jane, Joe isn't going to get pregnant,'. Maternity leave can be an issue for female engineers working in the USA, as there is no entitlement to paid maternity leave (Ionescu 2020), whilst in the UK women are entitled to 90% of their salary for the first 6 weeks and reduced pay for the remaining 33 weeks. However, despite such legislative protections, UK women working professionally in the construction industry remain worried about taking career breaks for crucial circumstances such as starting a family, as (Aboagye-Nimo *et al.,* 2019) found in some cases, statutory maternity pay is not implemented, and women can face redundancy when/if they decide to take their entitled maternity break, despite this being illegal. Globally, the culture of the construction industry remains one of complete commitment, any-time availability, and very poor work-life balance (Bowen *et al.,* 2018) which does not only impact women but anyone with a family.

Point of Departure

Although research of women in construction has both a recognisable history and resultant of knowledge, it arguably remains a space that is only seeing incremental improvements (Navarro-Astor *et al.,* 2017). Indeed, as gender equality has slowly improved (although the industry and specifically the civil engineering profession remains a long way from 50/50 representation in either the UK or USA), issues are now becoming more evident for women who have been retained and now reached senior roles in the industry because of improvements (Aboagye-Nimo *et al.,* 2019). This study therefore sought to add to the body of qualitative data that provides rich insights and understandings of gendered experiences of professional civil engineering specifically, aiming to examine the experiences of both men and women at a variety of career stages whilst also taking in two different geographical perspectives.

METHOD

To achieve the stated aim, interviews were held with a purposive sample covering all stages in a professional career. To that end, the sample for this study comprised one male and one female respondent from the UK and US at each of the following career stages, making a sample total of n=20:

- Student
- Recent graduate
- Professional with 0-10 years of experience
- Professional with 10-20 years of experience
- Professional with 20-30 years of experience

In adopting this approach, the sample that results inevitably reduces each sample strata to a different category of experience. Thus, whilst broad patterns could be identified, attention was also paid to the variety and differences between and amongst the sample. Each of the interviewees were asked the same 8 questions developed from common themes found within the literature:

4. Why did you decide to study engineering?
5. When did you develop an interest in engineering?
6. Who has supported or influenced you in your journey so far?
7. What are your opinions on the gender split in engineering?
8. How do you perceive the opportunities for advancement within your career?
9. Have you experienced or seen any sexism within your career and, if you have, how did you deal with it?

10. How long do you think you will continue to be an engineer?
11. What do you think would encourage more women to be a part of the industry?

All interviews were carried out via Zoom, transcribed, and the resultant transcripts uploaded to NVivo for analysis. Thematic analysis was used to unpack the transcripts to reveal the structure and shape of the dominant themes therein (Silverman 2022). This was further supplemented by content analysis which mobilised text searches and word frequency queries to provide more detailed insights from the data.

As with all research, there are limitations to this study. The small sample size is a notable limitation, as it has inevitably limited the extent and variation in the experiences explored, which may have introduced bias into the findings and impacts generalisability overall. The specific geographical locations of the participants are also a limitation of the sample; in the USA participants were based in California and in the UK in the North of England. The use of Zoom limited the personal interaction within the interview which may also have influenced the depth and scope of the data collected. This research received full ethical approval from the Northumbria University and where quotes are given, pseudonyms are used to ensure anonymity.

FINDINGS

One of the most fundamental findings from this work was that although the male and female civil engineers had very different experiences throughout their careers, their geographical location either in the UK or USA did not itself generate any notable differences within the data. Despite the myriad aspects that distinguish employment more generally between the UK and USA, and thus could potentially create inter-country differences, such aspects did not emerge within the data or the individual stories as meaningful differences in experience. It had been hoped that differences could be highlighted able to inform effective initiatives for the other country, but that was not the case, reflecting the conclusions of Navarro-Astor *et al. (*2017:210) that there are '…more commonalities than divergences in gender discrimination across nationalities.' Essentially it is whether you are male or female that matters for professional civil engineers, not whether you are working in the UK or USA.

Looking Back: How Did We Get Here?

Most of the interviewees (both male and female and British and American) explained that their interest in engineering developed between the ages of 15 and 19 and there was notable commonality in the development of their interest in the field. Many of the respondents expressed an affinity towards mathematics and scientific subjects from their time at school, describing a similar foundational experience at this age, however there was divergence as to the origins of this interest. Many of the male respondents noted how they had played with Lego bricks and other engineering toys such as ‘erector sets’ when they were young, whilst the women did not relay this same early-childhood experience. Indeed, female respondents felt that they lacked corresponding activities within their earlier years, for example one female interviewee suggested that children’s books should contain stories about women in engineering and questioned why ‘Bob the Builder’ wasn’t a woman. This thinking was mirrored by the male respondents too, with one mid-career male engineering working in the UK asking: 'Should we have baby books that have got those roles in them, yeah. and then, if you look at some of the baby books I know from when I was growing up, they'll be gender stereotype one. Yeah, the builder will be a guy … 'Bob the Builder, why's it got to be Bob?' This reflects Strachan et al.'s (2018) suggestions that children, and their influencers, should be educated on engineers and the pathways into engineering.

Regarding the influences the interviewees had been exposed to that made them choose civil engineering as their profession, the majority joined the industry because they personally knew someone who was already a part of it. This reflects a common 'reason' as to why women chose to enter the industry (e.g., Bigelow *et al.,* 2015). For these participants this was a family member or close family friend who was, or still is, working in the industry. Content analysis of the data found that the biggest influence on the interviewees becoming engineers was their parents, specifically their fathers. Interestingly, this was the case for all the UK male engineers and all of the female US engineers, with the exception of the late-career participant, but not all the UK female engineers. Across the 20 interviews, the word dad (or father) was mentioned 17 times with the word 'parents' being used 8 times. However, others were also influenced by an uncle or an influential teacher in high school.

Looking Forwards: A Long-Term Prospect?

The long-term priorities of the men and women in the sample was a notable point of difference. When asked how long they saw themselves staying in the industry, the men said they would be in engineering for the rest of their career until they retired. For example, the UK male student engineer felt this was his '…career in general probably My whole working life I'd say.' This was also the case for the US late career male: 'Well, I've been doing this for 31 years. I don't have any set timeline. I really enjoy the people; I enjoy what I do. I'd say sometime between 65 and 70 is probably, I see myself. Probably finishing up my career'.

This was markedly different to the women who were unable to have the same certainty about their future. The female engineers often brought up having children or starting a family, raising questions about the flexibility of the industry and its ability to accommodate them. As the UK early career female engineer said 'The long days to the long nights so you think sometimes [that] you might have to take time away and come back to it. I don't know, it depends… So how would you fit a family around that?' This was the same across the pond, with the US late career female engineer noting '…you either have the career and family so for me, as soon as the family comes becomes a factor. The family will be what I choose.' This was a concern that none of the men interviewed highlighted. The women interviewed mentioned the word 'family' 25 times, mostly in relation to future family life and children, whilst the males interviewed mentioned it 16 times, mostly in reference to their parents.

The perpetuation of such traditional gender roles, and resultant lack of flexibility within the construction industry has a significant impact on women civil engineers. They are forced to choose part time work, or end or pause their career which, in turn, limits their likelihood of promotion and career progression. As the UK late career female engineer noted: 'If I didn't have children, I would say the advancement [potential] was just the same as male colleagues' yet she had chosen to work part time which meant she hadn't '… been given the same opportunities as my male colleagues, because of my responsibilities at home.' She felt that the larger opportunities and projects would not be assigned to her but would be assigned to a full-time member of staff and argued that she would not be awarded an increase in position or salary, as she doesn't 'have the time in my three days a week, to be able to look after that responsibility'. This identifies another potential contributing factor behind the lack of women in senior industry roles (Gurjao 2006) which also creates a self-fulfilling prophesy in which the lack of representation makes it more difficult for women to see themselves in such positions. As the US early career female engineer said: 'I've only had one female manager in six years. And so that's really the that's really where I see the big gap right now is, is in the middle level management and up…The most important place like the higher role is probably the most, the biggest place for the change to occur.' In keeping with the truism that 'You can't be what you can't see', as the late career US female engineer said 'My experience and what I've seen is your, your high-ranking females in engineering, are single ladies' - successful women engineers with children and families are a rare thing indeed.

Confidence and Certainty

The content analysis of the data created an interesting finding around the theme of confidence and certainty. In part likely reflecting the uncertainty faced by women about their long-term future in the industry, but also potentially reflecting wider gendered positions within society, the data found women civil engineers to lack the confidence of their male counterparts through their choice of language within the interviews. The most frequently used word by women in the interviews was 'think' whilst the most used word by the men interviewed was 'know'. By saying 'I think' rather than 'I know', a person is more open to being incorrect and often willing to correct themselves. This can weaken an argument as it 'casts a shadow of doubt' on the statement and is also suggestive of the fact that women in the industry have a lack of confidence in what they are saying, that is not present in men.

Sexism and Stereotypes

When asked about their experiences with sexism, the men, at all stages in their careers, had not personally experienced any sexism and very few of them had even seen any sexism at all. As the UK male graduate said: 'I've not had any issues of sexism or observed it in my life' whilst the US male early career engineering stated: 'No, I have not. No, not at all, especially nowadays.' Conversely, all the women interviewed had experienced some sexism, including the students and graduates. Whilst the veteran engineers agreed that the number of women has increased over the last 10 years, none of the interviewees were willing to comment on whether the amount of sexism has decreased in that time.

Most of the sexism experienced by those interviewed was in the form of supposedly light-hearted comments and humour. Whilst this can be perceived as seemingly harmless, comments of this nature serve to undermine a woman's position as a qualified professional and would likely not be tolerated in other more professional industries. However, these comments, whilst degrading to women, do not seem to affect the women's day to day experiences as civil engineers, with most of them identifying it as a problem but not one serious enough to report. As the US graduate female engineer said with regards to whether she would consider an incident sexist: '…I can't say for certain sexism right … for some reason it crossed my mind … If it were to happen again, then I would be certain that it was. I [would say I] experienced some cynicism.' This was supported by comments from the US early career female, who felt she had experienced: 'Nothing extreme. I would say the subtleties.'

A specific aspect of their careers in which sexism became more problematic was for women seeking leadership positions, who often find it harder to gain respect and trust in leadership. One of the UK early career male interviewees referred to his previous female managers as 'fire-breathing dragons', whilst an early career female engineer in the USA explained that 'it's hard for a woman to be like a leader, without being called 100 names under the sun'. She argued that there are male role models in managerial positions whereas there are far fewer women in those positions. This is problematic for women in senior roles across all industries, where they experience microaggressions that undermine their authority, and are far more likely than men in leadership to have colleagues imply that they aren't qualified for their jobs (McKinsey and Company 2022). When embedded within the wider casual sexism of the construction industry, this becomes more influential and impactful in negative ways.

A final and fundamental point revealed by this study was the prevalence of unconscious bias within the industry as revealed by some of the comments made by the interview participants themselves. These included a UK senior male participant asking: 'why would a woman want to be a project manager?' and many comments about engineering being a 'masculine' industry. One early-career male participant from the UK suggested that women should be in 'a compassionate profession' such as nursing rather than engineering as it is 'quite confrontational' a comment made by one of the younger people interviewed. A late career male from the UK even said about engineering 'it is still a dinosaur industry' and suggested that his generation, and the generation above him need to 'get out of it before those attitudes will really move on'.

CONCLUSIONS

This study sought to explore the experiences of male and female civil engineers at different stages in their careers working in the UK and USA. The most interesting finding perhaps was that country location made no real difference to the experiences of the engineers at their different career stages, despite the potential for different work and employment practices and legislation to make an impact. Nor were there notable differences at the different career stages examined. The most significant differences were instead simply gendered - and not all that unfamiliar. Entry to the industry remains problematic, with familial connections providing the main impetus for a career decision, with a notable lack of early-years introductions to engineering and construction for girls. Logistical challenges and bearing the burden of family and caring responsibilities remain prominent for female engineers who struggle to see a long-term career in the industry, whilst their male counterparts are able to see civil engineering to retirement. This lack of confidence could even be seen in the language used by the female participants, who 'thought' whilst the men 'knew'. Bias, sexism and stereotypes also all endure, with female engineers struggling to secure leadership roles and facing everyday sexism in their roles. The perpetuation of stereotypes and the belief that women should not be civil engineers also endures, with the worrying finding that this belief is held by those across the generational spectra, making the 'solution' that such attitudes will retire with those who hold them unlikely to be realised.

This study adds to understandings of the differences in gendered experiences for civil engineers (who inevitably work within the wider construction industry) and demonstrates that there is still much work to be done to develop a working environment accommodating to all. It is recommended that further research continues to explore the richness of the specific challenges faced, to develop a critical mass of knowledge capable of bringing about effective changes towards equality in construction.

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HEALTH, SAFETY AND WELLBEING

MANAGING ONSITE PRODUCTION PRESSURE AND ITS IMPACT ON SAFETY PERFORMANCE IN CONSTRUCTION: AN ACTIVITY THEORY ANALYSIS

Bernard Acheampong Twum[1], Shabnam Kabiri, and Dylan Tutt

School of Built Environment, Whiteknights, PO Box 217, Reading, Berkshire, RG6 6AH, UK

Production pressure is a known contributing factor to accidents on construction projects. However, a detailed understanding of how disparate project groups use the contract and programme when confronted with production pressures and its impact on site safety is limited. Based on an ethnographic case study of a large building project in Accra-Ghana, activity theory is applied to analyse how the contract and programme used at the interface of distinct project groups feature in production pressure incidents and its impact on safety performance. The findings revealed that the project team collaboratively made a situated use of the tools for decision-making in managing the production pressure, where production demands were prioritised over safety. Acceleration as an adaptive practice was used in determining the number of additional workers, machinery, and equipment to hire. Second, productivity-based incentives were also used in negotiating early task completion targets with the workers. The practices adopted prioritised production, which, in turn, increased unsafe practices leading to accidents. This study provides ethnographic insights into the tension between safety and production demands and its impact on safety performance.

Keywords: production pressure; safety; activity theory; accidents

INTRODUCTION

Most construction firms often emphasise safety as a key priority as they expect their workers to return home safely from work unhurt or uninjured. However, the construction industry is still considered one of the high-risk industries in terms of accidents and injuries, particularly in developing countries (Hämäläinen, 2017). Safety management has been characterised as competing with other project goals, such as production in the construction industry. Production pressures are widespread in most construction projects as clients often want their projects to be completed within short time frames, and contractors also want to maximise profit in the execution of the works. This often leads to the development of unrealistic and tight construction programmes. Also, the consequences of not meeting contractual timelines are often severe, affecting the client, contractor's profitability, and reputation. Hence, most projects are faced with pressures on production demands during their execution. However, these production pressures are considered key contributors to accidents in the construction industry (Oswald *et al.,* 2019, Hashemian

[1] b.acheampongtwum@pgr.reading.ac.uk

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and Triantis, 2023). Construction accidents have serious reputational, financial, social and legal implications for clients and contractors (Oswald *et al.,* 2020). Research indicates unsafe practices contribute to about 80% to 90% of construction accidents (Guo *et al.,* 2016). Although it has been established that unsafe behaviours cause most of these accidents, studies reveal that project and managerial factors affect unsafe work behaviour. Oswald *et al.* (2019) posit that although production pressures are widespread in construction projects, there is limited understanding of the construction practices used when projects face such pressures and their impact on safety. This study is focused on the practice of managing production pressures and their effects on safety performance.

LITERATURE REVIEW

Production pressures are widespread in many working industries, such as transportation (e.g., aviation, railway), healthcare (e.g., anesthesiology, nursing), manufacturing, and construction (Hashemian and Triantis, 2023). Different terminologies such as schedule pressure, efficiency pressure, work pressure, deadline pressure, productivity pressure, performance pressure and time pressure are also used to denote production pressure. In this paper, the label of production pressure is adopted.

Different researchers have also defined the concept of production pressure in literature. For example, Nepal *et al.* (2006) described production pressure "as the induced demand perceived by individuals or workgroups to perform their work within a given time frame" (p.182). Probst and Graso (2013) also conceptualised production pressure as "organisational demands to attain operational goals to increase organisational profit and /or efficiency" (p.581). Although there are different views on what production pressure means, induced pressure to achieve production goals is a common theme underpinning these definitions. In this paper, production pressure is defined as the pressures from production demands which result from critical delays or an early voluntary project completion ahead of the contractual deadline by clients or contractors.

In the construction industry, production pressure is considered to manifest during the onsite execution stage of a project (Mohammadi and Tavakolan, 2019). In literature, studies highlight contributing causes of production pressures such as tight construction programmes (Han *et al.,* 2014, Neale and Gurmu, 2021), rework (Yap *et al.,* 2020) and management-related issues (Mohammadi *et al.,* 2018; Yap *et al.,* 2020). Production pressure is considered an ingrained challenge in the construction industry.

The Tension Between Production and Safety Goals in Construction Projects

Despite the increased understanding of the essence of prioritising safety at the workplace (Sousa *et al.,* 2021), literature still indicates operations management is often ranked over safety (Hasle *et al.,* 2021) or "safety often loses the battle when a trade-off is required with project costs'' (Oswald *et al.,* 2019, p.1). In the construction industry, the decline in safety performance can be attributed to the industry's labour-intensive nature, where productivity enhancement is often based on labour efficiency (Dozzi and Abourizk,1993). Han *et al.* (2014) applied system dynamics and investigated how production pressure impacts safety performance on a construction project in Canada. They found that rework and schedule delays were the critical managerial factors that led to accidents. In a similar study, Mohammadi and Tavakolan (2019) also utilised system dynamics and studied how production pressure impacts safety performance on a project in Iran. The authors also found that production pressure impacts safety performance through rework and worker fatigue.

Other studies have also investigated the impact of production pressures on workers' safety behaviour. Guo *et al. (*2016) developed an integrative model of construction workers' behaviour and evaluated it in New Zealand. They found production pressure as a critical factor influencing safety participation, motivation, knowledge and compliance. Although these studies provide an understanding of the impact of production pressures on safety, they are based on causal relationships and variables of interest, which do not offer in-depth insights into the phenomenon. An ethnographic study by Oswald *et al. (*2019) provided richer insights on the phenomenon than just determining their causal relationship. The authors unpacked the construction practice that occurs when a project faces production pressure and its impact on safety in the UK. They found covert, informal piece rate strategies were used by the site managers. Workers were incentivised with extra income and rest breaks for early completion of their tasks in meeting schedule demands. This study, however, focused on informal management practices and did not study how formal and informal practices interact and their effect on safety practices.

Activity Theory-Theoretical Approach for the Study

In this paper, activity theory, a practised-based approach and an epistemological framework is adopted as the theoretical approach for the study. As a practice-based approach, activity theory allows the phenomenon to be analysed in its systemic context and the change process. The theory considered a multi-disciplinary framework was first developed from the works of Lev Vygotsky in the 1920s. Vygotsky's work was based on Karl Marx's integrated perspective of work (Roth and Lee, 2007). The central idea of Vygotsky's work was that there was no direct interaction between humans and their environment, but their relationship was mediated through conceptual and material tools (Vygotsky, 1978).

Activity theory has gone through four generations of development. Lev Vygotsky's artefact mediation action is considered the first generation of activity theory. The second generation of activity theory was developed by Leontiev in 1978, who introduced the concept of collective activity. He conceptualised activities as a well-structured and object-oriented system. Engeström, in 1987 further developed the ideas of Leontiev and expanded the unit of analysis from individual to collective activity system focus. He developed a triangular model (Figure 1) which depicts elements such as subject, object, tools, rules, community, division of labour and outcome. In the triangular model, the subject (actor or actors who are executing the activity), with the help of tools (mediating artefacts), transforms an object (motive of activity) into an outcome (realisation of activity). The subjects who are members of the community (actors involved) actions are also guided by rules (norms and conventions governing the completion of the activity) and division of labour (distribution of roles and responsibilities). The third generation of the theory is also a further development by Engeström in 2015, who introduced the concept of interactivity. This comprises joint activity systems where the unit of analysis is the object of the two interacting systems. Engeström and Sannino (2021) developed the theory's fourth generation. It is based on Spinuzzi's (2019) argument that organisations and work currently operate in an unstable and poorly bounded environment, making the third-generation theory inapplicable in events with unstable stakeholders. The proposed unit of analysis is the merged cycle of expansive learning in a critical societal challenge.

Activity theory's fundamental principle is based on the concept of contradictions which provides an approach to understanding work activities (Engeström, 2001). Contradictions manifest as the breakdown of activities or events that result in problems (Engeström, 2001, Gade *et al.,* 2019). Contradictions in an activity system manifest in four types. Primary contradictions occur within an element in an activity system; secondary between elements; tertiary between an existing activity and a more advanced one; the quaternary occurs between an activity and a neighbouring one (Engeström, 1987). When such challenges and problems arise from contradiction, they need to be managed or resolved so they do not impact the desired outcome of the activity (Van Berg *et al.,* 2021).

Activity theory explores situated practice and has been applied by several construction management researchers. For instance, it has been used to study BIM implementation in construction (e.g., Van Berg *et al.,* 2021, Akintola *et al.,* 2020, Gade *et al.,* 2019). Other researchers have used activity theory to study partnering in road maintenance contracts (Hartmann and Bresnen, 2011) and studying environmental management and project practice (Gluch and Raisanen, 2014). In this study activity theory framework will be applied to explain how managing production pressures impact safety practices on a construction project.

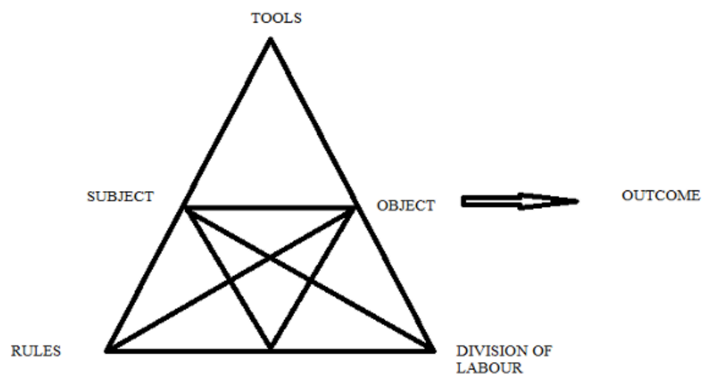

Figure 1: Activity system model, adapted from (Engeström, 1987).

METHOD

In construction management research, ethnography is considered an approach that provides valuable insights (Pink *et al.,* 2012). O'Reilly (2008) also posits that when a research question is exploratory, ethnographic methods provide an approach to exploring how reality is produced through interaction and everyday social experiences. An ethnographic case study approach was adopted to explore how disparate project team members use the contract and programme when confronted with production pressure incidents. Data for the study was collected from a large building project in Accra, the capital of Ghana. The project was a public sector one which involved demolishing existing structures and the construction of a new ten-storey office complex with a two-level basement parking space. The project started in 2020 and was expected to be completed in 2022. A large Ghanaian privately owned construction firm was executing the project. A large firm was selected for the field study as they are considered to demonstrate good safety performance and have the resources to implement good safety management systems compared to the smaller firms (Sunindijo, 2015). Most large construction firms in developing countries engage small and medium-sized construction firms as subcontractors in the execution of their projects.

The fieldwork was conducted for three months, from April to June 2022, where observational fieldnotes, semi-structured interviews and project documents were collected. Access to the project was negotiated through a former university colleague who worked as a project manager for the principal contractor on the project. I negotiated access as a safety and health intern of the health, safety and environment team. An overt moderate participant-observer approach was adopted where the study participants were made aware that I was studying safety. A total of 288 hours of observations of site activities, production and safety meetings were collected. In addition to the observations, seven (7) formal and seven (7) informal interviews were conducted with managers and workers. Document review of contract documents, programmes, designs (architectural and structural), production meeting minutes, safety policy documents, safe work method statements and reports were also conducted.

Data analysis consisted of coding and theoretical redescription. The data were divided into smaller chunks and linked to the characteristic elements of activity systems and their contradictions "in order to consolidate meaning and develop explanation" (Saldana, 2016, p.9). The concepts of the activity system model were assigned to parts of the data.

Production Pressure Incident

During the superstructure concreting works stage, the contractor experienced a critical delay which resulted in the emergence of production pressure. This resulted from the civil works subcontractor's deliberate halt in site production activities due to increased materials prices. The critical delay can be seen as a contradiction in the superstructure concreting works activity system. The disturbance, in turn, manifested as a secondary contradiction in the superstructure concreting works activity system. This can be interpreted as a contradiction between Rule (delayed superstructure concreting activity duration) vs Object (superstructure concreting works). This production pressure incident occurred onsite before my fieldwork started, so the narratives are based on retrospective accounts by the informants and a review of project documents.

Managing the Emerged Production Pressure

The project team agreed on a formal adaptive practice of production acceleration where a revised programme (tool) was developed using the activity crashing technique. The strategy of acceleration was agreed to be working two shifts. Additional labour, machinery and equipment were also hired. In addition to the formal adaptive practice, an informal accepting practice was also introduced onsite. Productivity target incentives were negotiated with the workers for early completion of their tasks. This quote reveals how this incident was managed on-site.

> We had to accelerate site production to be able to meet the timeline for the client. In the acceleration, we looked at deploying more workers.... and more resources in general. With acceleration, you can deploy more workmen and equipment... but if your procurement is not in tune with your programme, you'll still fall short. As your workmen will come, the other resources will not be present on site... so you'll not get the production the way you wish. So, putting the resources in place... we still tied it to getting procurement in tune with it to be able to achieve that. In terms of the practices

> adopted... we had to work two shifts and run some activities in parallel (Project manager, contractor).
>
> There were two key areas that we needed a lot of cooperation from the workforce... in the area of carpentry and steel bending works. So, we instituted some incentives... where we agreed on some targets for some number of days if they met it, it came with monetary compensations for them (Project manager, civil works subcontractor).

The Emergence of Additional Contradictions

The site managers relaxed safety rules and practice compliance on-site to achieve production targets. This impacted the project's safety climate, resulting in many unsafe practices leading to accidents. Two new contradictions emerged in the activity system resulting from the lack of strict compliance with safety rules during the period. The first was a primary contradiction between formal safety rules onsite and the introduction of informal safety rules during the production pressure period. This contradiction can be interpreted as formal Rule (strict enforcement of safety rules) vs informal Rule (laxity in safety rules enforcement). The second emerged contradiction was a secondary contradiction Community (client consultants, client reps., contractor's team) vs Rules (non-enforcement of safety rules and compliance) vs Subject (civil works subcontractor's team). The community in an activity system are responsible for ensuring the subjects adhere to the rules governing how to execute the object. For example, the client's team are responsible for ensuring the subject (contractor) always complies and adheres to safety rules and practices on the project. The contractor is also responsible for ensuring their subcontractors always comply with safety rules and practices. However, the community did not conduct this enforcement approach. The two contradictions are modelled in Figure 2.

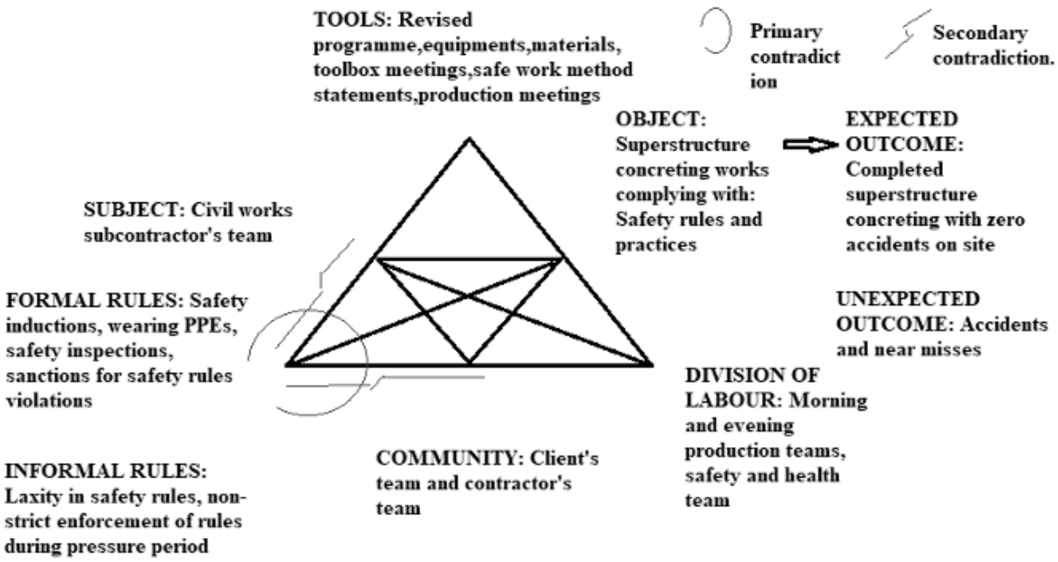

Figure 2. Evolved superstructure concreting activity system model showing the primary contradiction (formal safety Rules versus informal safety Rules) and secondary contradiction the non-enforcement of the project safety requirements during the pressure period by the community (client team and main contractor).

Safety rules and practices were strictly complied with during normal production periods on site. However, this practice changed during the production pressure period. This quote explains the laxity in the onsite formal safety rules and procedures during the production pressure period.

> "There are punitive measures that have been instituted for violating safety practices and rules. On the contrary, because I'm target driven if we find a culprit... I will rather use a different approach. If it was a normal production, the sanction is dismissal. But because we're moving under a target, if I lose one or two team members because of their non-compliance in a certain way, it'll affect me. So, I did compromise on the punitive measures just to keep the person to work" (Project manager, civil works subcontractor).

This was confirmed by one of the carpenters on the project:

> When there was production pressure on site, I remember we were working on the eighth floor on the scaffold... and I was not wearing my safety harness, but I was allowed to work. Although the managers knew it wasn't safe.... but they didn't say anything about it (Carpenter, fieldnotes, April 2022).

This led to many unsafe practices on site, leading to several accidents and near misses. The community (contractor and client's team) also relaxed in their strict enforcement of safety rules compliance during the production pressure period. However, after recording safety incidents, they adopted reactive strategies to prevent future accidents.

> So, after the incidents, we investigated the cause of the accidents. After we did re-induction and training for all the workers. We also re-emphasized toolbox talk on the activities they were undertaking. Also, we reviewed our safety systems of monitoring and supervision... as to see how best we can prevent future incidents (Project manager, civil works subcontractor).

> The target for safety was zero accidents... so the client became alarmed with the number of accidents that were recorded during the period. So, they hinted at certain steps they wanted to take to ensure strict health and safety compliance. The decision was to engage an external safety compliance team.... and transfer the cost to us. This was going to affect our profit... so we assured them we were going to ensure strict compliance at all times. So, to ensure strict compliance... the consultant's team paid regular unannounced visits to the site during the night shifts (Project manager, contractor).

This quote reveals the reactive approach adopted by the client and contractors after the recorded safety incidents during the production pressure period.

The critical delay disturbance that emerged as a contradiction in the superstructure concreting works activity system was managed collaboratively by the project team. However, their production-centred approach adopted during the period negatively influenced the worker's safety behaviour on site. This resulted in a systemic contradiction between adhering to formal safety rules and the informal safety rules introduced, leading to unsafe practices. However, the number of accidents that occurred during the period propelled the project team to balance the production and safety goals on site. This provided a learning opportunity, where accident investigations were conducted and re-training of the workers. Also, revised safety monitoring systems and supervision approaches were adopted to prevent future accidents.

DISCUSSION

The insights from the study revealed that production was prioritised over safety despite the construction project organisation's rhetoric that safety is a priority. This confirms the findings of prior studies in the literature (Oswald *et al.,* 2019, Jia *et al.,* 2019). The prioritisation of production over safety during the period influenced the workers' safety behaviour as management focused on meeting production targets. This led to many unsafe work practices during the period leading to accidents. The formal adaptive practice of production acceleration adopted reduced the duration for the execution of the activity. Also, the informal accepting practice of negotiating early task completion targets with the workers gave them an opportunity for safety shortcuts as faster task completion rates came with monetary rewards. This finding confirms Mullen's (2004) argument that workers will always compare the positives (e.g., money) against the negatives (e.g., potential safety risk) and will commit unsafe acts because they are rewarded for doing so.

CONCLUSION

Production pressure is widespread in most construction projects and is a major contributor to accidents. This study contributes empirically to the body of knowledge on how disparate project teams engage with the contract and programme when confronted with the phenomenon. The adopted strategy for this project in managing the production pressure incident was formal adaptive and informal accepting practices. The two practices adopted were collaboratively deliberated and agreed on by the project team before their implementation. The adaptive practice of production acceleration and the acceptable practice of early task completion targets with the workers were all geared towards recovering from the critical delay incident. However, the strategy and practices adopted prioritised production over safety despite the client's project objective of having zero accidents. Also, despite the construction project organisations' rhetoric that safety was a priority, this changed when the production pressure incident emerged.

The construction industry's challenge is that while it often claims safety is the top priority, ensuring safety even during production pressure periods is a big challenge. This study provides insights into the formal and informal practices associated with recovering from a production pressure incident and its impact on safety performance. Construction clients have an influential position in helping improve safety performance in the construction industry in developing economies. As we are constructing the future for a more sustainable construction industry, we must also improve safety performance by eliminating or reducing unsafe work practices. Achieving zero accidents in construction, especially in developing countries, should be prioritised by clients and policymakers. Enforcing strict adherence and compliance with safety rules and standards, even during periods of production pressure, is achievable when the client prioritises it in the contract administration process, just like quality. Construction practitioners, clients and policymakers are morally obligated to protect workers' safety and well-being.

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FACTORS INFLUENCING DFS ADOPTION: THE CASE OF MALAYSIAN CONSTRUCTION ORGANISATIONS

Che Khairil Izam Che Ibrahim[1], Patrick Manu[2], Sheila Belayutham[3], Clara Cheung[4], Mazlina Zaira Mohamad[5], Akilu Yunusa-Kaltungo[6], Shafienaz Ismail[7] and Azman Hussain[8]

[1,3,5,7] *School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, Malaysia*

[2] *FET - Architecture and the Built Environment, University of the West of England, Frenchay Campus, Coldharbour Lane, Bristol BS16 1QY, UK*

[4,6] *Department of Engineering Management, School of Engineering, The University of Manchester, MECD Campus, Manchester, M13 9PL, UK*

[8] *Department of Occupational Safety and Health, Ministry of Human Resources, Malaysia*

Despite the introduction of the Occupational Safety and Health in Construction Industry (Management) (OSHCIM) guidelines in 2017, little is known about the factors contributing to Design for Safety (DfS) adoption in the Malaysian construction industry. Previous studies have identified three main groups of factors for DfS implementation - organisational factors, industry related factors and external factors. To understand the DfS factors in the local Malaysian context, a gap analysis was conducted through an online questionnaire survey during four series of DfS webinars. The findings suggest that legislation, guidelines, training, client influence, and incentives were among the top five significant factors identified by construction organizations. This indicates that a strong regulatory and educational framework is crucial in promoting DfS. The study also found that different types of organizations may prioritize different factors in adopting DfS practices based on their specific needs and motivations. Understanding these factors would enable key duty holders to manage DfS more effectively throughout project lifecycles. This research contributes to the discourse on the promises of DfS as a preventive practice to improve safety and health performance in the Malaysian construction industry.

Keywords: Design for Safety; organisation; occupational safety; Malaysia

INTRODUCTION

In recent years, the topic of Design for Safety (DfS) has been progressively explored in construction literature, owing to the emergence of new regulations that govern construction practices across the world (Che Ibrahim *et al.,* 2022a; Jin *et al.,* 2022). DfS has been approached in various ways, for instance as a legal requirement, with Safe Design in Australia and New Zealand, and Construction Design and Management (CDM) in the UK as notable examples. It has also been adopted as a guideline on a non-mandatory or voluntary basis, such as Occupational Safety and Health in

[1] chekhairil449@uitm.edu.my

Ibrahim, C K I C, Manu, P, Belayutham, S, Cheung, C, Mohamad, M Z, Yunusa-Kaltungo, A, Ismail, S and Hussain, A (2023) Factors Influencing DfS Adoption: The Case of Malaysian Construction Organisations *In:* Tutesigensi, A and Neilson, C J (Eds) *Proceedings of the 39th Annual ARCOM Conference,* 4-6 September 2023, University of Leeds, Leeds, UK, Association of Researchers in Construction Management, 237-246.

Construction Industry (Management) (OSHCIM) in Malaysia and Guidelines for addressing occupational hazards and risks in design and redesign processes in the United States. Regardless of its terminology, DfS is widely recognised as a practice that promotes occupational safety and health (OSH) outcomes (Karakhan and Gambatese, 2017), and it enables organisations to ensure optimal consideration of OSH in their design processes (Hardison and Hallowell, 2019; Che Ibrahim *et al.,* 2020)

Despite a significant body of literature on Design for Safety (DfS) that addresses ways to make it more acceptable to academic, practitioners, and decision makers in various dimensions (e.g., practical, education), the factors and barriers that affect its effective implementation are still a major concern (Umeokafor *et al.,* 2022). The literature suggests that certain factors, such as external factors (e.g., legal, economic, and education), industry related factors (e.g., contract, and project delivery), organisational factors (e.g., interest, training and development, collaboration), and individual factors (e.g., knowledge, and awareness), could influence and inhibit the uptake of DfS. However, it is often unclear whether the proposed factors and barriers are valid within different contexts (e.g., regulated, or voluntary basis, and different geographical settings). For example, a recent study by Umeokafor *et al.,* (2022) investigated DfS barriers in Nigeria and found that the domestic context has a significant impact on sustainable DfS growth. Another study by Che Ibrahim *et al.,* (2022b) suggested that due to recent OSHCIM guidelines in Malaysia, continuous engagement in DfS activities could improve DfS learning.

Overall, it is apparent that developed countries such as the UK, USA and countries in the European Union have a considerable amount of research and practice in the subject of DfS (Manu *et al.,* 2021). However, DfS concepts are still at an early stage in many developing countries, including Malaysia. Recently, there have been significant improvements to Malaysia's existing OSH guideline framework to incorporate DfS principles, known as OSHCIM. Although this framework is new to the industry, it is important to understand what factors can facilitate the implementation of DfS. Unfortunately, no quantitative studies have been conducted in Malaysia that capture these factors. To address this gap in the current DfS knowledge, the objective of this study is to examine the factors that influence DfS implementation across different types of organisations. A more in-depth understanding of these DfS dimensions can help duty holders and stakeholders make informed decisions about DfS readiness and diffusion, thereby minimising negative impacts, and improving resource efficiency towards safety and health outcomes. In addition, an understanding of the DfS implementation across different organisational types could provide insight in formulating holistic and targeted strategies and interventions for successful future implementation.

Related DfS Studies in Malaysian Context

DfS research in Malaysia has been on the rise in recent years, largely due to the implementation of OSHCI(M). The focus of these studies has been on assessing the preparedness and understanding of stakeholders regarding DfS. For example, Che Ibrahim and Belayutham (2020) examined the knowledge, attitude, and practices of civil engineers on DfS guidelines, finding that factors such as education and training, industry related factors, and organisational factors were crucial for advancing their knowledge, attitude, and practice (KAP). Che Ibrahim *et al.,* (2021) analysed the extent of DfS education in civil engineering programmes at seven public universities in Malaysia and discovered that it was virtually non-existent. Ismail *et al.,* (2021) further used Che Ibrahim et al.'s (2020) designer DfS competence framework to survey 85 construction-related designers on their perception of DfS competence. The study found that knowledge-based attributes, design and construction experience, hazard-related skills, and collaboration skills were the primary attributes required for effective DfS practice. Che Ibrahim *et al.,* (2022a) expanded on the validity of DfS competencies by comparing them across three developing countries, namely Malaysia, Nigeria, and South Africa. The study identified a common pattern in these countries whereby designers possessed basic knowledge, skills, and experience in DfS but lacked the ability to analyse, synthesise, and evaluate advanced characteristics of DfS competence, especially regarding experience and skills. Christermaller *et al.,* (2022) found limited association between the implementation of DfS practices and designers' professional body membership or the size of their organization, but DfS awareness and training were associated with greater implementation. DfS education, client influence, and legislation were identified as key factors affecting DfS implementation. Che Ibrahim *et al.,* (2022b) suggested that creating a culture of shared DfS learning and continuous engagement in education and training could improve DfS learning. Che Ibrahim *et al.,* (2022c) conducted a recent study in which they utilised the established designer DfS competence framework to create an index based on 18 critical attributes and their corresponding weights. This index has the potential to serve as a means for clients, designers, or design organisations to conduct an initial evaluation of designers' DfS competence in construction. Despite the increasing attention on DfS in Malaysia, limitations in understanding what influences successful DfS implementation remain elusive. This information could be useful in meeting Malaysia's OSHCI(M) requirements and improving DfS implementation.

Factors Influencing DfS Implementation

This discussion is focusing on the various factors that influence the diffusion of DfS in the construction industry. A set of key factors influencing the adoption of DfS covering the three main domains; external factors, industry related factors and organisational factors was identified through the literature review exercise. The main factors identified include the availability of digital applications, early education of stakeholders, institutional pressure, practical guidelines or code practices, the recognition of DfS benefits from clients, new coordinating role in DfS management, incentives and funding from governments, and innovative contractual and procurement approaches.

The availability of digital applications such as Building Information Modelling (BIM) has been found to have a positive link with DfS, especially in visualising the construction process model to assess safety hazards (Zhang *et al.,* 2015). Early education of stakeholders has also been identified as a key factor in DfS diffusion as the significant gap in knowledge and skills among designers necessitates the need for formal education at an early stage to establish the foundation of safety knowledge (Toole, 2017; Che Ibrahim *et al.,* 2021).

Institutional pressure through legislation is another factor that greatly influences the adoption of DfS. The need for practical guidelines or code practices, specific guidance, or code of practice that focuses on the activities and interaction during design can improve the lack of safety experience and competence among existing designers in the industry (Morrow *et al.,* 2016). The recognition of DfS benefits from clients has also been identified as an important factor influencing DfS as proactive owner leadership is crucial to initiate DfS as well as to monitor the DfS expectation in the design review process (Tymvios and Gambatese, 2016).

Innovative contractual and procurement approaches have also been considered to enhance DfS implementation (Gambatese 2019). Efforts to promote DfS should also be one of the driving factors towards ensuring the effective DfS implementation. Wider communication efforts could influence owners and other duty holders on the awareness as well as enhancement of the technical skills and collaboration needed to perform DfS successfully (Karakhan and Gambatese, 2017). Incorporating DfS education into curricula at an early stage, as well as establishing one-stop centers for DfS education materials, can also facilitate the wider communication of DfS.

Earlier research has emphasised the significance of utilising tools and resources in the process of designing for safety. The incorporation of an array of qualitative and quantitative tools, in addition to various resources such as educational and design materials, can play a critical role in educating and informing designers about DfS solutions (Gambatese *et al.,* 2007). Digital technologies and resources like design guidelines, checklists, and best practices can also offer an innovative and valuable means for designers to consistently apply DfS principles (Tymvios, 2017; Poghosyana *et al.,* 2020).

METHOD

To gain a comprehensive understanding of the contextual factors that contribute to DfS implementation in Malaysia, a quantitative methodology was employed using a questionnaire survey. This method facilitates rapid gathering of information from a variety of stakeholders on specific characteristics (Fellow and Lui, 2015). To administer the survey, a questionnaire was designed using the SurveyMonkey platform and was made available to multiple stakeholders during four online DfS webinars held in 2022. The webinars were utilised as a platform for data collection as they facilitated greater interaction with participants who share a common domain and helped to establish expectations regarding DfS implementation (Ørngreen and Levinsen, 2017).

The questionnaire consisted of two sections. The first section aimed to gather demographic information from the respondents, while the second section assessed the level of importance of factors for DfS implementation. The level of importance was assessed using a five-point Likert-scale (ranging from 1 = not at all important to 5 = extremely important).

Over the four series of the webinars, a total of 871 participants (with an average of 125 per session) participated in the webinar. The initial invitation was sent to over 150 potential respondents through an industrial network of experts that have previously attended OSHCIM workshops and seminars. Out of the 871 potential respondents, 389 responses were received and 347were useable responses. The number of useable responses is considered appropriate when compared to the number of responses from other DfS studies (e.g., 33 responses reported in DfS studies in Saudi Arabia (Hassanain *et al.,* 2022) and 89 responses reported in DfS studies in Malaysia (Che Ibrahim *et al.,* 2022b).

Descriptive statistical analysis, including the mean and frequencies, was applied to the obtained data in Microsoft Excel and executed in IBM SPSS 26 Software. Inferential analysis was also used to ascertain variations in DfS factors across organisations.

Out of the 347 responses received, 68.9% were male and 31.1% were female. On average, the respondents had 15 years of experience in the construction industry. In terms of their organisations, 37.5% identified as contractors, 21.3% as government agencies, 26.2% as consultants, and 15.0% as developers/owners. Notably, 41% of the respondents were registered professionals (such as professional engineers, architects, surveyors, and technologists) under their respective professional bodies.

FINDINGS

Factors influencing DfS implementation

The table provides results on the factors that influence Design for Sustainability (DfS) implementation in organisations, based on the mean values and standard deviations for each factor. The study surveyed a total of 347 participants from four different organisations (G1 = consultant, G2 = contractor, G3 = government agencies, and G4 = developer/owners), with each organisation consisting of a different number of participants (n=91, n=130, n=74, and n=52, respectively).

The factors examined in the study are: (1) availability of digital software applications for DfS, (2) professional development training relating to DfS, (3) industry guidelines/practical guidance or codes for DfS, (4) introduction of legislation relating to DfS, (5) clients' motivation relating to DfS implementation, (6) inclusion of DfS lessons in formal education, (7) introduction of DfS coordinator in every project, (8) establishment of contractual agreement that embraces DfS, (9) more collaborative project delivery, (10) more outreach and communication efforts on DfS, (11) government should provide incentives for companies, and (12) a simple and effective tool for facilitating DfS practice.

The mean values for each factor range from 3.877 to 4.078, indicating that participants generally believe that all of these factors are influential for DfS implementation. However, there are some variations in mean values across the different groups, with developer/owners consistently having the highest mean values for each factor, followed by government agencies, consultants, and contractors. This suggests that developers/owners and government agencies may have a greater interest or knowledge in DfS compared to consultants and contractors.

Upon further analysis, it was found that among the consultants, the highest mean values (above 4.000) were for guidelines, legislation, client influence, and DfS education. This suggests that consultants consider these factors to be the most important for DfS implementation. This also indicates that consultants are influenced by external factors, as these factors provide a systematic framework and clear mandate that could help ensure the sustainability of DfS practices being integrated into the design process (Che Ibrahim *et al.,* 2021; Adaku *et al.,* 2021). Additionally, enhancing DfS principles through education is also important as it can improve the knowledge, skills, and experience of future designers prior to working experience (Toole, 2017). The least influential factors for consultants are DfS coordinator, outreach, and digital application. This may be because consultants might not have direct involvement in the planning and project execution phases (depending on the project delivery method) as well as the fact that the adoption of digital technology such as BIM is still gathering pace within the local industry (Sinoh *et al.,* 2020), limiting their applicability towards facilitating the DfS practice.

For contractors, the highest mean values are for incentive, contractual, digital application, and guidelines. It is well acknowledged that contractors are often motivated by financial incentives and such external economic incentives can increase an organisation's motivation to implement DfS practices. These incentives could come from local agencies acting as intermediaries, in addition to being provided at the national level, to encourage greater efforts in DfS (Karakhan and Gambatese, 2017; Che Ibrahim *et al.,* 2022b). Contractors are typically responsible for the physical construction of a project and may view contractual agreements as a set of requirements that they must comply with to avoid legal and financial penalties. They may also have more insights about the day-to-day challenges of implementing safety measures on a construction site and may therefore have keen interests on how the digital application impacts safety in practice.

Table 1: The responses on the factors influencing DfS implementation

Factors	Overall Mean	Mean values for each organisation				Standard Deviation	Significance (p)
		G1	G2	G3	G4		
	(n=347)	(n=91)	(n=130)	(n=74)	(n=52)		
Digital application for DfS	3.891	3.769	3.777	3.96	4.058	0.766	0.056
Professional development training	4.042	4.011	3.923	4.041	4.192	0.745	0.171
Guidelines / code of practice	4.072	4.121	3.908	4.068	4.192	0.778	0.077
Legislation	4.078	4.132	3.863	4.068	4.25	0.786	0.008
Client's influence	4.044	4.066	3.908	4.027	4.173	0.817	0.207
DfS education	3.993	4.055	3.846	3.878	4.192	0.816	0.045
DfS coordinator	3.892	3.879	3.823	3.77	4.096	0.815	0.117
Contractual	3.993	3.978	3.9	3.959	4.135	0.816	0.465
Collaborative procurement	3.881	3.912	3.738	3.797	4.078	0.772	0.121
Outreach for DfS engagement	3.877	3.912	3.808	3.824	3.962	0.758	0.674
Incentive from Government	4.013	3.956	4	3.865	4.23	0.866	0.124
DfS tool	3.946	3.934	3.815	3.919	4.115	0.782	0.133

Among the government agencies, the highest mean values are for legislation, guidelines, client influence, and digital application. It is argued that institutional pressure, driven by local authorities, is a necessary mechanism to enhance the implementation of DfS in a country. This can help ensure compliance with safety regulations and promote a culture of safety within the construction industry (Che Ibrahim *et al.,* 2020; Manu *et al.,* 2021). Additionally, they place relatively high importance on client influence, indicating that they are aware of the importance of client's commitment in DfS initiatives. This is supported by several studies where clients provide the greatest motivation for organisation to practice DfS (Goh and Chua, 2016; Gambatese *et al.,* 2017).

For developers/owners, the highest mean values are for legislation, incentive, guidelines, and training. Similarly, for contractors and government agencies, having a legal mechanism to frame the DfS ecosystem is significant, and industry-based guidelines could overcome barriers to the adoption of DfS practices, such as a lack of knowledge or awareness of the benefits of DfS. Specific incentives and training are also seen as important to ensure continuous DfS adoption and improvements. By providing organisations with the right incentives and training, they can create a culture that values safety and prioritises safety during the design process, thereby keeping up with ongoing improvements and changes in safety regulations and standards (Morrow *et al.,* 2016). The least influential factors for developers/owners are outreach and collaborative procurement. This could be due to their limited role in decision-making for procurement and outreach and dissemination activities.

The standard deviations for each factor range from 0.745 to 0.866, indicating that there is some variability in the responses for each factor. The factors with the highest standard deviations are "incentives" and "DfS tool", suggesting that there may be differing opinions on how best to motivate organisations to implement DfS and what tools are most effective.

Upon further analysis with ANOVA test to examine the differences in perceived importance of the DfS factors across the four groups of organisations (see Table 1), it was found that there was no statistical difference between the 10 factors ($p>0.05$) except for two factors i.e., legislation ($p = 0.008$) and DfS education ($p = 0.045$). Where significant differences were found, pair-wise comparisons were performed using the Post-hoc Test. Further investigation showed a statistically significant difference in the attribute of legislation ($p = 0.013$, $p \leq 0.05$) and DfS education ($p = 0.047$, $p \leq 0.05$) between contractor and developer/owner. This suggests that contractors and developers may have different opinions on implementing DfS practices due to their different roles and responsibilities as well as perspectives and priorities in delivering the project. Contractor may view DfS as an additional cost and an impediment to project completion. They may also feel that they already have adequate safety measures in place, and that DfS would simply add unnecessary bureaucracy and paperwork. On the other hand, developers are responsible for the overall design and planning of the project. They are concerned with ensuring that the project meets all relevant regulations and standards, including safety standards. Developers may view DfS as an essential element of the design process, ensuring that safety is built into the project from the onset. While contractors may have more direct experience with construction practices, developers bring a broader perspective on safety standards and regulations.

Overall, the results can be used to identify areas of improvement as well as those areas that represent strengths for individual organisations. For example, developers/owners place the highest value on legislation, guidelines, and incentives, indicating that they are more likely to invest in safety measures and comply with regulations. Meanwhile, contractors have relatively low mean values for collaborative procurement and outreach, indicating a need for more effort in these areas to increase collective efforts towards DfS. Similarly, government agencies have lower mean values for DfS coordinator and collaborative procurement, indicating a need to focus more on innovative approaches to establish governance and frameworks for DfS implementation.

CONCLUSIONS

This study has provided an overview of the factors influencing the implementation of DfS from a Malaysian construction organisation's point of view. The most important factors that influence the implementation of DfS were adequately captured via questionnaire surveys during four separate DfS webinars with four different types of organisations within the construction industry. Overall, the results suggest that while guidelines, legislation, and training are important factors for driving DfS practices across all types of organisations, there are nuanced differences in priorities depending on the organisation's role in the construction process. There are variations in mean values across different groups, with developer/owners consistently having the highest mean values for each factor, followed by government agencies, consultants, and contractors.

Overall, the consistency of the responses suggests that different types of organisations may prioritise different factors in adopting DfS practices, based on their specific needs and motivations. It is important to understand these differences to develop effective strategies for promoting, implementing, and monitoring DfS practices across different sectors.

The study confirmed the key factors that influence DfS, which were previously reported in the literature, within the context of developing countries. Such understanding could provide Malaysian OSH regulators (e.g., DOSH) with the basis to align the existing OSHCIM guidelines with the identified factors, enabling clear expectations, standards, and incentives for organizations to adopt and integrate DfS practices into their operations. Furthermore, related OSH training and research institutions could align their funding priorities with the identified factors. These factors could also serve as a basis for inclusion in related engineering or built environment educational curricula.
Although there were some limitations, such as unequal sample sizes, future research could broaden the scope of the study to include a larger sample size and explore a variety of organisational disciplines, such as architecture, civil and structural engineering, mechanical engineering, electrical engineering, and quantity surveying. Additionally, incorporating qualitative data (to achieve a mixed approach) could provide more insights into how and why these factors are more peculiar to certain types of organisations during their adoption of DfS.

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AN ILLUSTRATIVE CASE STUDY OF WORKAROUND AND ITS EFFECTS ON CONSTRUCTION SITE SAFETY IN SOUTH AFRICA

Fidelis Emuze[1]

Department of Built Environment, Central University of Technology, Free State, Private Bag X20539, Bloemfontein, 9300, South Africa

A workaround implies that a rule known to be correct has become an obstacle. A workaround is expedited to resolve a problem with obsolete rules or to create a problem by violating rules (cutting corners). In both scenarios, a workaround is a form of violation. This paper aims to depict workarounds, their frequency, and their impact on rule-related behaviours of workers in the frontline of construction. On-site interviews were used to collect data for the study. The interviewees answered questions based on lived experiences on construction sites. Data analysis showed that the 'workaround' - the practice of reconsidering rules that are incompatible with a task - was common and accepted on the three construction sites. Operatives who were interviewed resorted to workarounds whether the task was covered by appropriate rules (good rules), obsolete rules (bad rules), or where the task was not covered by a rule (no rule). The effect is an incorrect but rewarding violation, which is dangerous because it is habit-forming. In future, negative habit-forming through unrestricted workarounds should be discouraged in construction.

Keywords: construction site; rule behaviour; safety rule; workaround; South Africa

INTRODUCTION

Several viewpoints and perspectives exist regarding ‘workaround’ or improvisation. Workarounds might occur when unwieldy processes seem slow, when technology is faulty or malfunctioning when information about ideal procedures is not available, when circumstances constrain performance, when resources are scarce, and when people feel encouraged to bypass or undermine processes or decision criteria mandated by management (Alter 2014). Workarounds could be perceived as safety violations and unethical, questionable, and undesirable procedures, depending on the context. They can also be perceived as ways of resolving problems if specified rules are unsuitable for a task to be expedited. For example, workarounds can be executed to reduce the destructive impact of an unplanned task. Nevertheless, they are deviations from rules or procedures taken to navigate bottlenecks to make tasks easier and faster (Dunford and Perrigino 2018). Therefore, workarounds should not be uncontrolled or pervasive in the workplace because they will contribute sooner or later to project delays, higher project costs and safety violations (Kermanshachi *et al.,* 2020).

[1] femuze@cut.ac.za

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While commenting on OSHA violation data, it was argued in Professional Safety (2016) that approximately 3 million workers are injured, and more than 4,500 workers lose their lives annually. The estimated harm to people from safety violations is always a reason to seek ways to improve compliance. And one way to enhance compliance-based safety is to minimise ‘workarounds’ that are expedited, not to solve problems, but to bypass safe work procedures or rules. Moreover, Al-Shayea *et al.,* (2019) observed that construction workers might be unaware of the risk exposure related to cutting corners when they execute a ‘workaround’. That is why Larsen and Whyte (2013) emphasized the need for safe working practices and risk management before workarounds are carried out on construction sites. Dekker (2019: 39) said: 'The word "workaround" ….can only make sense if there is something that someone is actually “working around”. That something is the standard, the rule, the procedure, the protocol, the correct way of doing things, which is somehow seen as an obstacle.'

One can discuss a workaround or improvisation by referring to a rule. The reference point for this paper is a rule. However, the failure to follow the rules is often cited as a cause of accidents (Hale and Borys 2013a, 2013b). Rules are needed to allocate responsibilities, actions and working conditions on complex worksites. However, lived experiences on construction sites showed that operatives sometimes viewed rules as being unnecessarily strict. The compulsory use of the hard hat is an example. In most countries where health and safety (H&S) is regarded seriously, using the hard hat on-site is mandatory. However, the nature of construction work entails that there might be no one in authority above the level of workers in some sections of the work site, so certain operatives might debate the need to wear the hat. As a result of lax tendencies in compliance, such operatives might violate rules.

Since rules at the point of application are general in nature, there will always be situations where construction operatives will judge them as being either inadequate or unnecessary (bad). Attitudes of casual compliance are a major contributor to minor and major accidents in several industries because respect for rules is not always maintained (Hopkins 2011). The reality of safety rules on the ground often differs from what rule-makers expect. As an illustration, the reality of rules for the Dutch railways in the early 1990s showed that less than 5% of the surveyed workers used the rules often, while close to 50% did not use the rules (Elling 1991, cited by Hale and Swuste 1998). This observation is not limited to the Netherlands, as similar studies in the United Kingdom (UK) alluded to a similar outcome. When asked why the rules were not observed, the Dutch railway workers found them to be contradictory (77%), complicated (70%), unrealistic (47%), and anti-work progress (95%) (Elling 1991, cited by Hale and Swuste 1998). The similarities in rule related behaviours of workers in the Netherlands and the UK is not peculiar to these countries, as the results shared in this paper suggest a similar trend in South Africa. The factor of anti-work progress is an indicator of the tension between production and protection in hazardous sectors. Reason (2008) categorised rules into good, bad, and no rules. Good rules refer to situations where an appropriate rule or procedure covers a task. In contrast, bad rules refer to situations where an inappropriate rule or procedure covers a task. Where a rule or procedure does not cover a task, the situation is referred to as “no rule”. The three broad categories fall under rule-related behaviour, which accounts for actions that violate safety in industrial workplaces.

Violations are observed in most countries, including South Africa. In South Africa, Emuze (2019) asserted that some deviations that occur when operatives take shortcuts either to mitigate workload or improve productivity, might threaten a safe working place and escalate safety violations in construction. Notably, workarounds might be unavoidable in operations because of some reasons highlighted by Alter (2014) and Wibisono *et al.,* (2019), but it is imperative to mitigate likely risks by addressing issues related to the effects of safety violations. This is the main motivation for the study reported in this paper. This paper aims to depict workarounds, their frequency and their impact on rule-related behaviours of workers in the frontline of construction work. An illustrative case study that sought responses to the question: 'How should workarounds be controlled in construction?' was used to achieve the aim, as presented in the next section of the paper.

METHOD

A descriptive research design was employed for this study. Workarounds on three construction sites are depicted in the illustrative case study. The unit of analysis was, therefore, construction projects. The research design was motivated by the need to investigate the negative impact of workarounds resulting from a potential increase in safety violations on construction sites in South Africa. The pragmatic, illustrative case study addresses the central question of the reported research. The design is useful as it helps to describe what the participants know and sees regarding the phenomenon (Baron and McNeal 2019). The intention of this paper, derived from the purpose of illustrative case studies, is to provide descriptive details of workarounds on construction sites based on the lived experiences of the participants involved in the study (Hayes *et al.,* 2015).

A purposeful sampling technique and semi-structured, face-to-face interviews were used to collect the primary data for the study. Due to the nature of the study, all participants were assured of confidentiality and anonymity of information to be shared. Both closed-ended and open-ended questions were used to examine the issue with the site managers of three projects. In addition, a semi-structured, closed-ended (multiple choice) and open-ended questionnaire was used to collect data from three project sites. Examples of the interview questions include: ‘What do you understand about workaround?’; ‘How would you describe workarounds in construction operations?’; ‘How often do they occur in construction operations?’; and ‘What risks do you think workarounds and shortcuts pose in construction operations?’ The spoken responses to the open-ended questions were recorded using a computer tablet and then transcribed for thematic analysis (patterns in data) as indicated in Miles, Huberman, and Saldana (2014). The approach is appropriate for understanding and interpreting relationships between conceptions. The qualitative data analysis aimed to discover themes (patterns) to allow interpretations. The descriptive analysis of the responses is presented in the next section of the paper.

Given the illustrative case study design of the research, a purposive sampling technique was used to select participants for interviews who were well-informed about the topic. The three case studies were based on construction site projects where two students engaged project managers, construction managers, forepersons, and general workers to collect data in August 2022. The building projects were in Bloemfontein, South Africa. The principal contractors of the projects were medium-sized firms, employing more than 20 people. On each project, a manager was interviewed while five frontline workers were surveyed. This approach brought the total number of participants in the illustrative case study to 18 (6 per project site). The profile of the interviewees shows that 18 construction operatives participated in the study. With varying roles, including forepersons, artisans, and general workers, and site managers.

They have lived experiences on the subject matter since they have worked on sites for more than 5 years.

FINDINGS

The responses to the questions asked in the semi-structured, face-to-face interviews and the questionnaire survey are presented in this section. The responses from the managers on the projects are presented first. The case studies are referred to in the paper as Projects A, B and C to maintain anonymity.

Interviews with Site Managers

What do you understand about workarounds?
This question served as the icebreaker in all the interviews. The response to the question from Project A was that a workaround happens mostly when time is an important factor in the project. The interviewee said that if it were not implemented, delays would occur. On the same question, the Project B interviewee contended that the workaround is mainly related to solving construction problems as they arise. In contrast, the Project C interviewee believed that it is an alternative method of getting the job done. The third interviewee conceded that it is always different from existing methods that might have been pre-determined. Although the three interviewees did not express a negative view of workarounds at this stage of the engagement, the comments of the Project C interviewee re-affirmed the notion that a workaround is a 'violation in disguise'.

It was notable that the three interviewees viewed workarounds as an important concept because of reasons related to cost and time issues. The Project A interviewee said: 'Most of the time, it saves money and balances a healthy relationship with your workers. Instead of sending them home and waiting for the delay to be over, you tackle the problem on-site, so there are no delays, and nobody needs to be laid off.'

Located several kilometres apart, the response of the Project B interviewee appeared to endorse the quote from Project A. The Project B interviewee believed that workarounds help to create a workflow in construction because they avert problems that would have led to stoppages. The Project C interviewee was more in support of the concept with his views that: 'Yes, it is important; it is needed in the industry. I think it is important because, uhm… certain items cannot be completed because of various things, because of weather conditions, because of space so, therefore, instead of using, for instance, concrete truck inside a house, you have to use a wheelbarrow - its deemed as a workaround. A concrete truck has a sling that pours concrete, but when it's in a building, you cannot use it, you must use alternative methods.'

How would you describe workarounds in construction operations?
When asked to describe workarounds, the Project A interviewee said they are very useful because, without them, projects could come to a standstill to the detriment of production and profits. The Project B interviewee referred to a workaround as "communication bypass", "procedure and skipping"! He added that a workaround is also the use of people in a similar or closely related trade to fill in for missing roles, for example, using a carpenter to fill in for the work that a bricklayer should be doing on site. In Project C, the interview description of the workaround was elaborate, with his commentary being: 'I think I just made an analogy; I think I'd explain it by saying like the analogy I made - there are certain construction activities that need certain methods, so the methods might deviate from your initial planning and you need to

alternatively look at how you will execute the certain construction activity within the environment.'

How often do they occur in construction operations?
The interviewees were asked to mention the frequency of workarounds on their various sites. In Project A, the interviewee said that they occur in almost every project because the weather is controlled by nature and not a human being. In fact, according to him, the weather frequently causes workarounds on construction sites, especially if work is done outdoors. The Project B interviewee's response was just one word, 'regularly'. Whereas the Project C interviewee provided an explanation for his view. He said every activity on site has moments in which a workaround must be executed, and such execution is never planned. So, according to his account, workarounds occur often on site.

Which workers execute workarounds during construction operations when necessary?
The three interviewees identified the role profiles of operatives who executed workarounds on their sites. The responses were similar in that they all mentioned general workers, forepersons, sub-contractors, project managers, bricklayers, concrete hands, and plant operators. However, the Project A interviewee cautioned that workarounds should be executed by general workers only under the supervision of site management (either a project manager or a foreperson). The illustration from the Project C interviewee showed how workarounds are implemented in the work process on a site. He said: 'Your concrete guys, your plant operators, your bricklayers, I'd say those three mainly. For bricklayers, let's say you're building a stretcher bond and you reach a corner; you need to change your bond to suit the corner you need to construct on.'

Which shortcuts do you take during construction processes?
The Project A interviewee responded to this question with an example. He said, in winter, the walls tend to stay damp and wet on the inside after plastering because, usually, there is not much sunshine. The lack of sunlight thus delays the drying process of plastered walls. The lack of sunlight means waiting for a long time before the priming and painting work can start. What he usually does in such instances is to shorten the waiting time by putting fans or heaters in the rooms overnight. The Project B interviewee was more restrictive because he said that he takes shortcuts mostly to shorten standard procedures. The Project C interviewee only said: 'It is the most important thing; it's extremely important, uhm…to do that.' In other words, in his view, it is vital to learn how to cut corners.

What are the significant differences between workarounds and shortcuts?
After hearing their views on workarounds and shortcuts, the interviewees appeared to be familiar with the two concepts and were requested to differentiate between them. Their responses are presented verbatim below:

'Workaround is when you do what is expected, only in a different manner, but still as effective as the initial plan. Shortcuts are when you take risks like deviating from the legal method' (Project A).

'I don't believe there is any difference between the two' (Project B).

'Workaround is, uhm…the quality is not being compromised but the job still gets done on a set standard. Shortcuts would compromise quality and put your life at risk' (Project C).

These responses showed that two interviewees tried to differentiate the terms, while one of them could not do so. It is notable that risks are featured in the two responses.

What risks do you think workarounds and shortcuts pose in construction operations? Risk refers to the likelihood of an unplanned event (accident). This question followed the interview conversation where the participants already mentioned risk. In responding to this question, the Project A interviewee said that workarounds have low risks compared with shortcuts. Still, workarounds can fatigue workers because of overtime, and workarounds can be a costly but faster method. However, he argued that shortcuts have no legal guarantee and they can fail at any time. He cited an example of using concrete of weaker strength to save money, but, over time, the concrete element will crack under imposed load. In his view, the Project B interviewee said that both workarounds and shortcuts could cause more problems.

Survey of site operatives

As mentioned earlier, surveys of operatives were conducted on the three construction sites either to refute or confirm the views of site management on the phenomenon. Five surveys were conducted on each site, including two interns, three junior quantity surveyors, eight general workers (brick, cement and plastering, and road works), and two foremen. The total number of participants was 15. Owing to the limited number of participants, the number of responses instead of response percentages was used to present the results. As shown in Table 1, multiple-choice questions were used to understand how people working on the three project sites viewed workarounds. Most site interviewees (13) perceive that a workaround is helpful and an acceptable way of overcoming on-site issues (14). More than 10 also viewed the current rules as being amendable to construction workarounds, although some (7) had encountered accidents linked to workarounds.

Table 1: Perceptions of site operatives on workaround-related issues

Question	Unsure	No	Yes
Did the workarounds you executed on-site assist in projects?	0	2	13
Did you encounter any accidents while executing workaround(s)?	3	4	7
Do you think current rules allow workarounds in construction?	4	0	11
Are workarounds acceptable means of overcoming issues?	1	0	14

The answers of the site operatives to the open-ended questions confirmed the views of their managers, presented in the previous sub-section of this paper, that all the site operatives are familiar with workarounds. So, they were then asked what usually leads to the implementation of a ‘workaround’ or put another way, why they had to improvise on site. Four participants cited delays or change orders from the consulting teams, and five said that people do not implement H&S rules on-site. Such comment from one-third of the interviewees was significant. Three interviewees believed that they fell back on improvisation (workaround) when encountering unclear design, when the work method is unsuitable to actual site conditions, or when there is an unexpected change in site conditions. Three interviewees noted faulty equipment as a potential reason for a workaround on-site.

In a follow-up question the participants were asked how workarounds helped them to overcome the issues mentioned. Two interviewees said, 'improvised rush' in reply. Their reply implies haste in decisions and actions. Five were forthright in saying that the work method was usually changed. For example, a participant said, 'using sunlight soap in concrete as an emergency aggregate' or 'using a bottle to check levels and slope'. These two cited examples are extreme but result from improvisation (workaround) on site. The examples have implications for the quality of work, apart from H&S.

Another cited example also impacted quality and time because one participant said, 'there was a time when a scheduled cement truck could not reach the dipping [tipping] site, so we used push barrels [barrows]'. The participants implemented workarounds for various reasons, even though they believed that their actions increased H&S risk exposure on site. Three participants reiterated the notion that workarounds might lead to injuries when executing tasks, two said fatigue and health hazards might increase, and two said sub-standard work might result. In certain cases, according to one site operative, there might be no progress in work due to a workaround. Based on the survey of site operatives, it was concluded that quality might be compromised because of workarounds, accidents and injuries might occur (4 respondents), and damage to equipment is also likely (6 respondents).

DISCUSSION

The results from the illustrated case studies confirmed ideas regarding workarounds found in extant safety science literature. The results and the illustrations in Figure 1 confirm that one may see workarounds as an improvisation of a formal procedure; thus, it introduced both positive and negative outcomes for individuals, teams, organisations, and projects (Wibisono *et al.,* 2019).

Workaround and rule violation

Both from management and worker perspectives, workarounds are implemented on construction sites often instead of occasionally. The respondents also agreed that implementing workarounds increases H&S risk exposure, apart from time and quality issues. However, apparent widespread improvisation is a concern that should be noticed. It should be a concern because, in whatever form workarounds are examined, they all point to a violation of a rule. While obsolete rules can be violated to remove an impediment, other forms of rules require informed consideration. Operatives and their managers on site thus need guidance on how or when to implement workarounds.

Rule-related behaviours

From the shared perspectives, it is apparent that frontline construction operatives would do well to understand the implications of their rule-related behaviours. Rule-related behaviour relates to the local context (worksite) that either makes someone comply with or violate rules (Reason 2008). Understanding the local context is vital because not everything that can place workers in danger can be known completely. For example, rules can be good, bad, or lacking when undertaking a task on a construction site. Please refer to Reason (2008: 60-65) for a detailed explanation of rule quality and correct and incorrect actions, including psychologically rewarding and unrewarding actions.

Variety of rule-related behaviours

In the context of the data presented in this paper, Figure 1 illustrates that where the appropriate rules cover a task, the correct ways of executing the task should be followed. That is compliance with reward (No: 1 in the good rule callout). In such a case, there is no reason for improvisation or workarounds because the workforce promotes a safer working method. However, if the responses of site management and operatives in this paper are considered, the correct rules are not followed at times for expedience (No: 2 in the good rule callout). This is dangerous because every incorrect but rewarding, unsafe act increases the likelihood of future repetitions (habit-forming) and the probability of an accident. As mentioned in the previous section, expediting incorrect rules (workarounds) without negative consequences leads to harmful habits. This might happen in work situations where rules are deemed necessary but annoying. For instance, not wearing hard hats, reflective vests, and safety boots on a hot day in summer should not be permitted, even though it causes discomfort. This personal protective equipment (PPE) is mandatory, as it preserves life, so discomfort is not an acceptable reason to discard it while working on a construction site.

Figure 1: Five varieties of rule-related behavioural options

The bad rules callout is considered next. If a rule fails to cover a task to be completed, it is regarded as bad (not good enough). In such a case, if a worker follows the rule, he/she is incorrect (No: 1 in the bad rule callout). This is similar to No: 2 in the good rules callout. However, if the incorrect rule is not followed, the operative has violated a rule but in a positive manner. This occurs when actions are taken to overcome obstacles in the workplace. Finally, knowledge of rules and related tasks is paramount in the no-rule callout. This is when a workaround is mostly welcome (like No: 2 in the bad rule callout). In this case, if the outcome of improvisation is correct, it might lead to an efficient and safer working method. Knowledge of rules and tasks helps to control risk within a work team. It also assists in determining the correct approach to safety rules with concepts such as 'situation awareness', and 'mindfulness' (Stanton *et al.,* 2001; Zhang and Wu, 2014; Salmon and Plant, 2022; Liang *et al.,* 2022).

CONCLUSIONS

This paper aims to depict workarounds, their frequency, and their impact on rule-related behaviours of workers in the frontline of construction work. The aim was achieved using an illustrative case study design, according to which textual data were collected from frontline workers on three construction project sites. The results confirmed that the workaround is well known in construction operations, where the respondents said it was implemented often. Although the reasons for workarounds were highlighted in the response data, there is a reason to think twice before rules are violated because of the potential impact on H&S, quality, and time. The data suggested that unrestricted workarounds do not favour safety on construction sites. So, it is argued in this paper that navigating obstacles through a workaround should be based on adequate comprehension of rule-based behaviours. Site operatives and their managers should consider the options available carefully in a local work context when confronted with good, bad or no rules.

For example, a workaround may be permissible when there is no rule (correct improvisation in Figure 1) or when the rules do not cover the tasks to be completed (correct violations in Figure 1). Other actions outside these options expose people and property to harm or loss. Also, when a workaround is the only option, it must not be rushed (in contrast to the account of respondents in this paper). Instead, mental preparedness should guide the execution of such improvisations.

The limitation of most illustrative case studies applies to this paper. The data shared here might only be valid for similar cases in developing countries. The descriptive results serve as building blocks for future studies.

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THE ROLE OF EDUCATION AND TRAINING TO ACHIEVE POSITIVE MENTAL HEALTH AMONG YOUNG CONSTRUCTION WORKERS FROM THE GLOBAL SOUTH

Samuel Frimpong[1], Riza Yosia Sunindijo, Cynthia Changxin Wang and Elijah Frimpong Boadu

School of Built Environment, UNSW Sydney, Sydney, NSW, 2052, Australia

Education and training influence mental health. Past research, however, focuses mainly on negative mental health (e.g., depression), and very little is known about how education and training affect workers' positive mental health, a crucial component of mental health. Meleis' Transitions Theory, and Keyes' Two-Continua Model, both of which focus on human well-being, are employed to explore how education and training influence positive mental health among young construction workers from the Global South. We focus on young construction workers in Ghana aged 35 years and below. Using mixed methods, data were collected from different stakeholders, including young construction workers, and analysed using thematic analysis and structural equation modelling. Three types of education and training were identified, viz: formal education, personal mental health education, and workplace-supported education. All three types of education significantly influenced young construction workers' choice of coping, which in turn significantly affected their positive mental health. The findings can reorientate mental health education and training programs to promote the positive mental health of the current and future construction workforce.

Keywords: education; training; global south; mental health; young; Ghana

INTRODUCTION

Past research has highlighted the need to educate and train construction workers, especially younger ones, aged 15-35 years, to achieve good mental health, i.e., a "state of mental well-being" in which they can fully function by coping effectively with "challenges", develop their "skills", and effectively learn and contribute to their "community" (WHO 2022). This is especially important because young construction workers have an abnormally high prevalence of negative mental health (e.g., anxiety, depression, substance-use disorders, and suicidal ideation) and its associated outcomes such as low workability, poor-quality life, and suicide (ILO 2018; King *et al.,* 2019).

[1] s.frimpong@unsw.edu.au

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Although research shows that education and training influence construction workers' mental health, the current body of literature has some key limitations. First, there has been an exclusive focus on understanding and eliminating the risk factors and symptoms of negative mental health, with studies that focus on understanding and promoting positive mental health (i.e., good mental health and proper functioning) being scarce (Hutton *et al.,* 2022). As a result, the role of education and training in the achievement of positive mental health by construction workers remains unclear. This situation is inadequate for promoting the mental health of young construction workers because, achieving good mental health requires not only the reduction of negative mental health but more importantly, the promotion of positive mental health (Keyes 2013).

Second, most studies have focused on the general construction workforce in the Global North, neglecting the case of young construction workers, especially those from the Global South (i.e., lower-and middle-income countries) (Frimpong *et al.,* 2022). This situation is counter-intuitive because young construction workers from the Global South constitute a key source of labour for the global construction industry (Udah *et al.,* 2019) and they are part of a group which is known to have the highest burden of negative mental health and the poorest access to mental health care resources including education and training (Alloh *et al.,* 2018).

The current state of research can make it difficult to effectively use education and training as tools to promote the mental health of young construction workers, thus potentially jeopardising the health and well-being of the current and future construction workforce. This research, therefore, aims to understand the role of education and training in the attainment of positive mental health among young construction workers from the Global South, using the case of Ghana. Specific objectives include identifying the types of mental health education and training available to young construction workers and analysing the relationships between the types of mental health education and training and positive mental health.

Previous Studies on Education and Training and Construction Workers' Mental Health

Past research has focused on the impact that education and training-related factors have on mental health (Frimpong *et al.,* 2022). Specific factors explored in past studies include “educational attainment”, workers’ prior knowledge of the construction environment, and the level of professional training achieved by workers (Milner *et al.,* 2013). Young construction workers with low educational attainment tend to have high levels of psychological distress and are more susceptible to self-harm and suicide. This is attributable to underlying issues such as poor mental health literacy and low socioeconomic status, both of which are notable outcomes of inadequate education and training (King *et al.,* 2019). It is also known that young construction apprentices and workers with low professional training as well as those employed in manual occupations (e.g., laborers, masons, and carpenters) experience poor mental health and are more prone to outcomes such as suicide, whereas those undergoing professional academic training (Scott-Young *et al.,* 2018) and working professionals (architects, engineers, etc.), especially those employed in managerial roles, tend to have better mental health outcomes (King *et al.,* 2019).

Past studies have also examined the impact of education and training on young construction workers' choice of coping strategies, indicating that, educational and professional backgrounds determine whether young construction workers choose positive or negative coping practices, which in turn affect their mental health. Although past research (e.g., Sunindijo and Kamardeen 2017) has reported construction workers' use of positive coping strategies such as problem-focused coping, young construction workers, especially those with informal training, prefer negative coping practices such as drug use, aggressive behaviour, and absenteeism, when compared with highly trained professional construction workers (Fodjour *et al.,* 2019). Studies conducted in both the Global North (e.g., King *et al.,* 2019) and the Global South (e.g., Fordjour *et al.,* 2019) suggest that workers with low socioeconomic status because of their educational and professional backgrounds, tend to employ negative coping practices. Previous research has also focused on formal and informal education and training provided to young construction workers at the workplace (e.g., Broadbent and Papadopoulos 2014), often with the objective of improving mental health literacy. These programs are usually ineffective because of issues such as a lack of awareness of their existence and poor patronage by young construction workers (Franklin *et al.,* 2022).

The current body of literature adequately identifies factors associated with education and training, coping, and the mental health of young construction workers. Beyond this, however, research that thoroughly examines the interaction between these factors specifically in connection with positive mental health is lacking. This situation hampers efforts to review existing education and training programs and develop new ones for promoting young construction workers' mental health, especially for those with Global South backgrounds. Addressing this problem can help to improve the effectiveness and attractiveness of current and future education and training programs in this regard and contribute to solving the persistent problem of low patronage of these programs by young construction workers (Franklin *et al.,* 2022).

Theoretical and Conceptual Framework

The lack of research on the topic under investigation made it necessary to adopt a conceptual framework to guide this study and model the relationships among the study variables (i.e., education and training, coping, and positive mental health). A conceptual framework for young construction workers’ transition to positive mental health, proposed by Frimpong *et al.,* (2023a), was chosen. It combines the Transitions Theory (Meleis 2010) and the Two-Continua Model of Mental Health (Keyes 2013), both of which focus on promoting the well-being of vulnerable populations.

Transitions Theory has four main constructs - nature of transitions, transition conditions, nursing therapeutics, and patterns of response (Meleis 2010). The nature of transitions includes types, patterns, and properties of experiences that cause crucial changes in people's lives. Examples include changes in occupation, illness, lifestyle, level of education, and professional training. Transition conditions are the factors that promote or hinder progress towards achieving a “healthy” transition (Meleis 2010). They include personal knowledge and social beliefs and attitudes. Nursing therapeutics are provisions for ensuring the achievement of desired transition outcomes (Meleis 2010). Patterns of response indicate the progress and outcome of transitions and can be broken into the process (e.g., developing confidence and coping skills) and outcome indicators (e.g., subjective well-being) (Meleis 2010).

According to the Two-Continua Model of Mental Health, positive and negative mental health are two related but separate constructs, with mental health conceptualised as subjective well-being (Keyes 2013). Furthermore, low levels of mental illness or the absence of it does not necessarily indicate the presence of good mental health and vice versa. According to the model, positive mental health comprises three underlying dimensions, i.e., psychological well-being, emotional well-being, and social well-being (Keyes 2013). Emerging research (e.g., Joshanloo 2013) suggests that the three dimensions could be expanded to include a possible fourth - spiritual well-being.

The conceptual framework (Table 1) of this study designates positive mental health as the outcome of a healthy transition. This is because Transitions Theory focuses on positive outcomes and conceptualises a healthy transition outcome as subjective well-being, which is synonymous with positive mental health in the Two-Continua Model of Mental Health (Frimpong *et al.,* 2023a). It is proposed that positive mental health is an outcome of coping, which is in turn determined by the nature of transitions, transition conditions, and nursing therapeutics (Figure 1). Thus, we initially hypothesised that young construction workers' education and training influence their development and utilisation of coping strategies, which in turn, influences their achievement of positive mental health.

Table 1: Overview of conceptual framework

Constructs	Components	Study variables	Sources
Nature of transitions	Types and levels	Education (background and level completed)	Frimpong *et al.,* 2022; King *et al.,* 2019; Milner *et al.,* 203
Transition conditions	Personal, community, and social determinants of coping	Personal, community, and social education	Fordjour *et al.,* 209; Frimpong *et al.,* 2023b; king *et al.,* 2019
Nursing therapeutics (care strategies)	Preparation for transition	Other educational programs and interventions	Broadbent and Papadopoulos 2014; King *et al.,* 2019
Patterns of response	Process indicators	Coping strategies	Frimpong *et al.,* 2023b
	Outcome indicators	Positive mental health (emotional, psychological, social, and spiritual)	Joshanloo 2013; Keyes 2013

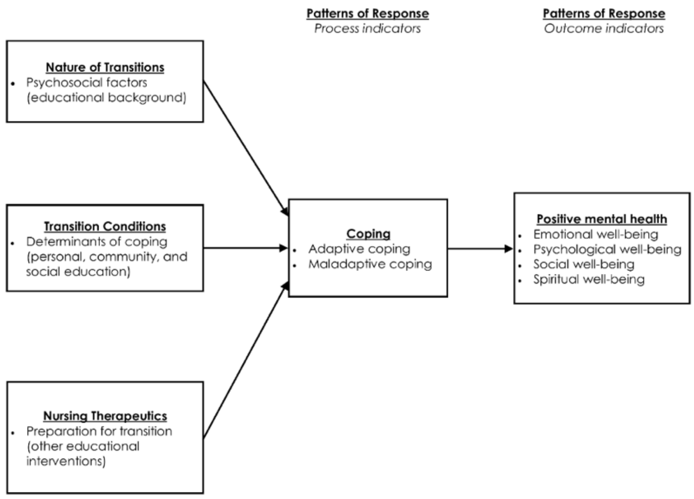

Figure 1: Research model (adapted from Frimpong et al., 2023a)

METHOD

There was a need to identify the types of training and education available to young construction workers that corresponded with the constructs "nature of transitions", "transition conditions", and "nursing therapeutics". This would help to validate the research model and extend the initial hypothesis on the relationships among the study variables. To test hypotheses and generalise findings required collecting and analysing both qualitative and quantitative data. A sequential transformative mixed-methods approach was therefore chosen. This involved first collecting and analysing qualitative data, followed by a collection and analysis of quantitative data (Cresswell 2014).

Phase 1 (qualitative): Data were collected through semi-structured interviews with 16 different participants drawn from different stakeholder groups viz.: young construction workers; mental health professionals; construction employers; social contacts of young construction workers; and youth mental health agencies and advocates. Interviews focused on the types of training and education that provided young construction workers with knowledge about mental health. All interviews were digitally recorded, transcribed, and subjected to a manual deductive and thematic analysis. This involved sorting textual data, making sense of data, and categorising results according to pre-defined themes based on the constructs of the research model. This was followed by two rounds of focus group discussions with 11 different participants (also drawn from the different stakeholders of young construction workers' mental health in Ghana) to validate interview findings, evaluate the conceptual framework (measurement model), and adapt survey instruments. Focus group data were analysed using the same procedures for analysing interview data. Interview and focus group participants were purposively selected and had to meet the criteria of being knowledgeable of or having lived experience of the research topic.

Phase 2 (quantitative): The objective of this phase was to validate the research model and test the generated hypotheses based on the results of Phase 1 and as modelled in Figure 1. Data were collected through an online survey of young construction workers in Ghana. Respondents had to be between the ages of 18-35 years (inclusive) and employed in any construction-related occupation. The survey questionnaire had items covering demographics, education and training details, coping, and positive mental health. Coping was measured using modified questions from Carver *et al.,* (1989). Under positive mental health (26 items: $\alpha = 0.95$; tested in this study), the dimensions of emotional, psychological, and social well-being were measured using a modified version of the Mental Health Continuum - Short Form (Keyes 2013). Spiritual well-being was measured using questions formulated based on Fisher's (2011) Four Domains Model of Spiritual Well-being. Positive mental health was measured for the two weeks before the assessment and was rated on a 5-point scale where 1=not at all; 2=several days; 3=mild or several days; 4=more than a week; and 5=nearly every day.

Data from 425 respondents were analysed with descriptive statistics, confirmatory factor analysis, and mediation analysis through Structural Equation Modelling (SEM) using maximum likelihood estimation with bootstrapping (2000 samples) in IBM SPSS Statistics and AMOS Graphics (version 26). Construct reliability was checked through Cronbach's alpha and composite reliability. Construct validity was assessed through discriminant validity (Heterotrait-Monotrait Ratios) and convergent validity (Average Variance Extracted). Ethical practices included seeking participants' informed consent before data collection and assuring them that their contribution was voluntary and that their identities would be kept anonymous. Ethics approval (No.: HC201891) was provided by the Human Research Ethics Committee of the University of New South Wales, Sydney.

FINDINGS

Respondents' ages ranged from 18 to 35 years (M = 28.6; SD = 5.03), and they had been employed for an average of 6.1 (SD = 4.32) years. Five respondents (1.2%) had never attended school, 46 (10.8%) had completed primary education (up to year six), 230 (54.2%) had up to high school education, and 144 (33.9%) had completed university. In terms of employment, 283 (66.6%) of respondents were trade workers (e.g., masons, plumbers, etc.) while 142 (33.4%) were construction professionals (e.g., architects, construction managers, etc.). The majority, i.e., 255 (60%) had acquired their occupation through apprenticeship, 100 (23.5%) through formal education, and 70 (16.5%) through a combination of apprenticeship and formal education.

Types of Education and Training

Three main types of mental health education and training were identified, viz.: personal mental health education (PMHE); formal education (FE); and workplace-supported training and education (WPSE).

Formal Education (FE)
This involved formal academic and non-academic forms of education such as "primary", "general secondary school", "technical/vocational", "university education", and "formal apprenticeships". Although the main purpose of such education was to enable young construction workers to acquire professional knowledge and skills, the content also focused on "life skills", "general science", and "construction health and safety" depending on the level of study. These components provided students with knowledge on issues such as "drug abuse", "nutrition", safe work practices, and "the use of [personal protective equipment]".

Personal Mental Health Education (PMHE)
This theme concerned the personal efforts of young construction workers to learn about mental health. Personal learning was often done by watching or listening to social media content. Young construction workers' objectives for engaging in personal learning were to "[satisfy their curiosity] about mental health", "understand the [risk factors] of mental illness", "to know where to seek help", and to "recognise symptoms of mental disorders in order to undertake [self-diagnosis]".

Workplace-Supported Training and Education (WPSE)
This comprised education and training obtained at the workplace. Specific examples included both formal and informal training programs (e.g., seminars or on-the-job training) provided to young construction workers to boost their occupational and professional skills. Employers and mental health experts sometimes teamed up to deliver specific education (e.g., "health talks" and "workshops") "on construction sites and in offices". This was, however, infrequent due to a lack of funds and other resources. Another form of workplace training that emerged and featured strongly in the focus group discussion was "education by workmates". This involved learning about "how to maintain strength and [stay healthy]", "pain medication", and "dealing with personal and [occupational challenges]" from their peers at work.

Based on the literature review and final themes, our hypotheses were expanded as:

H1: Formal education (FE) is negatively associated with young construction workers' development and utilisation of coping, which in turn, is positively associated with their achievement of positive mental health.

H2: Personal mental health education (PMHE) is positively associated with young construction workers' development and utilisation of coping, which in turn, is negatively associated with their achievement of positive mental health.

H3: Workplace-supported training and education (WPSE) is positively associated with young construction workers' development and utilisation of coping, which in turn, is negatively associated with their achievement of positive mental health.

Research Model Validation and Hypotheses Testing

The results of the SEM, including item-factor loadings (ranging from 0.40-0.92), are shown in Figure 2. Acceptable model fit statistics adopted in this study include a chi-square to degrees of freedom ratio (CMIN/df) between 1 and 3 (Hooper *et al.,* 2008); at least 0.90 for Comparative Fit Index (CFI) and Tucker-Lewis index (TLI) (Bentler 1990); and a maximum of 0.08 for both Root Mean Square Error of Approximation (RMSEA) and Standardised Root Mean Square Residual (SRMR) (Hu and Bentler 1999). Model fit was improved by using modification indices suggestions to covary error terms of some factors of PMHE and coping where this was theoretically acceptable. The resulting indices (i.e., CMIN/df = 2.90; CFI = 0.92; TLI = 0.91; RMSEA = 0.06; SRMR = 0.07) indicate adequate model fit to the data.

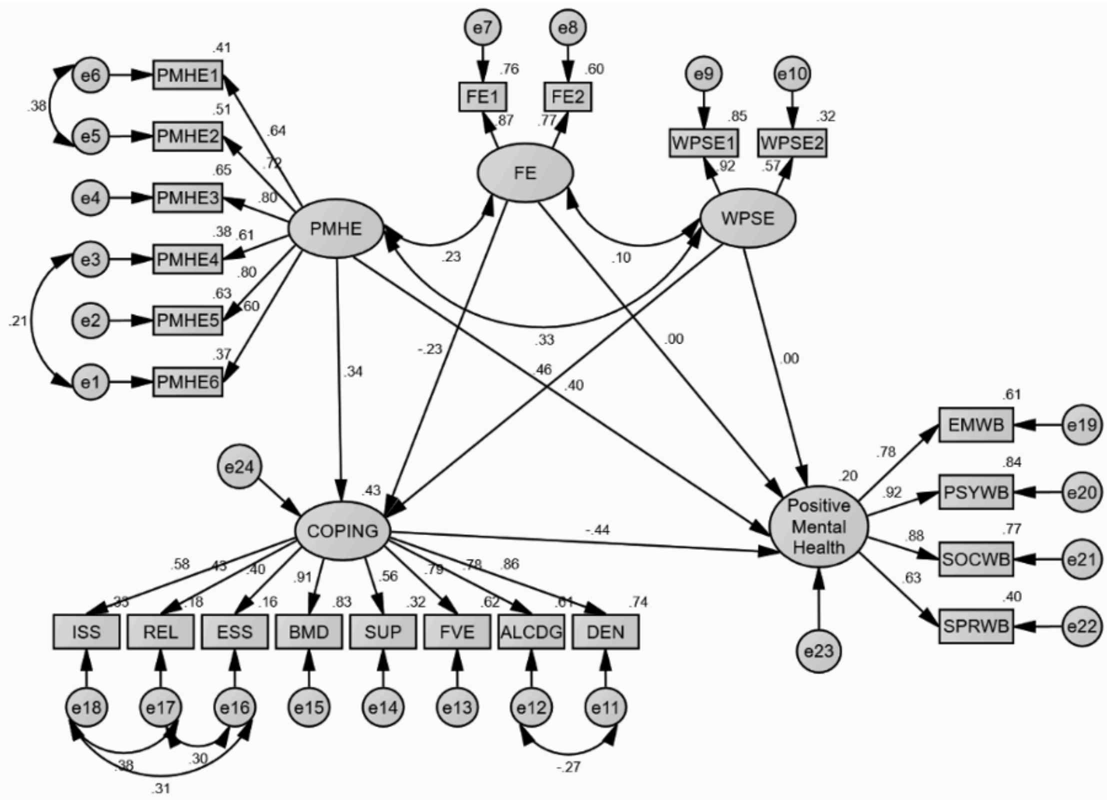

Figure 2: Structural equation model (standardised)

All three hypotheses were supported by the results of the mediation analysis (Table 2), indicating that coping, which was mostly negative, mediates the effect of FE, PMHE and WPSE on young construction workers' positive mental health. Partial mediation was observed only for PMHE. Overall, about 19.36% (r=-0.44) of the variance in positive mental health is attributable to coping. Despite this, the indirect effects of FE, PMHE, and WPSE on positive mental health are small (<5% of the variance).

Table 2: Results of mediation analysis

Hypothesis	Direct effect	Indirect effect	Result
FE→Coping→Positive Mental Health	0.003 (ns)	0.001*	Full mediation
PMHE→Coping→Positive Mental Health	0.404*	-0.146*	Partial mediation
WPSE→Coping→Positive Mental Health	-0.004 (ns)	-0.204*	Full mediation

* = $p < 0.01$; ns = "not significant"

DISCUSSION

Young construction workers' use of negative coping reduced with an increase in their level of formal education, leading to increased positive mental health. This could be explained by the fact that formal education improves workers' mental health literacy and increases socio-economic status by enabling workers to obtain good employment (King *et al.,* 2019). A practical implication is that the scope of formal education must be expanded to deliver mental health education to young construction workers by introducing new subjects or extending existing ones to focus on mental health literacy.

Personal mental health education, which was mostly done online, directly improved positive mental health. Young people have a strong preference for digital and online tools for mental health education (Odgers and Jensen 2020). Online education can, therefore, be used to leverage the provision of mental health education and training to young construction workers, especially in Global South settings with scarce resources. Personal mental health education also increased young construction workers' choice of negative coping, in turn, reducing their positive mental health. This could be attributed to the poor quality of content that young people usually engage with online (Odgers and Jensen 2020). To get the best out of this type of education, therefore, the quality of online information available to young construction workers must be improved by encouraging researchers, mental health experts, and other stakeholders to present information in video or audio format on social media platforms.

Workplace-supported mental health education and training had a stronger increasing effect on young construction workers' use of negative coping and consequently a larger negative effect on positive mental health. This could be because of the inadequate provision of mental health education and training at the workplace, as indicated by the qualitative study results. Perhaps, the little effort made in this direction is mitigated by young construction workers' ready access to poor advice from their workmates, many of whom likely have poor mental health literacy and often encourage negative coping practices such as denial and substance use (Fordjour *et al.,* 2019). Workplace-supported training and education could be made more effective by training some young construction workers as mental health champions to positively influence the coping choices of their peers.

Although "coping" is a higher-order factor with sub-factors, each of which exerts a different direction (negative or positive) of effect on positive mental health (Frimpong *et al.,* 2023a and b), it was bundled together in the research model of this study. This could account for the small magnitude of the indirect effects of FE, PMHE, and WPSE on positive mental health. Further research is, therefore, needed to examine the magnitude of the mediating effect of the individual sub-factors of coping.

CONCLUSIONS

This research has established that formal education, personal mental health education, and workplace-supported training and education significantly influence young construction workers' development and utilisation of coping, which in turn, significantly affects their achievement of positive mental health. To get the best out of such forms of education and training for promoting the positive mental health of young construction workers, current education programs must give more attention to mental health, especially its positive aspects. Furthermore, digital, and online tools must be employed in the provision of mental health education and training, since these are preferred by young people. Most importantly, quality content that focuses on improving young construction workers knowledge and utilisation of positive coping practices must be deliberately provided. The findings of this study can reorientate policy formulation and intervention design to focus on positive mental health. This will contribute to the construction industry's realisation of SDGs 3 (good health and well-being) and 8 (decent work and economic growth). Future studies should examine the specific coping practices that mental health education and training programs should focus on to improve young construction workers positive mental health.

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INTERRELATIONSHIPS IN SAFETY, HEALTH AND WELL-BEING: CONCEPTS, MANAGEMENT AND PERCEPTIONS

Andrea Gonzales Lazo[1], Mustafa Selçuk Çidik[2], Iain Rillie[3] and Simon Addyman[4]

[1,2&4] *The Bartlett School of Sustainable Construction, University College London, 1-19. Torrington Place, WC1E 7HB, London, UK*

[3] *Health Safety and Wellbeing Division, National Highways, Bridge House 1 Walnut Tree Close, Guildford, GU1 4LZ, UK*

Health, safety, and well-being are concepts of significant interest to construction researchers and practitioners. Although the interconnected nature of the three is acknowledged, there is confusion over their definitions, management practices and perceptions. Based on a critical literature review, this paper attempts to clarify the constructs of health, well-being and safety in construction and highlight their interrelationships by analysing the different management approaches and perceptions. The review reveals that the management of safety hazards in construction often overshadows health and well-being issues, increasing the growing gap between management's focus on demonstrating safety measurements and employees' focus on staying safe on site. The implications of the findings emphasize the need for an integrated approach that considers the interplay between health, safety, and well-being, enhancing workplaces conditions by addressing work design. This review contributes to the ongoing discussion on the importance of health, safety, and well-being in the construction industry.

Keywords: health; safety; interrelationship; perception; well-being; concepts

INTRODUCTION

'Health' and 'safety' are two distinct concepts with their respective literature, meanings, and practices. However, in the construction industry, the two have almost always been used together, with little critical thought given to how they relate to each other (Lingard 2019). In recent years, a third concept, 'well-being', has also been introduced in the belief that its promotion will positively impact health, safety, and workers' performance (Smyth *et al.,* 2019). Furthermore, it has gained more relevance since the global pandemic COVID-19, as it highlights the need to look after the workforce's safety, health and well-being (Pamidimukkala *et al.,* 2021). However, there is a lack of reflection on the distinctiveness of well-being and its relationship to health and safety concepts. Thus, although the construction industry's health, well-being, and safety (HWS) are assumed to be interrelated, there has been little reflection on this relationship. As a result, most of the extant literature either explicitly focuses

[1] andrea.lazo.17@ucl.ac.uk

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on one of the concepts ignoring the effects of the other two or bundles the three concepts together with the analysis focusing on one with a similar lack of consideration of such interrelationships (Carmichael *et al.,* 2016). Much of the academic and practitioner literature around HWS has developed in silos, using some of the terminologies interchangeably (Danna and Griffin 1999), leading to confusion and a lack of effective integrated approaches to improving HWS in construction (Smyth *et al.,* 2019). To effectively address HWS in construction, there is a need to address them in complementary ways through a holistic approach. For this, there needs to be a better understanding of the distinctiveness, as well as the interrelationships, of the three concepts.

This paper will aim to address this research gap through an exploratory literature review of the meanings attached to HWS from three different perspectives. These three perspectives are i) definitions, ii) management approaches, and iii) employee's perceptions. The selection of these perspectives is driven by their relevance in understanding the comprehensive landscape of HWS. The first section on definitions introduces each concept's origins and historical evolution over time. It highlights the differences between the definitions of HWS, in simple terms, in the workplace and the construction industry, shedding light on their interpretation within the context. The following section on management approaches discusses organisations' and policymakers' strategies and procedures for governing and managing HWS in the workplace and construction. The subsequent section on perceptions reveals that the views of practising employees on HWS can be considerably different from those who see them from a managerial perspective. Joint consideration of the three perspectives reveals insights about the distinctiveness and interrelationships of HWS in construction, adding clarity to the three concepts, thus, laying a foundation towards a holistic approach to studying and managing HWS in construction.

Definitions of Health, Well-being, and Safety

The concept of well-being can be traced back to ancient Greek and Oriental cultures. Aristotle introduced Eudaimonia, or happiness, as central to one's being, and Plato's holistic concept emphasised the health of the whole being, including body, mind, and soul (Kiefer, 2008). Well-being research has gained momentum, first in positive psychology (Diener 1984). Most authors relate the concept of well-being to life satisfaction and feeling good (Diener 1984) and suggest that it is an intangible concept that depends on individuals' perceptions of their conditions (Law et al.1998; Kiefer 2008). In line with these connotations, the Oxford Dictionary defines well-being as "the state of being healthy, happy, or prosperous".

On the other hand, since 1946, the World Health Organization (WHO) has described health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (World Health Organization n.d.). This concept was established post-WWII and expanded the concept of health beyond the body's concerns to include the mind and the social experience as essential for personal fulfilment (Law *et al.,* 1998). However, there have been disagreements about this view of health, which includes the idea of well-being and quality of life (Badash *et al.,* 2017), based on the argument that this definition is closer to happiness than health and is less achievable and measurable.

In a similar vein, safety is defined by the Oxford Dictionary as "the state of being safe and protected from danger or harm". Safety is a multifaceted concept applied to many areas, such as personal, transportation, environmental, and occupational safety. It is closely related to health and well-being, allowing individuals to live fulfilling lives in their community (INSPQ n.d.). It is evident from these everyday definitions of health, well-being, and safety that they are closely interrelated, as they commonly refer to each other for definition or contextualisation. However, this is confusing for research and practical management, and greater conceptual clarity is needed. In pursuing the distinctiveness and interrelationships of the three concepts, the following section will focus on the definitions of health, well-being safety at work, including in construction.

Health and Well-Being At Work

The concern for the health and well-being of workers has been gathering more awareness as it is widely accepted that a strong relationship exists between people's working lives and their health and well-being (Danna and Griffin 1999). The concept of well-being in the workplace is associated with the quality of working life, considering the psychological, physical, and social dimensions (Warr 1987). Defining well-being in terms of its benefits to employers is common in the literature on well-being at work. For example, Lambert *et al. (*2000) recap a long list of benefits of improving well-being, highlighting increased productivity, improved engagement, and reduced sick time and absenteeism in the workplace context. In addition, all workers have lives outside of work, so it is vital to acknowledge the overlap between non-work and work factors in workers' well-being (Danna and Griffin 1999; Peckham *et al.,* 2017).

On the other hand, the World Health Organisation defines occupational health (i.e., health at work) as the "area of work in public health to promote and maintain the highest degree of physical, mental and social well-being of workers in all occupations" (Word Health Organisation, n.d.). Besides the explicit reference to well-being, this definition also shows that the three dimensions, physical, mental, and social, are part of both health and well-being. Workplace health encompasses occupational health and health promotion (Hanna and Markham 2019), with the former focusing on managing work-related health risks, while the latter addresses various issues like stress management, diet, exercise, and smoking (Pritchard and McCarthy 2002). Health promotion is also closely linked to wellness initiatives (Conrad 1987) and is often confused with well-being initiatives, contributing to the misinterpretation of the concept in many.

To disentangle health and well-being concepts, Danna and Griffin (1999) analysed different conceptualisations of workplace health and well-being in research and found that some propose their own operational concepts, while others try to name specifically if they address either the physical or mental dimension. The inconsistent use of the exact words that allow for multiple interpretations and meanings has also been emphasised by Fleuret and Atkinson (2007) as a source of confusion. Inconsistencies in defining 'well-being' are prevalent in the construction industry. While some studies recognise it as a multifaceted concept (Carmichael *et al.,* 2016), including the impact of work on health and quality of life, consistent with previously analysed definitions of well-being, others consider it a work in progress, often mistaken for welfare (Smyth *et al.,* 2019). The confusion is understandable as the Health and Safety Executive defines welfare facilities as "necessary for the well-being of your employees" (Health and Safety Executive, n.d.), but this only refers to the material and physical conditions of the workplace.

Despite the differences in definitions, many authors agree that better measurement tools are needed to improve the conceptualisation of well-being in the construction industry (Carmichael *et al.,* 2016; Smith 2019). There is little interest in developing strategic initiatives to improve well-being whose impact will only be seen in the distant future (Smyth *et al.,* 2019) and have no short-term financial returns (Carmichael *et al.,* 2016; Hanna and Markham 2019; Smith 2019). On the other hand, the global COVID-19 pandemic has shown the world the importance and need to care for the workforce's physical and mental health and well-being (Pamidimukkala *et al.,* 2021). While some authors consider the pandemic as an opportunity to make fundamental changes in the construction industry and improve overall HWS (Sherratt and Dainty 2022), others highlight the negative impact it had on general workers' well-being (Stiles *et al.,* 2021)

While the construction industry has widely adopted the general definitions of occupational health by the WHO, the concept of health in construction is shaped by many structural issues that are inherent to the industry, such as the different roles, transient workforce, and size of organisations (Hanna and Markham 2019). Moreover, it is crucial to consider the time dimension, as the long-term health effects of occupational hazards are more challenging to demonstrate (Pritchard and McCarthy 2002). Sherratt (2018) further explores this issue and finds that the construction industry's view of health is more focused on achieving fitness to work rather than ensuring a healthy worker. This perspective promotes a short-term approach to health that prioritises addressing immediate hazards over issues that may have long-term consequences and are not immediately apparent. The implications of this approach will be further analysed in the management section.

Safety At Work

There is no single definition of safety at work. However, most literature agrees that it is related to 'the control of hazards' (Ball and Frerk 2015), 'avoiding harming people, environment or investment' (Rasmussen 1997), and the state where ‘as little as possible goes wrong’ (Hollnagel 2019). There is no recipe for safety nor a single way to study and manage safety at work, as it is impossible to cover all variables in any situation. Hence, in the following part, the origins and evolution of the concept of occupational safety will be examined to reveal how the definition of safety at work has changed over time. The initial conceptualisations of safety, referred to as Safety I, focus on studying human error (Reason 1997) and control of work processes (Rasmussen 1997). They advocate for the standardisation of procedures to be able to predict all the variables that could go wrong. For example, Reason pointed out, "safety is defined and measured more by its absence than by its presence" (as cited in Coze 2019, p. 265), showing the importance given to mistakes and fatal errors over good practices, which set the ground for the next age in safety science. In response, Hollnagel and Woods, in 1983, opened the debate about ‘human error’ by questioning whether individuals were the only ones at fault in an accident. They propose to focus on the functional coupling of the human and the machine (Le Coze 2022). This line of thought is called Safety II, and building from this approach, Dekker (2002) explored human error. He considered it a ‘symptom of trouble deeper inside the system’ and proposed that ‘safety is not inherent’ in practices. From this new view, the concept of safety should not only be based on the study of failures and accidents but also on those who excel. Recent literature on safety argues that these two approaches should not be considered contradictory but complementary in understanding safety practices (Ball and Frerk 2015). Meanwhile, the lack of empirical research supporting the success of the ‘New View’ of safety has been the source of much criticism (Cooper 2022; Le Coze 2019).

Safety in the construction industry is often defined by negative statistics that show the ratio of accidents and fatalities compared to other industries (Sherratt 2016). This view of safety considers accidents as an inevitable part of construction practices, and it defines safety by its absence, in line with Safety I approach (Hollnagel 2014; Sherratt 2016). However, a recent publication by Sherratt and Raiden (2023) proposes evidence in practice that the construction industry is now starting to adopt the 'new view' of safety (i.e., Safety II), moving away from a blame culture and human errors towards a more integrated approach considering adaptability and resilience. Overall, looking at the attempts to define HWS at work, it becomes clear that safety and health have been studied for longer than well-being. Both occupational health and safety have evolved independently over time, initially focusing on being 'the absence of something' - i.e., absence of accidents and illness. However, both areas now aim to recognise and replicate good practices, shifting the focus from the negative to the positive. While the definition of well-being is still a work in progress, it acknowledges the importance of caring not only about the body and the mind but also about the social experience inside and outside the work site. Thus, it is critical to adopt an integrated approach (Carmichael *et al.,* 2016; Lingard 2019; Smyth *et al.,* 2019) that links well-being to the definitions of health and safety, given the interrelatedness of these three concepts. Workers' lives outside work affect their health and well-being, as the boundaries between work and non-work issues are artificial constructs that cannot be separated in the real world. Without clear definitions, the use of HWS concepts together can lead to conceptual overlaps and confusion.

Management Approaches for HWS in Workplace

Various factors, including legislative context, organisational structure, and industry characteristics, influence the management of HWS in the workplace. (Hanna and Markham 2019). While health and well-being initiatives often rely on self-perception measurement (Law et al.1998), safety is typically regulated and standardised (Le Coze 2019). However, as Gherardi and Nicolini (2000) propose, safety can also be subjective and open to interpretation, and different actors may have varying perceptions of what constitutes safety. That said, Lingard (2019) highlights the semantic problem with using the acronym 'H&S' (Health and Safety) as a singular unit that may give the impression that managing health and safety hazards can be done with the same process. Several authors have pointed out that research under the H&S name is skewed, primarily focusing on managing safety while neglecting health (Cooper and Phillips 2004; Sherratt 2018; Jones *et al.,* 2019).

On the other hand, there have been attempts to develop a more comprehensive approach to managing HWS in the workplace, such as the US government's Total Worker Health® (TWH) program. TWH prioritises protection from hazards and then promotes the prevention of illness and injury. It also addresses the relationship between work and non-work conditions (CDC Foundation n.d.). However, Lax (2016) has criticised TWH for focusing too much on reducing healthcare costs and not enough on improving working conditions. Although TWH has received little research attention in non-US contexts, studies in the construction industry have shown positive impacts at the individual level, highlighting the need for managerial involvement to improve work design and manage trade-offs (Lax 2016; Borys 2009; Grant *et al.,* 2007).

Shifting our focus to the construction industry, it is important to note that legislation in the UK has historically prioritised safety over worker health and well-being, using a prescriptive model with a Safety I (see previous section) approach that many have criticised as complex and bureaucratic (Lingard 2013). Although improvements in physical safety have led to a significant reduction in fatalities over the past 50 years, the industry still struggles with high rates of suicide among workers in the UK and globally, highlighting the need for increased attention to worker health and well-being (Xu and Wu, 2023). Unfortunately, the industry tends to view health as secondary to safety and well-being as conditional on health (Carmichael *et al.,* 2016; Jones *et al.,* 2019; Xu and Wu, 2023), although more deaths in the UK construction industry are caused by health issues than accidents (Jones *et al.,* 2019). Lingard (2019) notes that the time lag between exposure and illness in the construction industry contributes to the perceived importance of safety over health and underscores the need for a more comprehensive approach to managing worker well-being in the industry.

Perhaps this is not surprising considering Grant et al.'s (2007) argument that the management of workplace HWS often contemplate trade-offs between the three dimensions (body, mind, social) by enhancing one aspect when the other need to be curtailed (Grant *et al.,* 2007). It aligns with the general perception of the construction industry that it is inherently dangerous, where worker health has been commodified and exploited within the system (Sherratt and Sherratt 2017). According to Lingard (2019), the construction industry's approach to well-being is more about urging workers to alter their habits than modifying the inherent systemic hazards. Although health promotion initiatives have the potential to improve health in the construction industry (Hanna and Markham 2019), these events should not be limited to wellness initiatives but should address the industry's structural risks inherent to construction work activities (Lingard 2013; Jones *et al.,* 2019). Overall, while most publications about managing HWS in the workplace focus on individual dimensions of physical, mental, and social hazards, they express interest in a holistic approach like TWH. Within the construction industry, it is crucial to give equal emphasis to all dimensions of worker HWS and address the root causes of problems to achieve meaningful improvements.

Employee Perceptions of HWS At Work

Employee perceptions of HWS are different from how HWS are seen from a managerial perspective, which further adds to the lack of conceptual clarity of health, well-being, and safety. For example, employees' perception of safety has many layers, and it can be linked to different factors such as the risk acceptance by workers (Jones *et al.,* 2019), safety climate (Cooper 2000), artefacts and power (Hutchinson *et al.,* 2022), and organisational culture (Neal *et al.,* 2000; Cooper and Phillips 2004). Under this complex set of arrangements, 'feeling safe' and 'being safe' can mean two different things, with the former relating to employees' individual perceptions and the latter relating to improving the safety of operations (Rae and Alexander 2017).

Smyth *et al. (*2019) observe that HWS initiatives in the UK are primarily driven by legislation and regulations rather than clients or providers, resulting in misalignment. Rae and Provan (2019) distinguished between 'safety work' and 'safety of work', highlighting the difference between managing safety from a corporate perspective and experiencing it as an employee. While 'safety work' focuses on performance indicators, risk assessments, and KPIs to satisfy managerial functions of safety, 'safety of work' emphasises employees' perspectives to prevent harm during operations. More importantly, Rae and Provan (2019) state that different actors' varying perceptions of the two concepts often generate confusion regarding the safety they are addressing.

Complementing the previous contrast, Borys *et al. (*2009) explored the perception of safety in 'work as done' by employees versus 'work as imagined' by top management. Safety that stays on paper is insufficient and needs to be translated into operations. Borys (2009) identifies common sense as a critical element in workers' risk awareness, but managers often reject it, while workers reject risk awareness paperwork crucial for managers. This approach aligns with the literature on organisational culture and safety culture (Cooper 2000; Borys 2009), emphasising the importance of considering the organisational culture beyond safety reports for management. In the construction industry, health and safety initiatives are commonly viewed as relevant to construction sites, while well-being initiatives are typically associated with office work (Smyth *et al.,* 2019). Even though employers may organise well-being initiatives, they are usually for healthy habits or smoking cessation, and workers may feel that these efforts are intrusive (Smyth *et al.,* 2019). While such actions are important for improving quality of life, they represent only a partial view of workplace well-being and do not provide a holistic approach to managing and enhancing it (Lax 2016). Sherratt and Sherratt (2017) connect this narrow perception of well-being with Corporate Social Responsibility (CSR) programs in construction, which may offer only superficial activities to improve workers' well-being without addressing the hazardous working conditions that exist in the industry.

DISCUSSION

The concepts of HWS are closely intertwined and often used in conjunction with one another for contextualisation. However, it is essential to note that they are not interchangeable words but complementary concepts with distinct characteristics that should not be overlooked. The lack of clear definitions for HWS has created a problem managing these crucial aspects in various industries. In the construction industry, the everyday use of the acronym H&S has given the impression that it takes care of health and safety as a single unit. However, safety tends to be the primary focus, often at the expense of addressing health concerns. Unfortunately, health issues are not given the same level of attention as immediate physical hazards. Furthermore, when it comes to addressing wellbeing, there is a tendency to rely on wellness activities that address superficial symptoms rather than the underlying causes.

Different industries have different approaches to management practices in health, safety and well-being, which are influenced by the legislation and structure of the organisation. The TWH program can serve as a starting point to improve these approaches by providing a holistic framework to manage HWS. However, it is essential to remember that while managers may invest in developing initiatives, the workers are who need to follow through with the procedures. A significant challenge in the HWS management of construction, is the trade-offs that have historically taken place favouring addressing safety over health and well-being, and commodifying workers health within the industry.

The different perceptions of well-being can be particularly confusing, as it is difficult for employees to distinguish between the factors that affect their well-being at work and outside of work. From a management perspective, measuring the effectiveness of well-being initiatives is also challenging, therefore more difficult to implement them. Superficial practices may have a placebo effect, making managers believe that they are improving the overall well-being of workers. However, workers often view such practices as intrusive and adding nothing to the inherent risks of their trade. In the context of the construction industry, although 'safety of work' (i.e., carrying out a job without accidents) is the main objective of occupational safety, the focus often shifts to 'safety work'. The management group prioritizes adherence to standards with their primary focus is on measuring and providing evidence of safety practices. On the other hand, employees are primarily concerned with their personal safety while working on-site. Therefore, addressing work design as the origin of safety risks and health hazards that affect the well-being of the construction workforce is crucial to achieving a holistic view of HWS. It must be part of the organisational culture and integrated into daily practices.

CONCLUSIONS

A more precise definition of health, well-being, and safety, along with a holistic approach to management practices and an understanding of the perspectives of both management and workers, are crucial for improving workplace HWS. By refining the definition of health, well-being, and safety and embracing a holistic management approach, we can make significant strides in enhancing workplace HWS. This inclusive approach, recognizing the relationship between employers and employees, guides the identification of appropriate management approaches. It guarantees that all stakeholders' health, well-being, and safety are considered. Through the implementation of integrated strategies and the consideration of work design, the construction industry can create a safer and healthier working environment for all individuals involved, paving the way for a better future in the industry.

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OSHCIM: A STUDY ON MALAYSIAN OSH REGULATORY CAPABILITIES READINESS IN THE DESIGN PHASE

Azman Hussain[1], Che Khairil Izam Che Ibrahim[2], Sheila Belayutham[3], Patrick Manu[4] and Mat Ali Nazruddin[5]

[1&5] Construction Safety Division, DOSH Putrajaya, Malaysia

[2,3] School of Civil Engineering, Universiti Teknologi Mara, Shah Alam, 40450, Malaysia

[4] Architecture and the Built Environment, University of the West of England, Frenchay Campus, Coldharbour Lane, Bristol BS16 1QY, UK

Continuous accidents and fatalities in construction projects have increased scholarly interest in addressing safety and health during the design phase. In Malaysia, the introduction of the Occupational Safety and Health in the Construction Industry (Management) (OSHCIM) in 2017 as a legislative framework to enhance Prevention through Design (PtD) practices has recently gained attention. This study aims to evaluate the regulatory capabilities of Malaysia concerning OSHCIM requirements and stakeholders' readiness. A mixed-method approach was employed, surveying 91 purposively sampled enforcers. The findings indicate that the regulator requires further clarification on OSHCIM requirements and additional information and guidance, particularly during the conceptual and design stage involving clients and designers. The Department of Occupational Safety and Health (DOSH) should organise seminars or short professional courses to support and raise awareness among enforcers. These study findings offer valuable insights for regulatory bodies, helping them understand the readiness of enforcers and address safety and health concerns throughout the project lifecycle.

Keywords: Prevention through Design, OSHCIM, enforcement, safety, Malaysia

INTRODUCTION

The construction industry in Malaysia is marked by hazardous work-related incidents and accidents, causing concern among all parties, particularly industrial players in a developing nation. Accidents and fatalities in the construction industry can be controlled or reduced through proactive measures taken by all stakeholders, especially clients, designers, and contractors within the construction supply chain. Government agencies such as the Department of Occupational Safety and Health (DOSH) and the Construction Industry Development Board (CIDB) have made significant efforts to ensure safety and health in this sector through enforcement, training, policy setting, and other initiatives. In addition to these efforts, introducing new regulations and guidelines is crucial to improving the construction industry's current safety and health practices and creating a safe and healthy environment. The willingness and

[1] azmanhussain@yahoo.com

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collaboration of all stakeholders are necessary to effectively manage workplace risks and reduce the occurrence of accidents and fatalities in this sector.

The Role of Occupational Safety and Health (OSH) Legislation and Designers' Responsibilities

Governments worldwide have introduced OSH legislation, including requirements for designers to incorporate safety and health measures into construction projects (Behm 2005). The European Framework Directive 92/57/EEC, known as the EU Design for Safety law and similar regulations in Singapore, Australia and other countries have played a crucial role in promoting safety in the construction industry (Martínez-Aires, Rubio Gámez, and Gibb 2016). However, the capabilities of regulatory authorities in Malaysia and other Asian nations need to be assessed to ensure effective compliance (Sha 2004). Understanding the enforcement capabilities of these authorities is essential to promoting safety and health in the construction industry.

Regulatory bodies like the Department of Occupational Safety and Health (DOSH) and the Construction Industry Development Board (CIDB), play a crucial role in overseeing and enforcing safety and health regulations in the construction industry. In Malaysia, it is important to assess the capabilities of these authorities due to the unique challenges and characteristics of the construction industry. Enhancing their capabilities can strengthen the enforcement of safety and health regulations and foster a safer working environment for construction workers and the public (Suresh *et al.,* 2017). The capabilities of regulatory authorities are crucial in setting standards, monitoring compliance, providing guidance, and taking enforcement actions to prioritize safety and health measures. Further exploration is needed to understand their capabilities and ensure effective compliance.

Implementation of OSHCIM Guideline and Regulatory Capabilities

To enhance safety issues in the construction industry, DOSH introduced the Occupational Safety and Health in Construction in Management (OSHCIM) guideline in February 2017, which applies specifically to the construction industry (DOSH, 2017). These guidelines, adapted from the CDM 2015 Regulations, aim to promote shared responsibility among all stakeholders involved in construction projects. However, as OSHCIM is relatively new and considering the diverse regulatory landscape in Malaysia. DOSH with its multidisciplinary composition representation in all states of Malaysia, it becomes crucial to understand the capabilities of regulatory authorities to ensure the effective implementation of OSHCIM by all stakeholders. It is worth noting that the multidisciplinary composition of DOSH allows for a comprehensive evaluation of safety practices and compliance. By collaborating with professionals from other agencies or departments, DOSH can effectively address specific issues, leverage external expertise when necessary, and ensure consistent and proactive enforcement efforts.

Promoting Practical Implementation of Design for Safety (DfS)

Previous studies have focused on Design for Safety (DfS) and its incorporation into construction projects. While much of the literature has concentrated on the concept, techniques, and utilisation of DfS in construction, there is a significant body of research on how DfS can be practically implemented. Most of the past research has examined DfS knowledge, attitude, practices, and the capabilities of designers and organisations in the construction industry (Patrick Manu *et al.,* 2018). Despite the awareness of DfS, there is a need for its more practical implementation. All stakeholders must work together to encourage design professionals to use DfS effectively, providing necessary support for its execution. While most engineers prefer Prevention through Design (PtD), the practical implementation of DfS is still evolving (Abueisheh *et al.,* 2020). Although design professionals generally have positive attitudes towards DfS and are familiar with its principles, they tend to apply it sparingly (Che *et al.,* 2020; Sharar *et al.,* 2022). Similar concerns regarding DfS implementation have been identified in Palestine (Abueisheh *et al.,* 2020). Even in developed countries like New Zealand, design professionals still need help in implementing DfS effectively (Guo *et al.,* 2021).

Various factors can influence the adoption of the DfS concept in the construction industry, as highlighted by Abueisheh *et al. (*2020) and Poghosyan *et al. (*2018). These factors include designer attitudes and acceptance of the concept, designer knowledge and education, DfS legislation, client influence, and the availability of DfS tools. The failure to prioritise safety and health has resulted in numerous incidents causing fatalities, severe injuries, and property damage. According to DOSH data (Official DOSH Website 2023) in 2021, the construction industry reported a fatality rate of approximately 6.3 per 100,000 workers, resulting in 73 deaths. These figures accounted for 24% of the total fatalities across all industries in Malaysia, which amounted to 301 fatalities.

The responsibility for managing safety and health in the construction industry extends beyond contractors and should involve clients, designers, and regulators. However, existing studies have primarily focused on the roles of clients, designers, and contractors, neglecting the critical role of regulators. The governments are responsible for implementing new rules and regulations, requiring significant effort in drafting, enacting, and enforcing them to meet evolving standards (Fungsi - CIDB HQ n.d.; Official DOSH Website 2023). Regulators in the construction industry play a crucial role in overseeing and enforcing legislation, conducting inspections and audits, addressing violations, providing guidance and education, and promoting safety. While various standards and codes of practice exist, it is essential to regularly assess the capabilities of regulatory authorities to ensure their effectiveness in promoting compliance and fostering a safe working environment. By addressing regulators' challenges, stakeholders can collaborate to enhance safety practices, achieve compliance, and establish a culture of safety and health.

The Critical Role of the Regulator

Regulatory bodies play a vital role in enforcing compliance in the construction industry, including prevention through design (PtD), in the construction industry. They conduct inspections, audits, and other enforcement activities to ensure adherence to safety regulations throughout the design and construction process (Che Ibrahim and Belayutham, 2020). This paper provides insights into the factors influencing construction site safety, although it does not directly focus on regulatory capabilities. The involvement of regulatory bodies contributes to the enforcement and promotion of safety in construction.

All stakeholders must effectively comply with safety requirements, and regulatory bodies must provide guidance, training, and support to designers, contractors, and other involved parties. Moreover, regulatory bodies may collaborate with industry groups, professional organisations, and other stakeholders to establish safety best practices and standards for construction design (Abueisheh *et al.,* 2020).

Further research is needed to understand the impact of regulatory bodies on the project life cycle, regarding PtD implementation. Regulatory bodies play a critical role in ensuring compliance with safety regulations, and their increased oversight and enforcement in PtD implementation is essential (Aksorn and Hadikusumo, 2008). Enforcers act as regulatory bodies, which are crucial in managing safety risks in construction projects and require the necessary resources and skills for effective compliance. This study highlights the role of enforcers possessing competency, a sound strategy, corporate experience, an intelligent and reliable system, suitable infrastructure and information structure, and fostering good collaboration with other agencies (Manu *et al.,* 2019). Law enforcement of safety regulations and promoting best practices in construction design by regulatory bodies can contribute to a safer working environment (Aksorn and Hadikusumo, 2008).

METHOD

This study employed a mixed-methods approach, combining quantitative data from questionnaires and qualitative data from semi-structured interviews to assess the readiness and capability of Malaysian enforcement officers in enforcing OSHCIM. Using mixed methods allows for a comprehensive understanding and enhances the credibility of the findings by incorporating multiple data sources (Jogulu and Pansiri 2011)

An analytical framework based on previous research, guidelines, and standards was employed to identify critical factors. The study incorporated the six categories identified by Patrick Manu *et al. (*2019), namely competence, strategy, corporate experience, systems, information and infrastructure, and collaboration. Additionally, factors from Aksorn and Hadikusumo (2008) study, such as worker involvement, safety prevention and control systems, safety arrangements, and management commitment, were considered. These factors align with the requirements of ISO 45001:2015, which emphasises continuous improvement through the Plan-Do-Check-Act cycle. The development of survey questions was guided by the OSHCIM guidelines to ensure their relevance to the local context. The study aims to identify areas for enhancing the implementation of OSHCIM in the construction industry by the regulatory body.

Instrument

This study utilised a combination of 91 questionnaires and in-depth interviews with participants selected through purposive sampling. The participants were required to have at least five years of experience with an engineering degree and be involved in either the design or construction phase.

Expert interviews were conducted to validate the constructed questionnaire for the Regulatory Capabilities Questionnaires. The researcher successfully interviewed five experts, each with over 20 years of experience in service. Four of them held the position of Deputy Director in charge of Construction Safety, while one was the Director of Construction Safety at DOSH Headquarters, responsible for formulating construction safety policies for the country. All the experts had extensive experience in enforcing construction safety regulations. The interviews lasted between 40 and 60 minutes, ensuring comprehensive insights.

Based on the feedback obtained from the expert interviews, the initial questionnaire was modified. Additional relevant elements were incorporated, such as the prosecution procedure, the issuance of fines, and other punitive actions. The importance of collaboration with other agencies was also emphasised, focusing on addressing this issue at the highest management level. Elements that were not applicable to the context of the Malaysian construction industry, such as additional remuneration for high-risk activities, were eliminated. The objective was to ensure that respondents could easily comprehend the survey questions and provide valuable data.

The questionnaire included elements derived from the recommendations outlined in OSHCIM 2017, covering various aspects of the construction life cycle. It was divided into three sections. The first part (SECTION A) gathered background information about the participants' experience levels. The second part (SECTION B) assessed the attributes related to DfS for Regulatory Body Capability. The third section (SECTION C) allowed participants to provide comments and suggestions.

During the interviews, selected enforcement officers were expected to share their perspectives, knowledge, abilities, and practices related to safety and health, specifically in implementing OSHCIM throughout the construction project life cycle. The interviews aimed to evaluate the regulatory body's capabilities in implementing OSHCIM effectively.

The Relative Importance of Factors

Respondents were requested to express their opinions on the importance of a list consisting of 6 main attributes and 28 sub-attributes related to the regulatory body's capabilities. They assigned scores ranging from 1 to 5, with '1' indicating unimportance and '5' being very important. The importance of each factor was determined by applying a scoring formula (Kometa, Olomolaiye, and Harris 1994). Subsequently, Equation (1) converted the scores into importance indices.

$$\text{Relative importance index (RII)} = \frac{\sum W}{A \times N} \qquad \text{Eq (1)}$$

W is representing the weighting assigned to each factor by respondents, with weights ranging from 1 to 5. In this study, the highest weight (A) was assigned a value of 5. N represents the total number of samples. The resulting relative importance index (RII) is then calculated and normalised within the range of 0 to 1.

Table 1 displays the RII for each factor that affects regulatory body capabilities, as reported by the respondents.

The survey was distributed during the workshop held across Malaysia. None of the participants was incentivised to participate; everyone who participated did so voluntarily. The University's ethical principles and standards assured that their response would be confidential.

FINDINGS

According to the survey, 91 out of 100 distributed forms were returned, representing personnel from 15 states of Malaysia. Around 61% of the regulators had between 5 and 10 years of experience in the construction industry, with all of them holding an engineering degree. Only 6% had a Masters degree, and 1% held a PhD. Most of the regulators were based in Central Malaysia.

Table 1 displays the mean results based on the Likert scale, where 1 indicates "not important", and 5 indicates "very important," measuring the regulatory body's capabilities in implementing OSHCIM. The sub-attributes are arranged in descending order according to the RII rank, as shown in Table 1.

Table 1: RII of factors affecting Regulatory Capabilities Body for the construction life cycle.

Ranking	Main Attributes	Sub Attributes	Existing Ranking	Very Important %	RII
1	Competency	Understanding the OSHCI(M) Knowledge requirement	1	75.82	0.94
2		…. identifying the critical elements for the roles of Stakeholders	2	70.33	0.92
3		OSHCI(M) continual improvement and training for the regulator	4	62.64	0.90
4		OSHCI(M) or similar experience of auditing, inspection on the stakeholders	3	61.54	0.89
5		Regulator reference and seeking advice from supervisor or an expert panel.	5	61.54	0.89
6		Selection and position of the appropriate personnel for enforcement.	6	57.14	0.87
7		Experience conducting any punitive action activities	7	51.65	0.85
8	Corporate Experience	Fund and allocation budget	9	61.54	0.90
9		System recognition from internal and external	8	57.14	0.89
10	SYSTEM	The procedure of enforcement (IP preparation, issuance of notices etc.)	24	64.84	0.93
11		Performance monitoring and measurement	26	61.54	0.90
12		Internal and external audit	25	60.44	0.89
13		Accident and incident investigation and reporting	28	61.54	0.88
14		Worker's participation.	27	53.85	0.87
15	Strategy	Top management commitment to OSHCI(M)	19	68.13	0.92
16		Safety at workplace	20	63.74	0.91
17		Organising, planning, managing, and monitoring	17	60.44	0.90
18		Understanding the requirement of the Regulator policy with OSHCI(M).	18	60.44	0.89
19		Public safety	21	63.74	0.89
20		Promoting and awareness program	22	54.95	0.88
21		Research and innovation	23	47.25	0.86
22	Collaboration	Intra-collaboration	10	56.04	0.87
23		Inter-collaboration	12	52.75	0.86
24	Infra and Info	ICT resources (software, gadgets (tablets, laptops, pc), etc.)	13	57.14	0.89
25		Workplace (workspace, workstation, telephone)	14	54.95	0.88
26		Accessing to any references, information and data related to OSHCI(M)	12	53.85	0.86
27		Technologies (BIM, drone, camera, smart tools, artificial intelligence etc.)	16	53.85	0.84
28		Official vehicle	15	46.15	0.81

The mean results align with the findings from the distributed surveys, indicating that the enforcers fully understand the importance of safety and health in the construction industry. This understanding demonstrates positive assurance that OSHCIM implementation can bring long-term advantages to construction projects, as supported by Hwang, Zhao, and Toh (2014).

The study's findings are consistent with the research conducted by Behm, Culvenor, and Dixon (2014), which emphasises the importance of competence as the most crucial attribute for regulatory capability, followed by corporate experience, system, and collaboration. Prioritising the prominent and sub-attributes according to the RII for enhancing regulatory capability in OSH enforcement aligns with previous research, apart from corporate experience and system. All the listed attributes received a score of over 50% in the "very important" category.

The finding that the sub-attribute of research and innovation received a score of only 47.25% for "very important" under the main attribute of strategy suggests that enforcers need to develop a greater appreciation for the value of research and its potential long-term benefits for their organisation (Tashakkori *et al.,* 1998; Jogulu and Pansiri, 2011). Regarding this sub-attribute, it is noteworthy that enforcers mentioned during the interviews that they work under a very tight budget, which significantly limits their ability to invest in research and innovation (Manu, Poghosyan, Mahamadu *et al.,* 2019). This financial constraint implies that their role primarily involves on-site physical activities, and they may not perceive the relevance of research as part of their day-to-day work culture. This finding shed light on the challenges enforcers face in prioritising research and appreciating its potential long-term benefits for their organisations.

Another good finding was that enforcers' preference for using their personal vehicles due to claim issues, additional allowances, and greater control, despite the provision of official vehicles with a score of 46.15%, along with limited availability and poor maintenance of such official vehicles, underscores their practical considerations and preferences in transportation during enforcement activities for the "Infrastructure and infostructure" attribute (Manu, Poghosyan, Mahamadu, *et al.,* 2019). This insight highlights enforcers' practical considerations and preferences regarding transportation during their enforcement activities.

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Based on extensive interviews, enforcers concur that accidents in construction projects often arise from a lack of safety considerations in the initial phases, supporting the findings of Mohd *et al.* (2020) and Behm and Culvenor (2011). However, there is a need to enhance the understanding of safe design concepts among supporting staff compared to the management level. Enforcers are still exploring the benefits of OSHCIM in monitoring, assessing, and enforcing safety regulations to improve overall performance. It is crucial to grasp the requirements of OSHCIM, particularly the client-designer-contractor relationship, for successful implementation in Malaysia. Additionally, enforcers need to learn from accidents and understand the impact of design on incidents. Supporting staff, who mainly interact with contractors, would benefit from more training on safe design in the pre-construction phase to broaden their applied knowledge beyond day-to-day construction activities.

These results highlight the significance of regulatory competence, corporate experience, effective systems, and collaboration in enhancing regulatory capability in OSH enforcement (Behm, Culvenor, and Dixon, 2014). Therefore, it is recommended that DOSH conduct a comprehensive education program to promote these ideas and improve the overall understanding and implementation of OSHCIM.
As for enforcers, they are more accustomed to enforcing during the construction phase, which means they usually only meet with the contractors. In OHSCIM, the most influential stage to reduce accidents is the design stage, suggesting they need to explore starting to meet and learn about the designer's roles and duties to clients and the new organisation that will focus on similar aspects as the designer. Most of them agreed that they also do not know how to enforce OSHCIM effectively since industry players mostly do not understand the PtD concept (Aksorn and Hadikusumo, 2008).

These results underscore the significance of regulatory competence, corporate experience, effective systems, and collaboration in enhancing regulatory capability in OSH enforcement (Manu, Poghosyan, Mahamadu *et al.,* 2019). Thus, DOSH should conduct a vast education program to promote these ideas (Aksorn and Hadikusumo, 2008).

CONCLUSIONS

The study findings suggest that enforcers understand construction processes and operations, worker safety, constructability issues, and hazard identification at construction sites, regardless of their engineering education level. However, the study also revealed that some enforcers needed knowledge of construction safety, particularly during the conceptual and design stage. Furthermore, clients and designers are new areas of enforcement that require attention, as they are still determining the OSHCIM requirements they must comply with. To address these issues, DOSH should focus on raising awareness of OSHCIM implementation among enforcers and provide them with seminars or short professional courses. Additionally, examining successful case studies from other countries can serve as a guide for achieving quick wins.

It is essential to acknowledge the need for specificity in addressing the unique characteristics of the Malaysian construction sector context. By delving into this specificity, future research can further explore the country's effectiveness of regulatory measures and enforcement practices. Additionally, to enhance the understanding of regulatory capabilities and their impact on safety and health in the construction industry, it is recommended that comparative studies with different geographical locations, especially in Asian regions, should be conducted to capture the similarities and differences of the regulator's DfS capabilities. Such a comparative analysis would provide valuable insights into the similarities and differences in regulatory approaches and their outcomes, allowing for identifying best practices and areas for improvement. This would contribute to the advancement of regulatory frameworks and promote the adoption of effective strategies to ensure safety and health in construction projects across various contexts in the region.

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A SYSTEMATIC REVIEW OF DIGITALISATION ADOPTIONS IN CONSTRUCTION SAFETY EDUCATION AND TRAINING

Clara Cheung[1], Lisley Muchoki[2], Ruoyu Jin[3], Zulfikar Adamu[4], Nai-Wen Chi[5] and Je-Chian Lin[5]

[1&2] *Department of Engineering Management, School of Engineering, The University of Manchester, MECD Campus, Manchester, M13 9PL, UK*

[3&4] *School of Built Environment and Architecture, London South Bank University, 103 Borough Road, London SE1 0AA, UK*

[5] *Department of Civil Engineering, College of Engineering, National Taipei University of Technology, No. 1, Sec. 3, Zhongxiao E. Rd, Taipei, 106344, Taiwan*

[6] *Department of Civil Engineering, College of Engineering, National Taiwan University, No.1, Sec. 4, Roosevelt Road, Taipei, 10617 Taiwan*

Construction industry has been facing high accidents and fatalities while on the job training and education in university has been found critical for improving safety performance. The advancement of technologies in this industry has been claimed to be useful in training and educating both workers and students on safety procedures. This review-based study aimed to identify and analyse technologies that have been adopted in built environment to help improve health and safety on construction sites through training and education. A systematic literature review approach was adopted by analysing 55 articles relevant to this theme. Safety scenarios addressed, safety regulations and standards, and learning outcomes were analysed to evaluate the identified technologies. The results indicated that the adopted immersive technologies were able to improve the learning performance of trainees and learners as evidenced by case studies. These technologies could increase the students and workers' user engagement and motivation on health and safety training. Further differences between education and training were unveiled, for example, training-based platforms were more likely to miss the content in safety regulations and standards.

Keywords: BIM; digitalisation; safety; safety education, training

INTRODUCTION

The Construction industry involves hazardous work leading to fatalities and repeated incidents (Lee *et al.,* 2020). Specifically, previous research shows that insufficient health and safety education and training for construction students is one of the underlying problems that lead to poor safety performance (Lee *et al.,* 2020). This is

[3] jinr@lsbu.ac.uk

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because when the students enter the industry, they have little knowledge on practical work on sites and safety management skills leading to accidents. However, many of these educational or training programmes (e.g., Bhandari et al., 2019) for construction safety were found inadequate in promoting student engagement.

Meanwhile, recent technology advancements such as virtual reality, Building Information Modelling (BIM), 3D and 4D gaming, augmented reality, mixed reality, serious game and 360-degree panorama in the industry (e.g. Swallow and Zulu, 2020) have shown that they were effective in improving the learning of safety management (Swallow and Zulu, 2019). Existing research had proposed technologies and frameworks that could be used for construction safety education and training with some of them already being tested on their effectiveness but very limited has been done on the combined analysis of these technologies. This review-based study aims to fill in this knowledge gap by identifying and analysing technologies that have been used in the construction industry to improve health and safety in construction sites and built environments worldwide.

LITERATURE REVIEW

Need for Safety Education and Training

Safety education has been seen to face many challenges due to outdated curricula and materials and a lack of qualified professionals and teachers teaching on this topic (Vatin *et al.,* 2014). Students and civil engineers who participated in an interview carried out by Le et al., (2014) stated that the adopted traditional safety education methods which had been passive and not engaging such as textbooks do not provide efficient skills to help curb the problem. This could be because they lead to cramming and short-term retention (Pedro *et al.,* 2019). This could also be because safety education requires practical and on-site experience as well as in-depth comprehension which traditional teaching methods do not offer (Yang and Goh, 2022). A systematic literature review carried out by Gao *et al. (*2019) proves this stating that computer-aided technologies greatly improve learners' training process as well as having more advantages over traditional techniques. Professional safety training on the other hand is more popular than training in higher education from the number of studies published in this area. This could be because workers need to have safety awareness knowledge to promote safe working conditions in construction sites ensuring their fellow workers are safe and the construction phases are progressing smoothly (Xu and Zheng, 2020). Even with much attention being given in professional training, workers are still unable to effectively recognize hazards in complex and dynamic environments (Albert *et al.,* 2014). Bahn (2013) carried out an experiment to test hazard identification skills of workers by categorizing hazards into 4 groups; obvious, emerging, trivial, and hidden and found out that the participants were only able to locate 46% of hazards under each category.

Technologies Adopted for Health and Safety Training and Education

In recent years, visualisation technologies such as virtual reality have proven to improve health and safety in the construction industry (Katika *et al.,* 2022). Teaching accident causation should be of high priority not only because of educating learners on past engineering failures but also to stop the recurring failure modes experienced in the past causing accidents and increasing learning advantages like ensuring long-term retention of the learning outcomes (Saleh and Pendley, 2012). Recent inventions of different technologies and virtual tools have majorly helped with the advancement of teaching health and safety, especially in the construction sector which requires active learning to ensure learners acquire the required knowledge and skills (Sepasgozar, 2020). Computer-aided technologies have in recent years been used globally to enhance the training of safety management in construction and built environments with game technologies becoming one of the novel approaches to help with training (Kazar and Comu, 2021). Ruggiero (2018) stated that game technology could be used to replicate real-world scenes in a computer-simulated environment. Sepasgozar (2020) developed a Group Wiki Project (GWiP), an interactive construction reality tour, digital twin, pilling augmented reality (PAR) and a virtual tunnel boring machine (VTBM) for learning purposes in a university to evaluate the effectiveness of mixed reality (MR) in teaching students on construction safety. It was discovered that MR allows tutors to easily monitor students work rather than traditional based techniques. Huang *et al. (*2019) however stated that the construction and architectural industry did not have enough application methods to be able to effectively provide the needed feature to users using this type of technology.

METHOD

A systematic literature review was adopted by this research by following five steps which were established by Kitchenham *et al. (*2009), inclusive of: 1) framing the research questions; 2) search process; 3) inclusion and exclusion criteria; 4.) data analysis; and 5) presentation of data. The aim of this review was to identify and analyse the technologies which had been proposed and used in the construction industry to improve safety on construction sites and built environment through education in tertiary institutions and in the working sector worldwide. To fulfil this aim, the following research questions (RQs) were formed:

RQ 1: What technologies have been adopted and are used in the construction industry to help with safety education in higher education and job training?

RQ 2: What safety guidelines and regulations were adopted in the technologies?

RQ 3. What were the learning outcomes from the technologies used?

The second stage was looking for studies which were related to the RQs to ensure that they were effectively answered, and little data was missed. The databases used for the research were Web of Science, Scopus, and Engineering Village. The former two were large databases containing scientific and engineering research articles (Gao *et al.,* 2019). The keywords used to find the data were construction, built environment, safety, technology, occupational training, and higher education. The keywords were reshuffled making some adjacent to the other while removing other words to widen the search. Furthermore, synonyms of the keywords were also used to find related articles.

A total of 2,604 papers were found with 798 from Web of Science, 1,074 from Scopus and 732 from Engineering Village. The search words and string used to find the papers were:

- ((“construction” OR “built environment”) AND (“safety” OR “health” OR “health and safety”) AND (“higher education” OR “universit*” OR “tertiary education”) AND (“technolog*”) OR (“virtual reality”) OR (“augmented reality”) OR (“mixed reality”))
- ((“construction” OR “built environment”) AND (“safety” OR “health” OR “health and safety” OR “occupational safety”) AND (“training”) AND

("technolog*") OR ("virtual reality") OR ("augmented reality") OR ("mixed reality"))

Thirdly, this process was done to narrow down further the research articles that came up and only choose studies that were relevant to the research topic. This was performed by coming up with criteria that should be included in the article (inclusion criteria) and those that should not (exclusion criteria) (Nunez-Merino *et al.,* 2020) to avoid articles that are irrelevant, lack quality or are outdated. Research papers were chosen on the basis that they were written in English, were journal articles, fell into the engineering category and were published between the years 2010 - 2022 to avoid using research that was outdated. The title, abstract and keywords of the articles were read to see if there was any correlation with the topic. If they were relevant the methodology and conclusion were then examined to further determine if the journals were a credible source. This then narrowed down the search to a total of 81 papers. It was then examined if there were any duplicates and a total of 26 duplicates were found leading to 55 articles being used for this literature review. During the data analyses stage, the 55 papers were read thoroughly in their entirety and an analysis of each paper's focus. In this last stage, all the data were combined and presented in a descriptive format. Furthermore, the limitations of this systematic literature review will also be presented.

RESULTS

An Overview of Selected Studies

The selected studies were initially summarised based on these coded items, namely types of technologies adopted in safety training or education, safety scenarios addressed, learning outcomes, and safety guidelines/regulations, etc. Table 1 presents some of the selected studies in the higher education sector as examples. Similarly, Table 2 presents some of the selected studies in professional training. Notice that only part of the articles from the whole sample were listed in the two tables.

Review of Studies on Digital-Driven Safety Training and Education

These key coded items from the whole sample of selected journal articles as demonstrated in Tables 1 and 2 are extended in detail. Depending on the qualitative or quantitative nature of data collections, these studies were justified with a sample size of recruited participants in the digital-driven safety education or training.

Technologies Adopted

Out of the 55 papers analysed, 31 articles adopted VR as the technology for construction safety education or training. Xu and Zheng (2020), for example, developed a multi-level VR training system that allowed mutual interaction between the participants. This was chosen because it allowed them to create a realistic workplace experience allowing workers to learn about undertaking risks in demanding environments while working on construction sites. Additionally, Dhalmahapatra *et al. (*2020) used VR because it allowed effective simulation and modelling for accident scenarios, real-time user interaction as well as a visual analysis in 3D perspective. They also added that VR-based accident causation modelling would help improve the transfer of knowledge to workers because of its increased user engagement and visualisation when training them.

The other widely adopted technology was augmented reality (AR) with six studies from the sample developing simulations and systems based on it. Albert *et al.,* (2014) adopted AR because it allowed the minimization of time required for modelling real-world photos and videos beyond the three-dimensional modelling of environments.

Wolf et al., (2022) who also used AR for training and safety education because it improved hazard identification, strengthened workers data collection skills improving their safety awareness like body motion tracking and localization. They showed that AR was effective for simulating realistic depictions of a real building, allowed the users with helpful information to solve tasks which enabled them to gain additional safety knowledge.

Another six articles chose to use mixed reality (MR) as their preferred immersive technology to offer safety training and education. Hasanzadeh et al. (2020) used MR whereby they combined the use of virtual and physical objects to examine risk taking behaviours of participants when they had different kinds of protection. They selected this technology because it was able to capture the users' naturalistic risk-taking behaviours within an environment that was risk free by allowing the developers to identify workers that were at risk. Another adopted technology was game technology. Ahn et al., (2020) used BIM to provide safety scenarios of falling hazards, being struck by falling objects and working with cranes. Pham et al., (2019) on the other hand introduced a visualisation-based anatomy system known as building anatomy modelling by providing students with contextual safety information and helping them understand safety issues in construction.

Table 1: Examples of digitalisation adoption of construction safety in higher education

Safety scenario(s) addressed	Types of technologies	Participation sample	Learning outcome(s)	Safety guideline or regulations	Origin
Four major hazards, i.e., fall from height, struck-by falling objects, caught-in-between, and electrocution	Virtual reality (VR)	40 university students and 40 construction practitioners	Hazard identification, inspection of improperly installed facilities, detecting unsafe worker behaviours	Occupational Safety and Health Administration (OSHA) standards	Taiwan (Yu *et al.*, 2022)
Tunnel collapse	VR and Mixed Reality (MR), and recorded video lessons	84 undergraduate students	Understanding causes of accidents and steps involved in accident investigations	Not mentioned	Singapore (Yang and Goh, 2022)
Fall from height, collapse, lack of protective equipment, struck-by, lifting hazards	VR	52 undergraduate students in construction subject	Site hazard identification	Not mentioned	China (Han *et al.*, 2022)
Slips, trips, and falls	Mobile technology	12 students from safety-related courses in Master level	Identification and understanding of different types of unsafe acts and unsafe conditions	OSHA standards	Russia (Vukicevic *et al.*, 2021)

This platform allowed students to interact with three-dimensional building models enabling them to access information on building elements and later developing safety knowledge and skills while giving them motivation to learn more on this topic.

Safety Guidelines and Regulations Followed

Health and safety guidelines as well as regulations have been formulated over the years to help ensure that construction workers are working in a safe environment with little to no risks. It was found from the reviewed sample that Occupational Safety and Health Administration (OSHA) standards was the highest implemented safety guidelines and regulations with 18 articles using this. Case studies conducted by

Pedro *et al.,* (2019) and Afzal and Shafiq (2021) adapted the OSHA standards to their countries' regulations, i.e., Korean Occupational Safety and Health Agency (KOSHA) regulations and Abu Dhabi Occupational Safety and Health Centre (OSHAD) code. Other guidelines and regulations followed are the Australian Work Health and Safety (Construction Work) Code of Practice, Global Mandatory requirements that comply with Work Health and Safety Standards, Singapore Workforce Development Agency (WDA) Risk Management Competency Standard and Israel Institute for Occupational Safety and Hygiene (IIOSH) (Xu and Zheng, 2021; Lee *et al.,* 2020). It was however discovered from the selected sample that most studies for professional training did not implement any safety guidelines and standards, i.e., with only 7 out of 23 mentioning safety regulations for the development of their case study, compared to 21 out of 32 studies for safety education.

Table 2: Examples of digitalisation adoption of construction safety training

Safety scenario(s) addressed	Types of technologies	Participation sample	Learning outcome(s)	Safety guideline or regulations	Origin
Falling, being confined in small spaces, mechanical injuries, foundation collapse, electrocution, struck-by moving objects	VR	117 construction workers in this VR training	Attaining safety knowledge	Not mentioned	China (Huang *et al.,* 2021)
Falling hazards	BIM and VR	A project manager, two project safety experts, and several workers	Hazard identification and precaution to prevent accidents	Abu Dhabi Occupational Safety and Health Centre Code	United Arab Emirates (Afzal and Shafiq, 2021)
Trip and falling hazards	Mixed reality	53 construction practitioners	Hazard identification and enhancing communication between workers	Not mentioned	USA (Dai *et al.,* 2020)
Fall hazards, struck by falling objects, working with cranes	BIM	189 construction workers	Hazard identification, understanding correct use of PPE and hazard prevention measures	Not mentioned	Korea (Ahn *et al.,* 2020)

Learning Outcomes

The learning objectives for each case study were set before the development of the platforms to ensure that they were able to achieve what the studies were looking for. Most of the studies were designed to enable participants to acquire skills in hazard identification and recognition. Dhalmahapatra *et al.,* (2020), for example, developed a VR Accident Causation Model (VR-ACM) to help workers with hazard identification and hazard avoidance training. Understanding risk compensation was also another learning outcome from a case study by Hasanzadeh *et al. (*2020). They used the CAVE automatic virtual environment which simulated a roofing activity to test participants' risk-taking behaviour. Li *et al. (*2012) developed a multiuser virtual safety training system (MVSTS) which was used to train workers on safely dismantling a tower crane through simulating the crane dismantling process. Other learning outcomes were like understanding fire management protocols, better and proper use of PPE, increasing communication skills between workers and acquiring knowledge on scaffolding, moving equipment, and working at height to reduce accidents (Getuli *et al.,* 2014, Ahn *et al.,* 2020, Dai *et al.,* 2020, Kazar and Comu, 2021). Though these studies mainly showcased the positive effects of adopting digital technologies on safety educational or training outcomes, the wider stakeholder community should also be aware of the potential limitations, for example, potentially negative emotional reactions due to nervousness and uncertainty of adopting immersive technologies during training (Han et al., 2022).

DISCUSSIONS

Following the interpretation and analysis of the adoption of the technologies in the industry, the main benefits of adopting these technologies are discussed to help with the teaching and training of safety in construction and the built environment. First, digital technologies increase user engagement which acts as a catalyst for performance improvement during training and produces greater learning outcomes, unlike traditional methods which are not as interactive reducing the participants attention (Gao *et al.,* 2019). It was also proved that different types of engagement like emotional and behavioural engagement could be improved using virtual reality which allows learners to practice without having to worry about time and space increasing these two factors (Seo *et al.,* 2021). It has however not been proven what amount of interactive control is needed to ensure that users are fully engaged with the system (Pena *et al.,* 2019).

Another useful benefit of digital techniques is increased motivation within the trainees. Students who were motivated tended to read more on their own further improving their knowledge and skills in the topic (Yang and Goh, 2022). According to Pham *et al. (*2018), construction-related studies have been deemed as passive, and that could affect the level of performance of learners in this field. The introduction of active learning through these technologies has hence improved this providing better results. Learners or students were seen to have increased enthusiasm and work for longer hours while using game technology hence educators and developers had opted to use this method to teach which could lead to an increase of their motivation (Din and Gibson 2019). Beh *et al. (*2021) stated that the nature of construction work being very practical and hands-on requires the learner's engagement to make connections between what they have learned in the classroom and its application. This will ensure that learners effectively understand the topics which is almost impossible due to the unsafe and hazardous conditions on construction sites. They added that this further led to students not being able to obtain real-life experiences because on site learning in such conditions is normally costly, time-consuming and could lead to accidents. The development of these technologies which imitate real-life environments has then proven advantageous because it allows this which is the third benefit. This has been previously stated by Alizadehsalehi *et al. (*2021) who revealed that using VR provides better visualisation of real-life environments which is not possible when using traditional-based methods.

Additionally, long term retention of acquired knowledge and skills is one of the other tested benefits of immersive technology. According to Han *et al. (*2022), virtual reality allows users to retain what they have learned for longer because of its ability to provide short but vivid images. Another benefit of these technologies is that they can offer text-free training and do not have to be necessarily in English. It was also observed that most job training case studies did not implement safety guidelines and regulations in their frameworks, unlike the education for students. The assumption for this was that most workers in the industry have already obtained training certificates while working or before obtaining jobs from programs like OSHA which offer safety guidelines that were created to reduce accidents in the construction industry. Further investigation on this should however be done to determine why most of them have not implemented these guidelines.

CONCLUSIONS

This study provides a systematic literature review on the analysis of adopted technologies in built environments which have helped in education and training for higher education students and industry workforce on health and safety. The study analysed 55 journal articles which helped to understand the types of technologies adopted, learning outcomes, as well as implemented safety guidelines and regulations. The review identified the technologies that have been adopted including VR, AR, MR, BIM, game technology and eye-tracking technology with VR being the most popular among researchers. It was also discovered that most studies decided to use trainers to instruct the trainees on how the platforms work with some of them providing introductory videos as well as allowing trainees to interact with the platform before the training started. This allowed them to effectively use the systems developed hence enabling them to acquire the required training outcomes. Furthermore, most of the studies evaluated the effectiveness of their adopted technology in achieving their intended outcomes. Though most of the selected studies stated that their inventions were effective, it should be further noted of the potential problems or limitations of these developed platforms, including but not limited to ease of use, comfort of end-users, level of details in the digital-driven virtual site, etc. Despite that most of the studies claimed that these technologies had added benefits such as increased user engagement, motivation, simulating real-life environments, and offering long-term retention, etc., further investigation should however be performed to validate this because many studies indicated that they had not tested the practical applications of these technological platforms.

This review has some limitations. First, only journal papers were analysed leaving out conference proceeding articles and reviews which could have increased the accuracy of the results obtained. Furthermore, the sample size was considerably small with only 55 papers being analysed. This was because of the choice of publications used for this systematic review. Future research could consider other types of technologies adopted and not just immersive technologies. It should be noticed that these technologies are likely to be inter-connected rather than siloed, e.g., information sharing between BIM, VR/AR/MR, and wearable technologies. Furthermore, more technical differences and effectiveness between traditional and digital technologies could be performed to provide researchers and practitioners with more knowledge allowing them to choose which method they would prefer to adopt.

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THE EFFECT OF COVID-19 ON CONSTRUCTION SITE PERSONNEL: PSYCHOLOGICAL AND PHYSIOLOGICAL PERSPECTIVES

Mohd Amizan Mohamed @ Arifin [1], Meor Johan Asmadi Hamzah[2], Nurul Noraziemah Pauzi[3], Nur Shuhada Nor Shahrudin[4] and Syahirah Intan Mohd Sheffie[5]

[1,2,3 and 4] *School of Civil Engineering, College of Engineering, UiTM Shah Alam, 40450, Shah Alam, Selangor, Malaysia*

[5] *Ministry of Education, 62604 Putrajaya, Malaysia*

The COVID-19 pandemic has caused a worldwide panic, with countries implementing restriction orders to curb its widespread infection. Aside from health, the pandemic imposed adverse impacts on global economic growth and its impact extended across various sectors, including construction. This study investigated the psychological and physiological effects of COVID-19 on construction site personnel, identified the contributing factors, and explored potential mitigation strategies for such issues. The quantitative study involved the distribution of a questionnaire to 227 construction site personnel in Selangor and Kuala Lumpur, Malaysia. The data were analysed using descriptive analysis via SPSS. It was found that anger, anxiety, and depression are psychological repercussions of insomnia, hypertension, and fatigue among construction site personnel. Factors like increased workload, job insecurity, and concerns about infection or exposure to the virus prompted it. They also expressed considerable apprehension about the possibility of losing their jobs and financial difficulties during the pandemic. This study suggested pre-construction workout programmes to strengthen construction site personnel's muscles and cardiovascular system, leading to better physiological and psychological well-being.

Keywords: COVID-19; pandemic; mental health; personnel; psychological

Introduction

The first case of COVID-19 in Wuhan, China in 2019 marked the beginning of a global pandemic (Hui *et al.,* 2020). By January 2021, the virus had spread to over 200 countries, affecting millions of people and causing significant fatalities (Hendrickson and Rilett, 2020; World Health Organization, 2020). In response, countries like Malaysia implemented Movement Control Orders (MCO) to curb the virus, leading to temporary halts in social and economic activities (Bartik *et al.,* 2020; Hashim *et al.,* 2021). However, these measures had severe economic consequences worldwide, including recessions and declining economic performance (Roy and Das, 2020). The construction sector, like other industries, was heavily impacted by the pandemic, with

[1] amizan8124@uitm.edu.my

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disruptions to work and potential income loss for construction workers (Bouchardie and Madalena, 2020; Karimi *et al.,* 2018; International Labour Organization, 2020). Understanding the psychological and physiological effects on construction workers is crucial, particularly in the context of Malaysia, where specific knowledge and practices are lacking.

To address this gap, this study aims to investigate the psychological and physiological effects of COVID-19 on construction workers in Malaysia, identify contributing factors, and provide practical recommendations to address their needs and mitigate the adverse impacts of the pandemic. By improving support systems and preparedness in the construction sector, the findings of this research can contribute to better coping mechanisms and responses to unforeseen events in the future (Choudhari, 2020; Jabeen *et al.,* 2021; Rouhanizadeh *et al.,* 2019; Esa *et al.,* 2020; Gara *et al.,* 2022; Sami *et al.,* 2022; Pamidimukkala and Kermanshachi, 2021; Serafini *et al.,* 2020).

This study is important as it investigates the causes of disruptions in construction activities during the MCO in Malaysia. By identifying these causes, construction companies can develop effective management plans to address crises' psychological and physiological effects. The findings will contribute to establishing robust risk management protocols for smoother project execution during crises and addressing future pandemic concerns. Additionally, this research deepens understanding of construction site personnel and the evolving construction environment during pandemics, benefiting the academic community and policymakers.

LITERATURE REVIEW

Correlation Between Psychological and Physiological

Psychophysiology explores the intricate interplay between mind and body, recognising the crucial role of mind-body communication. This field of study posits that changes in physiological processes can impact psychological responses while psychological experiences can influence physiological measures. By delving into this mind-body connection, the present study elucidates how the COVID-19 pandemic has affected construction site personnel's psychological and physiological well-being. Understanding the reciprocal relationship between these aspects is vital to comprehend crises' comprehensive impact on construction sector individuals. It will allow for a more holistic approach to designing strategies and interventions that address construction workers' psychological and physiological aspects. This integrated perspective can pave the way for more effective responses to unforeseen catastrophes and facilitate the development of comprehensive support systems for construction site personnel ("Psychophysiology" n.d.).

Covid-19 Impact on the Psychological Well-Being of Construction Site Personnel

COVID-19 has been linked to anger as a psychological effect, with pandemic-related rage arising from stress, fear, frustration, and other factors (Brooks *et al.,* 2020). While research specifically focused on anger among construction workers is limited, existing studies highlight the prevalence of psychological issues in this group (Cipolletta *et al.,* 2022; Söğütlü *et al.,* 2021). Understanding the causes and manifestations of anger in construction workers during the pandemic is crucial for developing interventions that address their needs. Similarly, the COVID-19 pandemic has led to increased anxiety among workers, with stress, workloads, and self-isolation contributing to heightened nervousness (AGC, 2018; Nawi *et al.,* 2017). This study aims to examine specific anxiety-related issues faced by construction site personnel, providing insights for alleviating anxiety and promoting mental well-being. Depression rates have also been significantly impacted by the pandemic, particularly among female workers facing increased responsibilities and income loss (Azcona *et al.,* 2020; Wenham *et al.,* 2020). Factors like wages, work schedules, workload, and access to leave have affected mental health in the construction sector (Jahan Nipa *et al.,* 2020). Investigating the causes and consequences of depression among construction workers during the pandemic is essential for implementing effective support systems.

Covid-19 Impact on the Physiological Well-Being of Construction Site Personnel

Insomnia, a sleep disorder characterized by difficulties in falling or staying asleep, is often associated with anxiety disorders (Cherney, 2018). The heightened anxiety during the COVID-19 pandemic can contribute to insomnia among construction workers, affecting their attitude, energy levels, productivity, and overall quality of life. Hypertension, or high blood pressure, has been linked to depression and chronic stress, which can be exacerbated by prolonged periods of stress like those experienced during the pandemic (Patten *et al.,* 2009; Seldenrijk *et al.,* 2015). Construction workers, who already face physically demanding tasks and potential work stress, may be particularly vulnerable to the negative physiological impacts of hypertension. Fatigue, commonly associated with depression, can worsen depressive symptoms, and is influenced by factors like increased workloads, longer hours, and added stressors experienced by construction workers during the pandemic (Ferentinos *et al.,* 2010; Salgado-Delgado *et al.,* 2011). Understanding the relationship between depression, fatigue, and the physiological well-being of construction workers is crucial for implementing interventions to mitigate the impact of COVID-19 on their overall health.

Factors Causing Psychology and Physiology Effects on Construction Site Personnel during COVID-19

Increased workloads in construction can be attributed to project deadlines, implementation of safety protocols, and operational challenges (Umer *et al.,* 2017). The physically demanding nature of construction work exacerbates the impact of increased workloads, leading to fatigue and impairments in attention, concentration, cognitive functioning, productivity, and safety on construction sites. Job insecurity, heightened during the COVID-19 pandemic, particularly affects younger and educated construction workers, leading to psychological challenges, stress, anxiety, decreased motivation, and overall well-being (Giorgi *et al.,* 2020). Concerns about the risk of contracting and transmitting the virus further contribute to insecurity among construction workers, impacting their mental health and well-being. Addressing job insecurity, implementing preventive measures, and providing support systems are crucial for mitigating the negative consequences and promoting better mental health among construction site personnel (Nabe-Nielsen *et al.,* 2021).

Ways to Mitigate the Effect of COVID-19 on the Psychological and Physiological Well-Being of Construction Personnel

Boosting construction workers' morale is crucial for mitigating the psychological and physiological effects of COVID-19 (Bhat, n.d.). Creating a positive work environment, recognizing employees' efforts, and fostering a sense of belonging and purpose can significantly improve morale, leading to better well-being and performance (Cooper and Bevan, 2014). Providing financial support is essential in alleviating the financial pressures caused by the pandemic (Gunnell and John, 2020).

Governments should implement measures like financial aid programs, wage subsidies, and unemployment benefits to reduce financial stress and improve workers' psychological well-being. Encouraging regular exercise before starting work can have physiological benefits for field staff (Angulo *et al.,* 2020). Exercise, particularly aerobic exercise, offers various health benefits, such as reducing the risk of cardiovascular diseases and improving overall health (Izquierdo *et al.,* 2021). Engaging in regular physical activity can also help reduce the risk of severe COVID-19 symptoms and hospitalizations (Sallis *et al.,* 2021). Incorporating exercise into the work routine can improve physical fitness, boost immune function, and enhance workers' ability to cope with the pandemic.

METHOD

Research Process

This study employed the quantitative design involving the use of a questionnaire survey. Figure 1 shows the flow of the research. In this study, the non-probability criterion, a simple random sampling, was used to select the samples (i.e., participants) from a diverse population of construction workers in Malaysia. The Krejcie and Morgan table determined that 227 samples were sufficient for this study (Krejcie and Morgan 1970). All participants were asked to complete a survey questionnaire that was administered through both online and in-person formats. It contained close-ended questions with multiple-choice options and comprised three sections as follows:

- Section A: To investigate the effects of COVID-19 on construction site personnel (20 questions)
- Section B: To identify the factors causing psychological and physiological effects on construction site personnel during COVID-19 (8 questions)
- Section C: To explore the strategies used by construction personnel to mitigate the psychological and physiological effects of COVID-19 (5 questions)

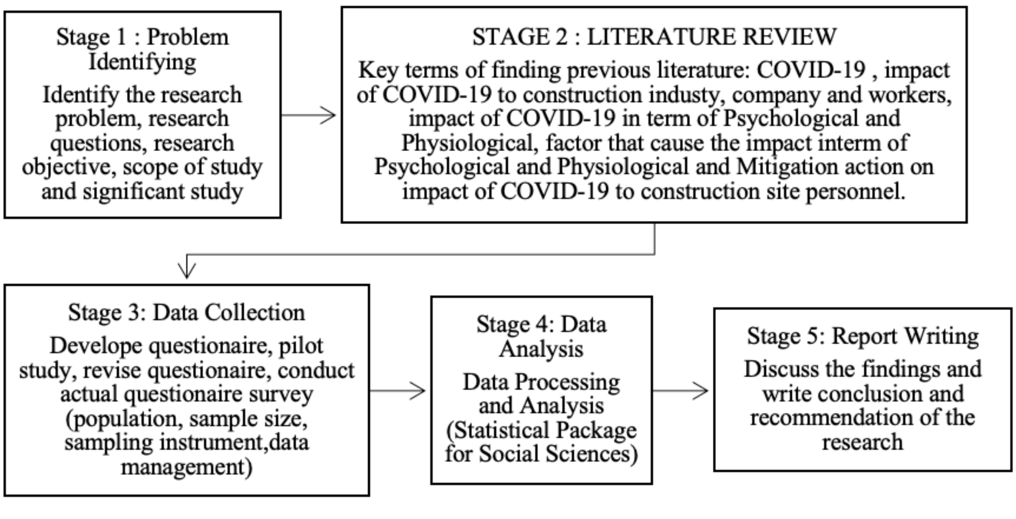

Figure 1: Flow of Research

Data Analysis

This research aimed to examine the impact and factors of COVID-19 on the psychological and physiological well-being of construction workers and explore their strategies to mitigate these effects. Data was collected from 227 participants working on construction sites in the Klang Valley, and analysis was conducted using IBM

SPSS software. The reliability and internal consistency of each item were assessed using Cronbach's alpha value.

Table 1: Results for Research Objective 1

Questions	Mean (μ)	Rank
I feel restless while working on the construction site during the COVID-19 pandemic.	3.76	1
I have daytime tiredness or sleepiness due to working on the construction site during the COVID-19 pandemic.	3.68	2
I experience shortness of breath while working on the construction site during the COVID-19 pandemic.	3.67	3
I have problems controlling my worry while working on the construction site during the COVID-19 pandemic.	3.63	4
I feel anxious working on the construction site during the COVID-19 pandemic.	3.59	5
I need better concentration while working on the construction site during the COVID-19 pandemic.	3.57	6
I have sore or aching muscles due to working on the construction site during the COVID-19 pandemic.	3.56	7
My heart rate increased rapidly while working on the construction site during the COVID-19 pandemic.	3.56	7
I feel angry working on the construction site during the COVID-19 pandemic.	3.55	8
I lost interest or pleasure in hobbies or activities while working on the construction site during the COVID-19 pandemic.	3.54	9
I have vision problems due to working on the construction site during the COVID-19 pandemic.	3.52	10
I have hypertension due to working on the construction site during the COVID-19 pandemic.	3.49	11
I have thoughts of death or suicide, or suicide attempts while working on the construction site during the COVID-19 pandemic.	3.45	12
I feel depressed working on the construction site during the COVID-19 pandemic.	3.44	13
I feel striking out verbally or physically during working on the construction site during the COVID-19 pandemic.	3.42	14
I feel sad, anxious, or “empty” while working on the construction site during the COVID-19 pandemic.	3.40	15
I have difficulty maintaining my sleep time due to working on the construction site during the COVID-19 pandemic.	3.39	16
I have fatigue due to working on the construction site during the COVID-19 pandemic.	3.35	17
I have insomnia from working on the construction site during the COVID-19 pandemic.	3.34	18
I have sleeping problems while working on the construction site during the COVID-19 pandemic.	3.22	19
I have nosebleeds from working on the construction site during the COVID-19 pandemic.	2.62	20

Objective 1 concerns the psychological (anger, anxiety, and depression) and physiological (insomnia, hypertension, and fatigue) effects that COVID-19 had on construction site personnel as shown in Table 1.

Most participants agreed that working on a construction site during the COVID-19 pandemic made them restless ($\mu = 3.76$). They also agreed that working on a construction site during the COVID-19 pandemic made them feel daytime tired or sleepy (μ = 3.68) and that working on a construction site during the COVID-19 pandemic caused shortness of breath (μ = 3.67). The results suggest that working on a construction site during the COVID-19 pandemic caused insomnia, sleeping problems, and nosebleeds among the third minority of the respondents.

Table 2: Results for Research Objective 2

Questions	Mean (μ)	Rank
I am insecure about losing my job with my current construction company during the COVID-19 pandemic.	4.60	1
I am worried about my financial difficulties during the COVID-19 pandemic.	4.59	2
I am insecure about being infected and affected by others from the COVID-19 virus on the construction site.	4.49	3
My workload on the construction site increased during the COVID-19 pandemic.	4.28	4
I feel hard to adapt to the working environment and working pressure on the construction site during the COVID-19 pandemic.	4.19	5
My working hours on the construction site have been prolonged during the COVID-19 pandemic.	3.74	6
I fear non-optimal management to respond to the crisis on the construction site during the COVID-19 pandemic.	3.73	7
My rest time on the construction site has been shortened during the COVID-19 pandemic.	3.70	8

Objective 2 focuses on factors causing the psychological and physiological effects on construction site workers during the COVID-19 pandemic as shown in Table 2. These factors include their workload, job insecurity, and insecurity about being infected or affected by the virus.

Most respondents were concerned about losing their jobs with the construction company (μ = 4.60) and financial difficulties during the COVID-19 pandemic (μ = 4.59). The third prominent factor was their concern about being infected by the virus or affected by other people on the construction site (μ = 4.49).

As shown in table 3, Objective 3 focuses on mitigating the psychological and physiological effects of COVID-19 on construction site personnel using strategies like boosting the workers' morale, providing financial support, and exercising before working. It is essential to minimise these effects to reduce and eliminate their detrimental impacts on various sector components. During the COVID-19 pandemic, most respondents believed that their companies should conduct exercise sessions before they began working (μ = 3.93). They also agreed that construction companies should encourage employees to express their concerns to the supervisors (μ = 3.87) and that the Malaysian government should provide financial support for construction workers (μ = 3.77).

This study investigated how COVID-19 affected construction site personnel and proposed strategies to reduce those effects. However, it focused on construction workers in the Klang Valley. Future research should include construction workers across Malaysia, use interviews alongside surveys for data collection, and aim for larger sample sizes and longer research periods to enhance the findings' applicability.

Table 3: Results for Research Objective 3

Questions	Mean (μ)	Rank
My company provides exercise sessions before starting work on the construction site during the COVID-19 pandemic.	3.93	1
I can share my feelings and problems with my superiors during the COVID-19 pandemic.	3.87	2
The Malaysian government provides financial support to construction workers during the COVID-19 pandemic.	3.77	3
My company provides construction workers with mental and physical health consultations during the COVID-19 pandemic.	3.44	4
My company acknowledges and rewards my working efforts during the COVID-19 pandemic.	3.43	5

CONCLUSION

This study aimed to understand how COVID-19 affects construction site workers psychologically and physically, identify contributing factors, and suggest ways to mitigate the effects. The findings show that the pandemic has had a significant impact on workers' psychological well-being, leading to symptoms such as anger, anxiety, and depression, which can be associated with insomnia, hypertension, and fatigue. Factors like increased workload, job insecurity, and concerns about infection contribute to these effects. To mitigate the impact, the study recommends measures like implementing pre-construction workout programs, promoting open communication, and providing financial support through government initiatives. These findings are valuable for policymakers, construction companies, and stakeholders to develop targeted interventions and support systems for workers' well-being. Further research and collaboration are needed to refine and implement these strategies effectively.

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EVALUATING THE HEALTH AND SAFETY PRACTICES OF HUMAN-ROBOT TEAMS

Adetayo Onososen[1], Innocent Musonda and Ramabodu Molusiwa

Centre for Applied Research and Innovation in the Built Environment, Faculty of Engineering and the Built Environment, University of Johannesburg

Human-robot teams will become increasingly prevalent in the construction sector as technology advances. These teams, consisting of both human and robotic members, have the potential to improve efficiency and productivity while also reducing the risk of injury to human workers. However, it is important to evaluate these teams' health and safety practices to ensure that they are functioning safely and effectively. This includes evaluating the methods used for communication, such as verbal or visual cues, and the effectiveness of these methods in ensuring that the team is working towards a common goal. Additionally, it is important to assess the physical interactions between the human and robotic members, such as the design of the robot and the safety measures in place to protect the human workers from injury. This study adopts a systematic review approach to assess critical factors that significantly impact the health and Safety of human workers in human-robot teams and to ensure that they are optimised for the specific tasks being performed.

Keywords: H&S, health and safety; human-robot teams; collaboration

INTRODUCTION

The deployment of robots to enhance construction performance has also attracted safety concerns regarding the nature of its disruption and how it impacts healthy human-robot teaming. The construction environment is highly labour-intensive and social, with diverse social interaction tasks and understanding that facilitate communication and has been linked to safety collaboration between humans (Fernández-Macías *et al.,* 2021). When fully adopted, collaborative robots (cobots) will be disruptive and an important accelerator of growth in the built environment (Berx *et al.,* 2022). While their potential is undisputed, their adoption is still low in developed and developing countries. Extant studies have identified safety issues critical in hindering human-robot collaboration in future industrialised networks. Evaluating human-robot teams' health and safety practices is essential to construct a new future in the built environment, where technology and human workers can work together seamlessly and safely. This topic is crucial as it addresses the concerns surrounding the increasing use of robots in the construction industry and the need to ensure that their integration with human workers is done safely and efficiently.

[1] Onososen@outlook.com

Onososen, A, Musonda, I and Molusiwa, R (2023) Evaluating the Health and Safety Practices of Human-Robot Teams *In:* Tutesigensi, A and Neilson, C J (Eds) *Proceedings of the 39th Annual ARCOM Conference,* 4-6 September 2023, University of Leeds, Leeds, UK, Association of Researchers in Construction Management, 306-313.

METHOD

The method of review utilised in this investigation is predicated on content analysis. Because of its broad applicability and universal recognition as an efficient means of analysing, synthesising, and justifying previous research findings, this methodology has seen considerable application in engineering and construction management (Li *et al.,* 2018; Onososen and Musonda, 2022). The Scopus database was utilised to choose several first-tier publications on health and safety practices in human-robot teams. The selection criteria were based on; an exhaustive search using Scopus. Secondly, keywords such as Robotics, Human-Robot teams, cobots, collaborative robots, and health and Safety were attempted so that the search could have a broad range of results. This round of searches identified 65 most related articles. Publications not comprising the previously mentioned keywords in their titles or abstracts were screened out in stage 2. For the less relevant and irrelevant papers, after a brief visual examination of the article's content, 10 articles were left. Li *et al. (*2018) state that while the two-stage search method cannot ensure complete coverage of all papers worth reviewing, it adequately provides a substantial number of noteworthy state-of-the-art works. These works offer valuable insights that can be generalised to draw conclusions and make recommendations for future research. These articles were chosen to identify articles relevant to the study's aims. These papers were selected from respected and authoritative academic journals on engineering and construction management, science, technology, Safety, and human factors. Figure 1 shows the process taken to identify the selected articles.

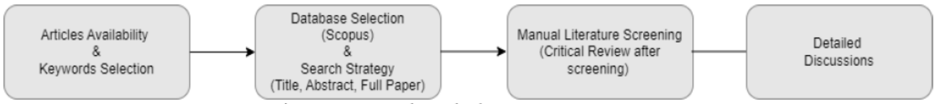

Figure 1: Research Method Process

FINDINGS

Health and Safety in Human-Robot Teams

Safety Risks associated with human-robot interactions.

Robots' adoption in the built environment has attracted interest in design and development due to their flexibility, cost-saving, and task efficiency. However, their characteristic also raises safety and ergonomics concerns. Safety for cobots has primarily been focused on the technology concerns linked to physical design safeguards (such as preventing accidental contact and limiting the accessibility of the workspace), which are fully covered in the ISO 15066 standard. This is a limited perspective on the Safety of human-robot interaction in physical space, where safety regulations also emphasize techno-centric design protections. This indicates that additional factors must be considered when designing safe, collaborative workspaces to cope with the emerging risks associated with complex systems such as cobots. These risks are associated with the fact that complex systems are becoming increasingly prevalent. Collaborative robotics has profoundly changed how robots can be used in the industry. In that regard, they introduced a new paradigm regarding the Safety of machinery and human-machine interaction.

Safety risks identified by previous studies include.

Importance of health and safety practices

The developed robotic systems are intended to exploit great power, speed, and accuracy to accomplish repetitive and demanding tasks in construction job sites.

However, construction sites are dynamic and unstructured, triggering numerous complications for everyday task performance. Such complications necessitate employing highly flexible robotic systems that can accomplish complicated tasks. Yet, given the limitations of current technologies, incorporating such flexibilities into construction robots can be challenging for the health and Safety of workers.

Additionally, safety mechanisms, such as safety sensors, vision-based safety systems, and safety controllers, are essential for implementing such robots in commonly shared workplaces. Certain construction robots, such as brick-laying robots, must be repositioned and recalibrated while working to cover the full workspace. This contrasts with the regular industrial robots used in other industries. Therefore, the requirement for such dynamicity can inflict enormous physical and cognitive pressures on construction employees, especially in repetitive building jobs. This makes it important to highlight the importance of health and safety practices in human-robot collaboration.

Table 1: Safety Risks associated with human-robot interactions

S/N	Safety Risks	Description	Sources
1.	Physical Hazards	Robots used in construction are typically large, heavy, and powerful machines that can pose physical hazards to human workers if not properly operated or maintained. These machines can cause crushing injuries, lacerations, or even amputations.	(International Federation of Robotics (IFR), 2020)
2.	Collisions	Robots and humans working close can collide, potentially leading to injuries or damage to equipment. This can be especially dangerous in busy construction sites with a lot of activity and movement.	(Kim *et al.,* 2020)
3.	Malfunctioning	Robots can malfunction, leading to safety hazards for both humans and the equipment. This could happen for various reasons, such as software errors, hardware defects, or environmental factors like extreme temperatures.	(Wang *et al.,* 2015)
4.	Ergonomic risks	Human workers may be required to perform tasks in awkward or uncomfortable positions to work alongside the robots, leading to musculoskeletal injuries, strains, or sprains.	(Marinelli, 2022; Onososen and Musonda, 2022a)
5.	Electrical and fire hazards	The use of robots in construction often involves the use of electrical equipment, which can pose a risk of electrocution or fire.	(Beckett and Ross, 2017)
6.	Lack of Training	Improper use of robots or lack of training on how to work with them can lead to safety hazards.	(Kas and Johnson, 2020; Onososen and Musonda, 2022b)

The importance of health and safety practices in human-robot collaboration is presented in Table 2, and critical factors affecting health and Safety in human-robot teams are presented in Table 3.

Factors Affecting Health and Safety in Human-Robot Teams

Addressing Critical Factors Affecting Safety in Human-Robot Collaboration

Ergonomics: Proper ergonomic design of robots and tools can be achieved through collaboration between engineers, designers, and workers. Tools and robots should be designed with consideration for the physical requirements and limitations of human workers, with a focus on minimising the risk of musculoskeletal disorders and other injuries (Pauliková *et al.,* 2021); (Lorenzini *et al.,* 2023)

Workload Management: Proper workload management can be achieved through proper planning and scheduling of tasks, the use of automation to reduce repetitive tasks, and the use of data analytics to monitor worker fatigue and workload (Lorenzini *et al.,* 2023)

Human Factors: Addressing human factors requires focusing on worker well-being, including physical and mental health. This can be achieved through proper training and education for workers, regular check-ins and assessments of worker well-being, and technology and automation to reduce the risk of human error (Lorenzini *et al.,* 2023).

Table 2: Importance of health and safety practices in human-robot Collaboration

S/N	Importance	Description	Sources
1.	Protecting Workers	The primary reason for having health and safety practices is to protect workers from injury or harm. Human-robot Collaboration in construction can be dangerous, and without proper precautions, workers can be at risk of serious injuries or even fatalities.	(Storm *et al.,* 2022)
2.	Reducing Risk	Implementing health and safety practices can help reduce the risk of accidents or incidents occurring on construction sites. Identifying potential hazards and implementing controls can minimise the risk of incidents.	(Aghimien *et al.,* 2019)
3.	Improving Efficiency	When workers feel safe and confident in their work environment, they can focus on their tasks and perform them more efficiently. Health and safety practices can help create a culture of Safety that promotes worker productivity.	(Liang *et al.,* 2021)
4.	Impede Adoption and Collaboration	Workers who don't feel safe and confident in their work environment can impede the adoption and collaboration with robots.	(Manuel *et al.,* 2019)
5.	Enhancing the Reputation of the Industry	Good health and safety practices demonstrate a commitment to worker safety and can enhance the construction industry's reputation. This can attract more workers and increase confidence in the sector.	(Zhang *et al.,* 2023)
6.	Legal Compliance	Compliance with health and safety regulations is a legal requirement for construction companies. By implementing proper health and safety practices, companies can avoid legal repercussions and ensure that they meet regulatory requirements.	(Bröhl *et al.,* 2019)

Data Security: Protecting worker privacy and preventing cyber threats can be achieved using secure data storage, the development of protocols for data access and sharing, and the use of encryption and other security measures (Soh *et al.,* 2020).

Ethics: Addressing ethical concerns around using robots in the workplace requires a focus on worker well-being and ensuring that automation does not lead to job loss or other negative consequences for workers. This can be achieved through collaboration between industry stakeholders and worker representatives to ensure that the use of robots is balanced with worker needs and priorities (Doyle-Burke and Haring, 2020).

Maintenance and Repair: Regular maintenance and repair of robots and equipment can help prevent breakdowns and malfunctions that can put worker safety at risk. This requires collaboration between engineers, technicians, and workers to identify potential issues and develop preventative maintenance schedules (Follini *et al.,* 2021)

Communication and Training: Proper communication and training can help workers understand the risks associated with working with robots and how to operate them safely. This requires collaboration between management, supervisors, and workers to develop training programs and protocols for communicating safety information (Akiho and Sugaya, 2016).

Risk Assessment and Management: Regular risk assessments and developing risk management plans can help identify and mitigate potential safety risks associated with human-robot collaboration. This requires collaboration between management, workers, and safety experts to identify potential risks and develop mitigation strategies (Berx, Adriaensen, *et al.,* 2022).

Table 3: Critical factors affecting health and Safety in human-robot teams

S/N	Critical Factors	Description	Sources
1.	Robot Design	The design of the robot itself plays a significant role in worker safety. A poorly designed robot can cause injury to human workers or malfunction, leading to accidents.	(Pan *et al.*, 2020)
2.	Training	Human workers need adequate training to work safely with robots. The lack of proper training can lead to accidents, injuries, or equipment damage.	(Akiho and Sugaya, 2016)
3.	Communication	Effective communication between human workers and robots is essential to ensure Safety. Workers need to know how to communicate with robots to avoid potential hazards.	(Akiho and Sugaya, 2016)
4.	Risk Assessment	Conducting a risk assessment of human-robot collaboration can help identify potential hazards and assess the risk associated with each hazard. Regular risk assessments can help identify new hazards when implementing human-robot collaboration.	(Berx, Adriaensen, *et al.*, 2022)
5.	Maintenance	Regular maintenance and repair of robots are critical to their safe operation. Neglecting maintenance can lead to accidents or malfunctions, putting human workers at risk.	(Follini *et al.*, 2021)
6.	Emergency Procedures	Having emergency procedures in place can help prevent accidents from becoming more severe. Workers need to know what to do in an emergency, such as a malfunctioning robot.	(Kas and Johnson, 2020)
7.	Workplace Culture	A workplace culture that prioritises Safety can help create a safe work environment. Workers need to feel comfortable reporting potential hazards or unsafe practices without fear of retaliation.	(Calitz *et al.*, 2017)
8.	Regulatory and Legal frameworks	Safety standards and guidelines on the nature of collaboration between humans and workers on the construction site are imperative	(Pan and Pan, 2019)
9.	Government Policy	Governments can enforce safety regulations through inspections and penalties for noncompliance. This can encourage organisations to prioritise Safety in the workplace.	(Onososen *et al.*, 2022)
10.	Research Funding	Government funding can be used to promote research and development of safer robot technologies and promote safety training programs for workers.	(Pan *et al.*, 2020)
11.	Ergonomics	Ergonomics refers to the design of equipment and tools to fit human workers' physical requirements and limitations. The poor ergonomic design of robots or tools can lead to musculoskeletal disorders and other injuries.	(Pauliková *et al.*, 2021); (Lorenzini *et al.*, 2023)
12.	Workload Management	Human-robot Collaboration can lead to increased workloads for human workers. Managing workloads is essential to avoid fatigue and prevent injuries.	(Lorenzini *et al.*, 2023)
13.	Human Factors	Human factors refer to the physical and psychological factors that can impact the Safety and performance of workers. Understanding and addressing human factors can help create a safe and productive work environment.	(Lorenzini *et al.*, 2023)
14.	Data Security:	In the construction sector, robots are increasingly used to collect and process data. Ensuring the security of data collected by robots is critical to protect workers' privacy and preventing cyber threats	(Soh *et al.*, 2020)
15.	Ethics	Robots in the construction sector raise ethical questions about the impact of automation on employment and the role of robots in the workplace. Ethical considerations must be considered when implementing human-robot collaboration.	(Doyle-Burke and Haring, 2020)

CONCLUSIONS

In conclusion, using robots in the construction industry has the potential to improve efficiency and productivity, but it also brings safety risks that must be addressed (Akiho and Sugaya, 2016). Critical factors affecting human-robot collaboration safety include ergonomics, workload management, human factors, data security, ethics, maintenance and repair, communication and training, interoperability and standardisation, and risk assessment and management. Addressing these factors requires collaboration between industry stakeholders, workers, and government entities and a comprehensive approach encompassing all aspects of workplace robot use.

Implementing these measures ensures that human-robot collaboration in the construction industry is safe and beneficial for all involved. A research agenda for constructing a smart and resilient future work involves further studies and development in comparative studies across different construction projects and companies to identify best practices in health and safety practices for human-robot teams, long-term effects of human-robot collaboration on worker health and Safety, productivity, and job satisfaction. Also, to explore the need for updated safety standards specific to human-robot collaboration in the construction industry, Conduct in-depth studies on risk assessment methodologies for human-robot teams in construction. Investigate the management of potential hazards, including physical hazards, collisions, malfunctioning, ergonomic risks, electrical and fire hazards, and lack of training.

Much progress is also impossible without consideration for the impact of human factors and ergonomic considerations on the Safety and performance of human-robot teams. Examine the design of robots and tools to optimise their compatibility with human workers' physical requirements and limitations, with a focus on preventing musculoskeletal injuries and promoting worker well-being. This would further spur the need to investigate the influence of workplace culture on safety practices and collaboration between human workers and robots. Policies are inevitable with the need to Investigate the security and privacy concerns associated with using robots in the construction sector, particularly in data collection and processing.

Lastly, the ethical implications of integrating robots into construction work, their impact on employment and worker well-being, and strategies to mitigate negative consequences are critical to advancing the adoption of human-robot teams in the construction industry.

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IS IT POSSIBLE TO FOSTER LONG-TERM CONSTRUCTION-SITE SAFETY LEADERSHIP THROUGH BEHAVIOURAL TRAINING?

Christine Räisänen[1], Max Rapp-Ricciardi[2], Martin Grill[2] and Pernilla Larsman[2]

[1] *Division of Construction Management, Department of Architecture and Civil Engineering, Chalmers University of Technology, Sven Hultins Gata 6, Gothenburg, Sweden*

[2] *Department of Psychology, Gothenburg University, Universitetsplatsen 1, Box 100, 40530 Gothenburg, Sweden*

Despite the increasing popularity of organisational leadership training, context-specific longer-term training transfer remains under-researched. We examine how two safety-leadership behaviours - giving performance feedback and listening actively -were retained, applied, and transferred from the learning context to the construction-site workplace. Four to five months after the completion of a nine-week individualised behaviour-based safety-leadership training (IBST), carried out in Sweden, open-ended life-story, 90-minute interviews were carried out with seven site-manager participants and their respective seven foreman/woman. The findings suggest that long-term safety-leadership behaviours may be transferred to the workplace; however, contextual contingencies and exigencies, for example, participant characteristics and situated work-environment, proved of crucial importance for training transfer. To achieve effective safety-leadership training transfer that reinforces safe behaviour on construction sites, it would be wise to problematise the dynamics of participant motivations and situated construction-project factors.

Keywords: learning, safety behaviours, safety-leadership, training, situated practice

INTRODUCTION

Organisational interventions aimed at changing participants' leadership behaviours are becoming increasingly popular although the learning outcomes remain contradictory (Gemmano *et al.,* 2022). Much of the safety-leadership intervention research tends to be quantitative, focusing mainly on positive safety factors and self-report (Conchie and Donald, 2009). Yet, Keiser and Payne (2019) have argued that as many as a third of self-reported answers are unreliable. Behaviours are neither determinable, rational, nor context-neutral; they manifest differently across and within industries and are situation-dependent on an individual basis. Based on a meta-analysis of training designs and implementations, Lacarenza *et al.,* (2017) advised that leadership training should be based on the individual managers' current behavioural repertoire and contextual circumstances.

This is certainly true for construction-safety leadership, which plays out in complex, multifaceted and dynamic socio-technical interactions (Oswald *et al.,* 2020; Oswald *et*

[1] christine.raisanen@chalmers.se

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al., 2022). Such exigencies make it difficult to measure long-term behavioural training transfer effects of safety-leadership training interventions to local contexts such as construction sites (Nielsen *et al.,* 2022). Moreover, to unpack safety behaviours in situ and to understand how behavioural interventions may transfer from an intervention forum to everyday work practices, alternative and complementary qualitative research designs and methods are warranted. Qualitative research would also facilitate the capture of valuable information at the intersection between 'top-down' organisational safety rules and strategies - most often underpinning the interventions - and 'bottom-up', project and site practices and exigencies (e.g., Oswald *et al.,* 2022). Therefore, to evaluate whether and how behaviour safety-leadership training may result in changed behaviours, and how these behaviours and changes manifest in practice, a deeper understanding of the various organisational contexts and the possible ways in which these contexts may influence participants' uptake from safety training is necessary.

The overall aim of this paper is to examine whether and how learnings from an individualised behaviour-based safety-leadership training (IBST) carried out in Sweden were retained, applied and transferred from the learning context to the construction-site workplace. The IBST studied focused on two safety-leadership behaviours - giving performance feedback and active listening. Qualitative in-depth, life-story interviews were used to elicit some answers to two research questions: 1. Did the IBST safety-leadership training enhance the participating construction-site managers' safety leadership behaviours? and 2. Did the targeted safety behaviours transcend hierarchical levels? Here, we briefly describe the ISBT and discuss preliminary results from the interview study. The paper contributes insights into the affordances and possible barriers to safety-behaviour transfer, which in turn could lead to improvements of IBSTs for construction-site first-line managers.

Safety-Leadership Training Intervention

The individualized behaviour-based safety leadership training (ISBT) was designed to enhance two fundamental transformational safety-leadership behaviours: giving performance feedback and listening actively. The developed training curriculum was carried out three separate times during 2020 and 2021 with three different site-manager cohorts. Each training curriculum encompassed five modules spread over a period of 9 weeks (Figure 1). Modules one, three and four were six-hour group-training sessions while modules two and five each consisted of three-hour on-site individual shadowing and performance feedback. In between the modules, the participants were provided reading material and assigned reflective 'learning-by-doing' writing tasks. Note: pre- and post-training questionnaires were answered by site managers (SMs), forepersons (Fs), and the SMs' immediate superior managers. These data are beyond the scope of the paper and reported elsewhere.

To tailor the safety-leadership performance feedback and active listening to individual and contextual circumstances, the first group-module focused on differentiating the meanings of the terms 'characteristics' versus 'behaviours', analysing participants' prevalent and preferred safety behaviours (behaviour analysis), and tapping into personal safety experience to recall situations in which performance feedback and active listening could have been, and if so how it could have been used, to activate and reinforce employee-safety behaviours. Apart from providing some relevant additional tools (not described here), the remaining two group modules focused on exchanging experiences and reflecting over their learning-by-doing implementations of the two behaviours on their construction sites. These behaviours were also observed during the two individual performance-feedback modules on site, where one of the researchers provided individual performance feedback.

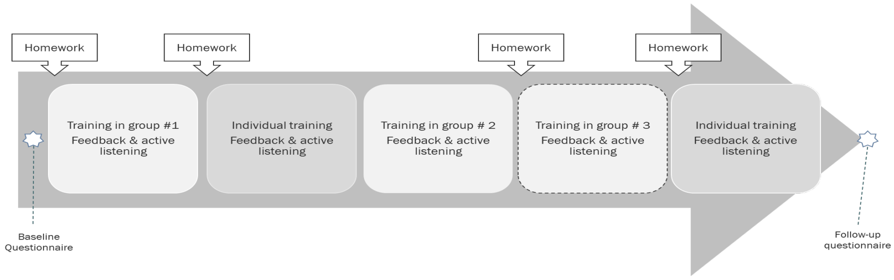

Figure 1: Schematic of the leadership training curriculum

The ABC-model, Antecedent-Behaviour-Consequence (Hanley *et al.,* 2003), from behavioural psychology served as theoretical underpinning for the training behaviour analysis, where A represents elicitation of feedback and/or active listening behaviours to trigger activate employee preferred safety behaviours (e.g., organize risk-assessment meetings in which workers are invited to describe how a work task may be performed in a safe manner); B represents preferred site-safety behaviours (e.g., voicing suggestions for improving safety of a work task); and C represents the performance feedback and active listening behaviours enacted to reinforce preferred employee safety behaviour (e.g., listening to, appreciating and implement workers suggestions of safety solutions identified at the risk assessment meeting).

The site-managers were tasked to design individualised ABC-plans as learning objectives based on two selected specific site-safety behaviours they wanted to improve. The theoretical rationale is that if the SMs' initial behaviour analyses are 'correct', they will see an improvement in their targeted safety behaviours in their site workers. This positive experience will then reinforce the SMs to continue performing the trained safety-leadership behaviour and encourage the site workers to continue performing the safety behaviour (i.e., instrumental reinforcement). Hence, the ABC-plan is the foundation that informs all the training activities, in group session activities, in homework assignments, and in individual training supervision on the construction sites (Figure 1). Throughout the training activities, the managers' individual ABC-plan was continuously adjusted to fit emergent changes in contextual circumstances and to the responses the managers received from their site workers as they successively worked on implementing their ABC-plan.

METHOD

A qualitative and interpretative approach, consisting of in-depth, life-story interviews, (conversations as we would like to see them) was chosen. Storytelling has been suggested as an appropriate interview technique for capturing lived experiences of a phenomenon or event, where interviewees' personal stories are allowed to evolve, and in which their underlying assumptions and beliefs guide the conversation rather than the interviewer's pre-defined questions (Clandinin and Connelly, 2000).

All the participating site managers were duly contacted by telephone to schedule a 90-minute individual interviews to be carried out 3 to 4 months after the intervention. We also requested permission to interview their respective foremen/women (henceforth referred to as foreperson), and we asked them to provide names and contact information.

Nineteen of the total 23 SMs that participated in the three training curricula were interviewed. Not all the site managers had forepersons (Fs) due to the size of the firm or the project, and many of the ones named were uncontactable. We managed to secure seven interviews with forepersons (see Table 1). The data set for this paper consisted of seven site managers and their respective forepersons (14 interviews). Among the seven pairs, four were male and two were composed of male site manager and female foreperson. The remaining pair was composed of a female site manager and a female foreperson.

All the interviews were conducted by the same interviewer and lasted between 70 to 90 minutes. Due to the COVID pandemic, these were all carried out via zoom, which allowed for the interviews to be both recorded and filmed (upon received permission from all the respondents). Zoom proved a valuable analytical medium, enabling us to retrospectively view and listen to the interaction while scrutinising the interview transcripts. Retrospective access to multi-modal expressions (e.g., body language and facial expression) adds ‘thickness’ to the data, providing important attitudinal and affective data.

Table 1: Overview of total training participants and interviewees per intervention

Training interventions	SM participants	Intv. SMs	Intv. Fs	Companies tot.
Cohort I	5	5	2	3
Cohort II	7	6	1	6
Cohort III	11	8	4	6

Broadly speaking, the aim of the interviews was to elicit respondents’ reflections on their everyday experiences and enactments of 'safety leadership' and 'on-site safety' in an attempt to probe the two research questions posed. In other words, we were interested in what 'safety leadership' meant to the SMs and the Fs. Since our focus here was training transfer, we were interested in capturing the site managers' assessment and retentions of the training as well as how the lessons-learned were applied (or not) over time. Concerning the forepersons, we were interested in capturing their perceptions of possible manifestations of change in their respective site-managers interpersonal safety-leadership behaviours.

Classical content analysis was initially used to sort the data, largely based on concepts drawn from the literature regarding intervention transfer, i.e., participant characteristics, intervention design, and work environment. This initial theory-driven categorisation was then followed by a deductive narrative-oriented coding in which three researchers separately scrutinised themes and fragments from the initial coding to form coherent storylines portraying the SMs' situated safety-leadership development as a life-world narrative. These storylines were then triangulated with the storylines of the forepersons' perceptions of safety-leadership. We have sorted the findings into two main sub-sections: participants characteristics including work-environment context and participants' perceptions of the training (SMs) and of possible effects of the training (Fs).

FINDINGS

Participant Characteristics: Personal Drive

General characteristics

The SMs and Fs of the given paired data set were between 25 and 35 years old. Most of them had come up through the construction ranks, many starting as apprentice carpenters in their high-school years. About half of the respondents had higher-education or vocational degrees, usually a bachelor's degree. They all shared a strongly articulated affinity for the operational construction phase. The SMs had worked in the role between one and three years and had all previously worked as Fs for several years, as is common practice in the Swedish construction industry. Typically, they described their career path as 'growing into the SM role', often thanks to a supportive mentor. Their principal motivation for their voluntary enrolment in the 9-week training was a strong interest in honing their leadership skills (all but one SM had previously attended several leadership courses). Some of the pairs had worked together on several projects, and all but one pair described their work relationship as 'very open and good'. SMs and Fs had experience of working in at least two construction companies before their current place of work, and were well versed in safety laws, organisational rules and policies.

Work environment characteristics: Safety leadership on site
The data set included large (2), small to middle-sized (3) and small (1) construction companies. The projects were residential or commercial, in different phases of the project. Site safety was depicted as a company priority, and for some of the SMs it was also a personal urgency, requiring constant and persistent attention, which their Fs corroborated. This was especially so for the SMs of relatively newly established and fast-growing companies, which one SM likened to the 'wild west'. The SMs were formally and ultimately accountable for site safety and seemed to be actively engaged with and present on their construction sites. Regardless of company or project, they elaborated on similar prevalent unsafe site behaviours. The most common and seemingly frustrating unsafe behaviours were workers' negligent cleaning up of workspaces and faulty cordoning off behaviours. These were also the behaviours many of the SMs targeted for improvement in their ABC plans.

The Fs' safety-on-site stories matched those of their SMs, often recounting the same incidents and similar frustrations. The association that the life stories of the SM and F pairs evoked were that of synchronised, well-orchestrated centripetal (SM) and centrifugal (F) forces at work. SMs worked from the inside (site office) toward the outside, and Fs worked from the outside inwards:

> We [Fs] mostly take care of what's going on outside, and he [SM] essentially takes care of budget and administration […] and of course a load of ideas about technical issues out there, but maybe spends a bit less time and has less control out there. (F)

> Expectations of a foreperson is to be the one who maintains safety on the site since the SM is less often out there […] and then a mantra that we have always had 'If it feels unsafe to you [F] […] you possess the right and duty to stop it. (SM)

Perceptions of the Safety-Leadership Training: Application, Adaptation, Transfer

Site managers' perceptions
Overall, the SMs expressed high satisfaction with the safety-leadership training, many saying that it was the "best leadership course" they had attended. Although, as mentioned earlier, the SMs had attended past leadership courses and were familiar with leadership theory and instruction, they agreed that the current training curriculum had provided three major take-aways or lessons.

1. It revealed new ways of thinking: "The focus on behaviour was very new to me … that the focus is not on outcome, not 'I want to see more clean spaces' but 'I want to see more people cleaning up'".

2. It affirmed and provided SMs with a vocabulary through which they could articulate what they felt they were already doing: “The ABC method … I had actually been using it even if not so explicitly … just hearing about it was as though a large part of my behaviour was put in writing … yes … this is what I usually do and I know it works … it became so much clearer to me […] to get this ABC, and knowing that I already do it, that was really what made the penny drop”
3. It provided SMs with simple tools, the use of which produced immediate positive response when practiced in the workplace: “… I am a problem-solver … what I thought I really learnt well was to give positive feedback […] and to specify exactly what I referred to when I said something was ‘good’ […] this I learnt, and I’ve struggled sometimes when I walk on site and I see … with harnesses for example, that they attach themselves … and once they have done so … to be able to THEN praise them instead of screaming every time they do NOT attach their harness. Damn it … it gives a positive feeling of ‘Now I’ve done something good’”.

Four months after the training, 'positive feedback' and 'active listening' was what the SMs retained and could still describe in some detail. They recounted how they had practised these behaviours to achieve better safety involvement on their sites. They explained how they had targeted specific desired behaviours in their ABC plan, e.g., reporting incident risks, cordoning off areas or cleaning up spaces, and how they had created conditions and/or processes to facilitate enactment of the behaviours by respectively, e.g., having workers digitally photograph risks and immediately sending the photos to the SM, or by creating regular 'idea meetings', where everyone involved was encouraged to articulate their views, or by ensuring that cleaning apparatus was located on all floors. Last, but not least, the SMs recounted how they reinforced the desired safe behaviours through positive individual and/or group feedback each time the behaviour was enacted and how empowering this had made both them and the recipient of the feedback feel.

However, despite the obvious uptake, and targeted application of the trained behaviours in the workplace while the training lasted, very few of the SMs were able to carry over the behaviours trained when their project went into another phase or from one project to the next. Only one SMs continued to actively use and adapt the learnings across project contexts. Interestingly, he was also the only SM to mention benefitting from using additional tools offered in the training such as measuring behaviour improvements. The reasons for the effective training transfer can partly be explained by individual characteristics and interest but also by the timeliness of the training, which coincided with the implementation phase of a new project. The SM was highly motivated to improve safety-involvement on site and had discussed ideas with his F. The training thus provided viable methods and the breeding ground for testing the new ideas. During the interview, he reflected on how he was planning to further develop his and his project members' safety behaviours.

For most of the other SMs, however, conscious recourse to the safety-leadership tools learned seems to have somewhat faded over time mainly due to change of project phase, for example to inspection or aftermarket phases, when uncertainty and pressure got in the way, and forced them to revert to business as usual. Other contextual circumstances for which they felt they would have needed training was dealing with rejection of feedback and language barriers, both of which were common features on their sites. One SM expressed it: "… even include the negative, not only praise, praise, praise, because sometimes it doesn't work, which we know, right!"

Forepersons' perceptions

All the Fs had been cognisant of the SM's participation in the safety-leadership training; some SMs even involved their Fs by sharing their ABC plan with them and actively involving them in the on-site implementation of the plan.

> I knew about the training … clearly could see that he was thinking about what he was being taught … we appreciated that the SM put down energy on … everything from doing things himself to giving positive feedback to someone who was doing something correctly […] If he does it, then so do I … do it … "more", and it sets off a chain effect and even the lads do it. (F) (our quote marks)

Indeed, concerning safety issues and safety leadership on housing and commercial construction sites, the stories of the Fs were well aligned with those of their paired SMs, identifying the same organisational and project safety-related contingencies, exigencies, and concerns. The seven pairs of narratives offered some new insights into the division of labour of SM and F. As already mentioned, the Fs managed the day-to-day practical running and coordinating of site activities: they were 'out there' continuously interacting with the site workers while the SMs were largely resided 'inside': their interactions with ongoing site were oftentimes mediated by their computers, a situation which they also deplored. So, even though the SM tried to be 'outside' as much as they could, the implications for transfer of behaviours across hierarchical boundaries would be more likely to be mediated from SM via F to site workers than directly from SM to site workers. Indeed, it may be this kind of mediation route the F is alluding to in the quote, where he seems to be implying that when the SM exhibits leadership-safety behaviours, and then, when he, the F, follows suit and does it "more", then the "lads do it".

In this data set, safety behaviours did transcend hierarchical levels, at least from SM to F in the pairs where the SM already had a strong safety-leadership 'mindset' which was discursively and practically enacted. Interestingly, in two pairs, we saw reversed (bottom-up) transfer, from F to SM: "I am out with the workers and talk to them constantly and monitor their work. If an incident occurs out there, I describe it to my SM, and he reports it. If I deem something needs to be done in a different way to make it safer, I explain this to the SM and we implement the change" (F). The second pair in which transfer seemed to be reversed had a 10-year work relationship with the SM having started as the F's carpenter apprentice.

CONCLUSIONS

Research has shown that there are correlations between safety leadership and organisational safety climate, as well as other safety outcomes (Clarke, 2013; Hoffmeister *et al.,* 2014). Yet, most approaches to construction-site accident prevention remain normative, relying mostly on short safety courses with introductory information on safety laws and on organisational and site-specific regulations and practices. Although there have been calls for behaviour-based leadership training (Lingard and Rowlinson, 2005), such training remains scarce. Furthermore, little research has been carried out to evaluate whether and how learnings from training translate into behavioural changes (Nielsen *et al.,* 2022) over time. In view of contradictory evidence concerning leadership training outcomes (Bhatti *et al.,* 2013; Hughes *et al.,* 2018), it is important to qualitatively evaluate and problematise the effectiveness of training endeavours to enable improvements of the training design.

The aim of this paper, therefore, was to examine whether and how learnings from an IBST had transferred from the learning context to the construction-site workplace.

One interesting contribution of this study is the empirical examples of the entanglement of individual characteristics and work environment in the construction industry. The life stories depict site practices that consists of dynamic interplay between past and present and between contexts of culture (organisational and site-safety culture) and contexts of situation (project type, project phase, activities, and safety risks). The implications for developing effective leadership training for construction is that individual characteristics and work environment need to be viewed as relational and dynamic rather than separate and discrete.

In their ethnographic study, Oswald *et al.,* (2022) describe how first-line managers enact transformational safety-leadership behaviours on construction sites, showing how these are intrinsically related to immediate work-environment realities. For example, the expectation on, 'contingent rewards' and 'inspirational motivation' were respectively manifested as 'giving positive feedback' and 'engaging workers in solving safety challenges' rather than the theoretical conceptions of 'monetary remuneration' and 'visionary goals', respectively. The enactments found in our study matched those of Oswald *et al.,* (2022) and reflect a pragmatic and practical approach to safety leadership that is well-aligned with the problem-solving characteristic that site-managers take pride in (Sandberg *et al.,* 2021). Furthermore, these findings support our targeting of the behaviours 'providing positive feedback' and 'listening actively' in our ISBT. Even though many of the respondents were familiar with these leadership concepts as potentially useful, they were nevertheless unaware as to how to activate them as daily behaviours. They were also unaware, as the quotes in the finding section show, that these simple concepts, when activated as behaviours, could, and did, produce immediate and positive response.

The life stories disclosed strong affective connections between the respondents and 'leadership as topic' on the one hand, and between respondents and 'site safety as experience', on the other. All the SM participants were strongly motivated to participate in the intervention due to their self-interest in improving their leadership skills and due to experiences of antecedent safety incidents. However, the findings would likely be different had the participants been resistant or neutral to safety-training interventions; the facilitators would then need to create an emotional connection, which may be an uphill struggle, especially if intangible individual characteristics such as values, beliefs and trust are not articulated and discussed (e.g., Loosemore and Malouf, 2017; Gemmano *et al.,* 2021).

We found no evident change in the SMs' safety mindsets; rather, the training seemed to strengthen their commitment to site safety by affirming that what they were already doing was the 'right things' to do. This affective affirmation, we surmise, made them receptive to the two safety-leadership behaviours being trained, which, as mentioned earlier, they came to view as not only leadership behaviours they themselves needed to improve, but also as active safety problem-solving tools they could use to obtain immediate explicit reinforcing outcomes. This, as well as the individual and participative learning-by doing design may explain the unanimously positive assessments of the training, evidenced by their detailed recall of their uptakes. So, in answer to the first research question posed: Can construction-site managers’ safety leadership behaviours be enhanced through safety-leadership training, the answer based on this study would be YES, at least in the short term. We would, however, suggest that the training curriculum be better tailored to the situational context of construction-project phases and the increasingly heteroglossic cultural context to improve prospects for long-term effects.

The findings also provide interesting insights into the division of labour between SMs and F, which implicate training transfer and intervention design. There seems to be an implicit shared managerial safety leadership arrangement between site managers and forepersons, which to our knowledge has not been addressed in previous construction leadership literature. In other words, Fs, at least in the Swedish context, have an important leadership role on construction sites. Whereas, the SMs have an overall, formal leadership with responsibility and accountability for safety on the construction site, Fs deploy the more mundane yet critically important managerial-leadership role in everyday practice (Tengblad, 2012).

Drawing on the narrative of the Fs, we would argue that the Fs are the ones who do the safety leadership on construction sites; yet traditionally, leadership is inherently a hierarchical concept implying a cascading or learning transfer downwards. This means that Fs are less likely to be offered possibilities of attending 'leadership' interventions even though they may be the ones to benefit most. As our data show, downward transfer was more likely to occur when SMs articulated their safety mindset and actively involved their Fs. However, and more interestingly, we also discerned transfer upwards, in which Fs transferred learnings from practice to their SM.

To maximise the positive benefits of IBSTs (as perceived by the SMs in this study), further exploration of both the nature and the practical unfolding of 'safety-leadership' in the construction industry is warranted. We need to further probe participants' experiences of the interventions, why and how they appropriated 'new' behaviours, and what behaviours and tools they adapted and applied in their daily practice. Understanding the micro-level of the 'whole' history of past intervention cycles - conditions and requisites, delivery, and long-term outcomes - as well as problematising these would provide valuable insights to better succeed with future safety interventions.

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MAKING THE COMPLICATED SIMPLE? THE CASE OF CONSTRUCTION SAFETY CULTURE

Emi Szabo, Hayley Hansen and Fred Sherratt[1]

Construction Safety Research Alliance, University of Colorado at Boulder, UCB 428, Boulder, CO 80309-0428, USA

The construction industry has yet to find a comfortable home for safety culture within wider safety management operations. With myriad definitions, proprietary assessment tools, and maturity models available, practical application can be confusing and challenging. Yet regulators in the USA have begun to demand formal reporting of safety culture as part of licensing procedures, repositioning it as a top priority for firms to operationalize. Thus, whilst academic safety culture is developing ever-more complex conceptualizations and frameworks, industry is seeking a simpler, more utilizable version for practice. To take a meaningful step forward in this space, a focus group of industry safety professionals (n=28) participated in a Q-Methodology workshop to unpack the current extensional definitions of safety culture, prioritizing, and evaluating the various elements therein. Findings show that the most important components are those that are also the hardest to measure, such as commitment and leadership. Suggestions for alternative metrics, such as financial commitment could reveal alternative routes for evidence-based rather than opinion-based determinations of culture in the future.

Keywords: measurement; regulation; reporting; safety culture

INTRODUCTION

Despite decades of safety research, the construction industry remains one of the most dangerous worldwide. A key concept in the promotion of occupational safety is that of safety culture, first captured in the evaluation of the 1986 Chernobyl disaster which highlighted 'poor safety culture' as a causal factor in the incident (IAEA 1986). Subsequent interest in safety culture as a concept grew throughout the 1990s and 2000s, however despite continued research into and of this specific aspect of occupational safety management, things remain complicated. In their recent systematic review, Deepak and Mahesh (2023) note that although articles about safety culture continue to be published year-on-year, there remains a lack of consistency and coherence in definition, constituent factors and assessment tools. Whilst there is general agreement that a 'positive safety culture' is a good thing (Gadd and Collins 2002) and thus something to strive for, how to best go about 'doing it' seems to have less focused momentum. Overcomplication from myriad models, evaluative tools, frameworks, and conceptualizations, each with their own definitions of safety culture, have led to an incomplete and incoherent body of work (Deepak and Mahesh 2023).

[1] fred.sherratt@colorado.edu

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This also has consequences for practice. For example, the Australian Institute of Health and Safety's (AIHS 2019:14) Core Body of Knowledge for the Generalist OSH Professional concluded that, following their evaluation of academic and grey literature in the safety culture/climate space, we simply don't know; how to define safety culture, how to change it, how to measure any interventions and what theory works best. They also highlight a large gap '…between evidence-based knowledge and industry needs' (ibid 2019:17). This is supported by anecdotal evidence suggesting that US-based construction firms are removing 'safety culture' from their occupational safety management lexicon, as it's just too unhelpful in their day-to-day operations.

However, and not unironically, improving organizational safety culture is an increasing concern amongst construction and utilities firms in the USA, not least because in 2019 the California Public Utilities Commission was tasked with developing '…a process for an annual Safety Culture Assessment for each electrical corporation.' (California Office of Energy Infrastructure Safety 2023). These assessments now form the basis for regulatory compliance - and underpin the issue of licences to operate. Thus, although the AIHS (2019:29) argue that '…in a practical sense, it is fruitless to continue to define safety culture', others now demand it, and thus safety culture, whatever it is, endures.

Here, first steps in a larger project seeking to make safety culture useful, to consider if it is even possible to make the complicated simple, are shared for reflection and discussion. Appropriate use and application of safety culture in the field has the potential to ensure we can Construct the Future more safely, but we should also consider whether and in what form it merits a place in that Future at all.

Mobilising Q Methodology, the body of construction safety culture literature was unpacked and sorted by a focus group of US-based construction safety practitioners. The aim of the exercise was to establish consensus of the most important and impactful 'elements' of a positive safety culture from professional perspectives through application of this methodological approach. In addition, by using a unique 'spaghetti and meatballs' model, the practitioners were also asked to categorize all the elements in terms of their utility - i.e., how 'easy' they felt they would be to measure and thus impact in practice. We hope to revitalize discussions around safety culture through this novel work, able to provide insights from professional perspectives, revealing the complexity and simplicity therein, whilst also raising questions about utility for practice.

The concept of safety culture

Whilst academia is still very interested in expanding understandings of safety culture, it has not always been so easily translatable to practice (AIHS 2019). There have been many theoretical frameworks, models, and assessment tools proposed for both general high-hazard industry safety culture and specifically for construction (e.g., Cooper 2000; Choudhry *et al.,* 2007; Trinh *et al.,* 2018; Feng and Trinh 2019; Probst *et al.,* 2019), however there is not yet an accepted definition - instead each academic or academic team sets their own. For example, for Cooper (2000), safety culture is the 'Observable degree of effort by which all organizational members direct their attention and actions toward improving safety on a daily basis', firmly positioning his safety culture in the realm of the observable and tangible. In contrast, Fang and Wu (2013) argue it is the more intangible that matters, defining safety vulture as 'a mixture of attitudes, beliefs, values, behaviours, and norms held by the individuals and groups from different parties in a construction project team, and it is gradually formed and evolved in the construction project environment' - things far harder to capture and measure without the use of proxies.

One of the main reasons that there are so many different and varying definitions is because academics often take an extensional approach to defining safety culture, meaning they explain what elements, dimensions, or components (this terminology also varies) make up safety culture. They essentially seek to define it by listing all the things that it can include. Yet the use of extensional definitions is fundamentally unhelpful for several reasons: It does not enable clear and simple communication between academics on the phenomenon, it negates meaningful comparisons between construction sites, firms, and sectors, and it prevents scientific evaluation in the truest sense. Mature scientific fields have agreed and shared definitions to enable all the above to be carried out effectively - for example astronomy moved from an extensional definition of a planet (which was until that point simply a list of all the planets in our own solar system) to an intensional definition which was able to define a planet through just three applied rules. Sadly, Pluto did not make the grade and is no longer a planet in scientific astronomical terms, but astronomers can now converse much more precisely about their research of planets in the wider universe.

Although an intensional definition of 'construction safety culture' is probably still far over the horizon (if it can ever be achieved), a better understanding of current extensional definitions may prove helpful. Indeed, as many of the elements often used to define safety culture extensionally are themselves inconsistent, and often not easily measurable in scientifically valid ways, knowledge of which are considered most important, and how they find fit with practice could underpin research able to move towards making the complicated a little simpler.

What we can and cannot measure

This work looks to three models of safety culture, as suggested by Edwards *et al.,* (2013), Guldenmund (2010), and Silbey (2009), combined by the authors here:

- Model 1 - engineered (Silbey 2009) and normative (Edwards *et al.,* 2013). Safety culture is grounded in organizational management, processes, and procedures around safety.
- Model 2 - analytical (Guldenmund 2010) and pragmatic (Edwards *et al.,* 2013). A safety culture revealed through measurable attitudes and behaviours.
- Model 3 - emergent (Silbey, 2009), anthropological (Edwards *et al.,* 2013) and academic (Guldenmund 2010). A socially constructed safety culture revealed through shared understandings, meanings, and beliefs.

These Models are helpful in grouping the various elements used within extensional safety culture definitions together, in terms of their practical consideration. Model 1 is relatively easy to measure and quantify - through documentary analysis and the mere presence of rules, policies, and procedures. Model 2 is more difficult to measure, but we can use proxies to generate valuable data, such as using safety climate surveys to determine worker attitudes and behaviours - the 'climate survey' remains one of the most popular, yet not unproblematic, methods of safety culture assessment (Guldenmund 2007). Model 3 is extremely difficult to measure; these are the nuanced elements of safety culture that can't be seen but add to the overall impression and unconscious feeling of a site's safety culture.

To make these Models more accessible for practitioners, an analogy of 'spaghetti and meatballs' was developed:

- Model 1 - these are the meatballs, easy to see and count.
- Model 2 - this is the spaghetti (pasta), we can 'count' it by strands, or 'total spaghetti length', but it's not ideal, things are going to get a bit messy, not least because we often must use proxies.
- Model 3 - this is the tomato sauce, which is difficult to evaluate and measure. We could try to unmake the recipe, and figure out what's in there, but that's very hard to do, particularly in terms of proportions, and we may well miss things. We could ask people to 'taste test' it for us and get their opinions, but everyone's taste varies - and we certainly don't all like the same things. Or we could try to break it down into joules and calories for a nutritionally focused evaluation, but that won't ever tell us what it really tastes like.

This analogy provides a useful approach to grouping the various elements of safety culture at this stage - although admittedly it only considers the 'eating' rather than the 'cooking' - as meatballs of course can also be the result of complex recipes. Yet it allows us to position academic theory in a vernacular realization of what we are attempting to do, and the various problems and limitations of how different established approaches for the measurement of safety culture can manifest.

Q Methodology

Q Methodology was initially developed by William Stephenson to allow participants to provide their subjective opinions of a dataset in a way that is comparable and quantifiable (Stephenson 1953). Q methodology enables enquiry of the subjective through an interactive approach, prioritizing and categorizing the subjective, capturing different viewpoints on a topic and ultimately enabling broad consensus to be drawn (Stenner and Capdevila 2019). Here, this methodology was used to develop consensus of the most important elements of a positive safety culture. For this study, the P Set sample of participants consisted of 28 industry safety professionals from the North American construction industry, who were members of the Construction Safety Research Alliance and attended a workshop to undertake the Q Sort in small groups of 4/5 in person at the University of Colorado Boulder.

The Q Set, the elements to be categorized in the Q Sort, were drawn from a review of the wider construction safety culture literature. The ARCOM Abstracts databased was accessed and a keyword search carried out for [Construction] AND [Culture] and [Construction] AND [Safety] AND [Culture]. Sources for these elements can be seen in Table 1. This review yielded n=27 elements. Prior to the Q Sort, the participants discussed the elements and added n=6 of their own that they felt were relevant and appropriate given their professional experiences. The question used to direct the Q Sort was: "How important is this element in creating a positive safety culture?" The participants then arranged cards with the n=33 elements in the quasi-normal distribution pattern required - with +5 being most important and -5 being the least. Following the Q Sort, the participants were then asked to discuss and assign a category of meatballs, spaghetti (pasta) or sauce to each element in their Q Sort using different coloured stickers. This provided an additional level of evaluation of the elements with regards to their 'measurability'. The entire exercise took approximately 3 hours in total and was followed by group discussion and reflection on the process.

Table 1: Q Sort Elements, Combined Analysis and Sources

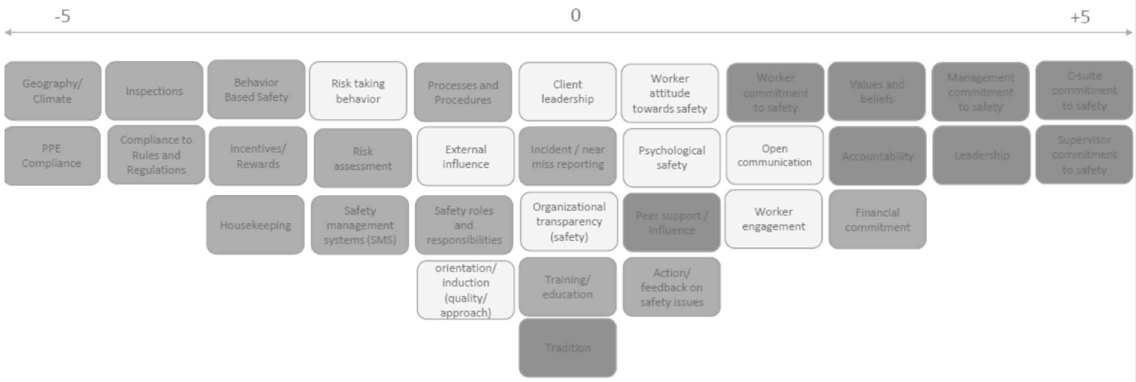
Element	Average Ranking	Standard Deviation	Final Ranking	M/P/S	Source
Geography/Climate	-4.83	0.84	-5	M	From Workshop
PPE Compliance	-4.17	2.90	-5	M	Hartley and Cheyne 2010; Ahmad and Gibb 2003; Fleming et al 2022; Deepak and Mahesh 2022; Ahamed & Mariappan 2023
Compliance to Rules and Regulations	-3.89	1.03	-4	M	Alruqi et al 2018; Deepak and Mahesh 2022; Fang and Wu 2013; Mohammadi et al 2018; Aboagye-Nimo et al 2013; Deepak and Mahesh 2019; Ahamed & Mariappan 2023
Inspections	-3.39	2.34	-4	M	Ahmad and Gibb 2003; Fang and Wu 2013; Fang et al. 2020
Incentives/Rewards	-2.89	1.86	-3	M	Feng and Trinh 2019; Tappura et al 2022; Deepak and Mahesh 2022; Mohammadi et al 2018; Deepak and Mahesh 2019; Molenaar et al. 2009; Xu et al. 2023; Liu et al. 2023
BBS (Behavior Based Safety)	-2.39	1.37	-3	M	Fang and Wu 2013; Molenaar et al. 2009
Housekeeping	-1.50	1.67	-3	M	Hartley and Cheyne 2010; Ahmad and Gibb 2003; Ahmad and Gibb 2003; Deepak and Mahesh 2019; Wamuziri 2008; Sherratt and Aboagye-Nimo 2022; Xu et al. 2023; Ahamed & Mariappan 2023; Liu et al. 2023
Safety Management System(s)	-2.17	2.66	-2	M	Ahmad and Gibb 2003; Fang and Wu 2013; Fleming et al 2022; Deepak and Mahesh 2019; Hutchinson et al. 2022
Risk Assessment	-1.61	1.37	-2	M	Ahmad and Gibb 2003; Aboagye-Nimo et al 2013; Fleming et al 2022; Deepak and Mahesh 2022; Deepak and Mahesh 2019; Danso et al 2022; Xu et al. 2023
Risk Taking Behavior	-1.39	1.83	-2	P	Fang and Wu 2013; Ahmad and Gibb 2003; Hartley and Cheyne 2010; Alruqi et al 2018; Danso et al. 2022
Orientation/Induction (Quality/Approach)	-0.67	1.10	-1	P	Hartley and Cheyne 2010; Feng and Trinh 2019; Alruqi et al 2018; Deepak and Mahesh 2019
Processes and Procedures	-1.00	1.41	-1	M	Aboagye-Nimo et al 2013; Deepak and Mahesh 2022; Deepak and Mahesh 2019; Molenaar et al. 2009; Ahamed & Mariappan 2023
Safety Roles and Responsibilities	-1.50	1.67	-1	M	Alruqi et al 2018; Deepak and Mahesh 2022; Fang and Wu 2013; Xu et al. 2023
External Influence	-0.67	2.86	-1	S	From Workshop
Client Leadership	-0.11	2.07	0	P	From Workshop
Tradition	-0.39	1.37	0	S	From Workshop
Training/Education	-0.11	1.03	0	M	Feng and Trinh 2019; Alruqi et al 2018; Tappura et al 2022; Deepak and Mahesh 2022; Fang and Wu 2013; Aboagye-Nimo et al 2013; Ahmad and Gibb 2003; Fleming et al 2022; Deepak and Mahesh 2019; Molenaar et al. 2009; Wamuziri 2008; Xu et al. 2023; Ahamed & Mariappan 2023; Liu et al. 2023
Organization Transparency (Safety)	-0.44	1.94	0	P	Fleming et al 2022; Deepak and Mahesh 2022; Deepak and Mahesh 2019
Incident/Near Miss Reporting	-0.11	1.03	0	M	Feng and Trinh 2019; Fang and Wu 2013; Ahmad and Gibb 2003; Deepak and Mahesh 2019
Action & Feedback on Safety Issues	1.39	1.83	1	M	Hartley and Cheyne 2010; Feng and Trinh 2019; Alruqi et al 2018; Tappura et al 2022; Deepak and Mahesh 2022; Fang and Wu 2013; Deepak and Mahesh 2019
Peer Support/Influence	1.00	1.26	1	S	Mohammadi et al 2018; Fang and Wu 2013; Aboagye-Nimo et al 2013; Hartley and Cheyne 2010; M.D. and Mahesh 2019
Psychological Safety	0.78	2.50	1	P	Hartley and Cheyne 2010; Deepak and Mahesh 2022; Ahmad and Gibb 2003; Deepak and Mahesh 2019; Liu et al. 2023
Worker Attitude Toward Safety	0.39	2.14	1	P	Ahmad and Gibb 2003; Fang et al. 2020
Worker Engagement	1.61	1.37	2	P	Feng and Trinh 2019; Alruqi et al 2018; Tappura et al 2022; Fang and Wu 2013; M.D. and Mahesh 2019
Open Communication	1.94	0.75	2	P	Alruqi et al 2018; Fleming et al 2022; Tappura et al 2022; Ahmad and Gibb 2003; Deepak and Mahesh 2022; Deepak and Mahesh 2019; Wamuziri 2008; Fang et al. 2020; Xu et al. 2023; Liu et al. 2023
Worker Commitment to Safety	2.11	1.86	2	S	Alruqi et al 2018; Fleming et al 2022; Tappura et al 2022; Deepak and Mahesh 2019; Xu et al. 2023
Financial Commitment	2.06	2.71	3	M	From Workshop
Accountability	2.89	1.86	3	S	From Workshop
Values and Beliefs	3.00	1.41	3	S	Aboagye-Nimo et al 2013; Molenaar et al. 2009; Danso et al. 2022; Sherratt and Aboagye-Nimo 2022
Leadership	2.78	2.50	4	S	Hartley and Cheyne 2010; Feng and Trinh 2019; Fang and Wu 2013; Tappura et al 2022; Deepak and Mahesh 2019; Molenaar et al. 2009; Fang et al. 2020; Liu et al. 2023
Management Commitment to Safety	3.94	1.63	4	S	Hartley and Cheyne 2010; Feng and Trinh 2019; Alruqi et al 2018; Tappura et al 2022; Deepak and Mahesh 2022; Fang and Wu 2013; Deepak and Mahesh 2019; Molenaar et al. 2009; Wamuziri 2008; Danso et al. 2022; Fang et al. 2020; Xu et al. 2023; Ahamed & Mariappan 2023
Supervisor Commitment to Safety	4.00	1.10	5	S	Hartley and Cheyne 2010; Tappura et al 2022; Aboagye-Nimo et al 2013; Fang et al. 2020; Ahamed & Mariappan 2023
C-Suite Commitment to Safety	4.44	1.60	5	S	Alruqi et al 2018; Deepak and Mahesh 2022; Fang and Wu 2013; Mohammadi et al 2018; Aboagye-Nimo et al 2013; Deepak and Mahesh 2019; Ahamed & Mariappan 2023

RESULTS

Following completion of the exercise, the 6 group's Q Sorts were individually captured, collated, and statistically analysed to create a shared final Q Sort. The resultant final element rankings (including Standard Deviation) can be seen in Table 1, which also contains the full list of the elements and their sources within literature.

The final combined Q Sort and subsequent consensus of the 'Spaghetti and Meatballs' analysis is visually represented in Figure 1.

Figure 1: Workshop Consensus Q Sort Distribution with 'Spaghetti and Meatballs' analysis



DISCUSSION

Despite their familiarity with both safety culture and the elements used within the Q Sort; the professionals found many of the elements 'easy to say but difficult to define'. Context was also considered to be an important factor, with many of the elements felt to be interconnected and influential of and by each other, with a notable difference between drivers and consequences for safety which are often muddled in the literature. Relationships for some elements, for example peer support/influence, are particularly complicated, as it is both a result of and a driver for safety culture, thus making its definition within a safety culture space challenging. The quality of each element was also felt to be critical - not only should they be done but done well - to make an effective contribution to a positive safety culture, however capturing this nuance was beyond the scope of the Q Sort. This provides useful insight into the general utility of extensional definitions for safety culture, and if they are even worth pursuing (AIHS 2019) - as when component elements also require extensive discussion for definition, the utility of an extensional definition of safety culture becomes even more questionable.

Overall, the professionals were in general agreement as to the relative importance of the various elements of construction safety culture. As shown by the Standard Deviations in Table 1, the most contentious elements were PPE Compliance and External Influence. PPE Compliance is an interesting element, as it is often used as an easily monitorable 'benchmark' for more significant compliance or even evidence of a positive safety culture (Hartley and Cheyne 2010). Yet is also in and of itself superficial in terms of occupational safety management, sitting relatively low on the 'Hierarchy of Control' (Barnett 2020) which could well have influenced discussions around this element. External Influence was also contentious, perhaps due to its rather fundamental ambiguity. This was a workshop suggested element, rather than one that had been generated from the literature, and it emerged from considerations of other sites workers may have recently worked on which held less rigorous safety standards, as well as wider industry common practices. Thus, whilst a valid element for consideration, precisely how this should be considered 'correctly' certainly generated uncertainty amongst the professionals.

As shown in Figure 1, there was a general trend of low ranked elements equating to meatballs, moving through the spaghetti (pasta) to sauce evaluations of measurement for the elements ranked most important by the construction safety professionals. Many of the most highly ranked elements are thus also the most nebulous and difficult to capture, reflecting Model 3 of safety culture, in which safety is emergent and socially constructed. The professionals also highlighted that many of the meatballs were important for practice and more behaviourally focused, yet the quality of their delivery was the result of the sauce, which contained the actions that influence such safety behaviours. Put another way, the meatballs were generally more transactional and safety-specific, whilst the pasta and sauce were more transformational and organizational-specific in nature. A further interesting comment was that this may reflect the temporal nature of safety management as a profession, as many of the meatballs were established some time ago (e.g., BBS) whilst the sauce contained more contemporary considerations for safety such as leadership.

That leadership was considered sauce was itself interesting as safety leadership is a significant area of contemporary academic safety research (e.g., Fang *et al.,* 2020). Whether academe has not yet produced something practical, or the research has simply not yet reached the field, is therefore worthy of consideration.

Commitment in various forms also featured highly in the combined Q Sort, suggesting this should be an area of future focus in terms of measurement or assessment of culture. Traditionally, this is the remit of the safety culture survey, however opinion surveys do not always equate to scientific evidence, and as such there is a need to develop alternative metrics able to demonstrably prove any commitment in practice. The 'hierarchy' of commitment in the Q Sort (running: C-Suite, Supervisor, Manager, Worker in terms of importance) does however generate curiosity around what could effectively be evaluated as ongoing and demonstrable commitment. The Q Sort makes one such a suggestion here, as Financial Commitment was an element highly ranked in importance in the workshop and evaluated as a meatball. This indicates that Financial Commitment is itself easy to determine and offers a variety of different aspects to consider, including policies and practices in tendering and subcontracting activities. This also reflect more general Q Sort findings, that importance has shifted from on-site behaviours to upstream organizational activities, where decisions are made that can and do affect site operations negatively in terms of safety (Hovden *et al.,* 2010). Thus, a metric based on a firm's financial commitment to safety could also demonstrate C-Suite Commitment to safety, and a way in which measurable actions (for example prioritization of safety through robust subcontractor selection processes) could be clearly evidenced. This, and other alternative ways to scientifically measure the other highly ranked elements of safety culture, will be explored further in the next stage of this research which will look to co-create a suite of relevant safety culture metrics as suggested by this exercise with the same group of safety professionals, and subsequently seek to validate them in practice.

CONCLUSIONS

This empirical work is shared for consideration by and discussion with the ARCOM community. Q Methodology provided a novel approach to exploring safety culture with US safety professionals and resulted in an empirical consensus as to the most important elements needed to create a positive safety culture, and an evaluation of their relative ease of measurement - with a broadly inverse correlation. What it has not succeeded in doing is making the complicated case of safety culture simple! However, the venture is not entirely quixotic, as the findings from the Q Sort provide empirically grounded insights to direct the next steps in this ongoing research project - for example, the need to de-silo safety culture from organizational culture given the transformational nature of many of the most important elements, and thus the potential for measurement beyond traditional safety metrics further upstream. Feedback and comments from the ARCOM community on this work is most welcome.

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A FRAMEWORK FOR IMPROVING THE PERFORMANCE OF HEALTH AND SAFETY OFFICERS IN THE CONSTRUCTION INDUSTRY

Llewellyn Walljee and John Smallwood[1]

Department of Construction Management, Nelson Mandela University, PO Box 77000, Port Elisabeth, 6031, South Africa

The appointment of construction health and safety officers (CHSOs) is a requirement of the South African Construction Regulations. However, several studies have indicated that the performance of CHSOs can be improved. The aim of this study was to evolve a framework for improving CHSOs' performance. A self-administered questionnaire distributed to 196 members of a national H&S association resulted in 69 responses, and a net response rate of 38.8%, The salient findings include the CHSOs in general are above average in terms of the core competencies, and combined knowledge and skills areas, however, there is potential for improvement. The proposed framework includes predictors of performance in the form of the core competencies, combined knowledge and skills areas, professional registration, and professional association, and enablers of performance in the form of H&S should be afforded status at least equal to that afforded to the other project parameters and be integrated into the construction process and activities, and CHSOs should be an integral part of site management and included in decision making.

Keywords: framework, health and safety; health and safety officers, performance

INTRODUCTION

The South African construction industry generates a high level of injuries relative to construction industries globally. Based upon a total of 255 572 workers insured by The Federated Employers Mutual Assurance Company (RF) (Pty) Ltd (FEM) (2023) for the year 2022, the fatality rate (FR) was 17.6 / 100 000 workers, the accident rate (AR) was 228.9 / 10 000 workers or 2.29 / 100 workers, and the disabling injury incidence rate (DIIR) was 0.19 or 0.19 / 100 workers.

The Construction Industry Development Board's (cidb) (2009) seminal industry H&S report 'Construction Health and Safety Status and Recommendations' highlighted the significant number of accidents, fatalities, and other injuries that are prevalent in South African construction. The report attributed this to a lack of compliance with H&S legislative requirements and referred to a lack of sufficiently skilled, experienced, and knowledgeable persons to manage H&S on construction sites. Furthermore, the recommendations in the report included the need for professional registration of construction H&S practitioners due to, inter alia, the finding that there was a lack of competencies, and no formal registration process. The South African Council for the Project and Construction Management Professions (SACPCMP) was

[1] john.smallwood@mandela.ac.za

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then mandated to register construction H&S professionals, including CHSOs, in terms of Act No.48 (Republic of South Africa, 2000).

Given 'Constructing for the Future' is the theme of the conference and the related focus on sustainability, which includes H&S and wellbeing, the relevance of the performance of CHSOs within the context of South African construction H&S is amplified. Furthermore, given the findings in the cidb report, subsequent research findings, a further study was conducted to determine, inter alia, the importance of core and surface competencies, and the rating of CHSOs relative thereto, in addition to the management of H&S, the aim being to evolve a framework for improving their performance.

LITERATURE REVIEW

Knowledge and Skills Areas

Singh (2004) suggests that competencies are divided into two categories: the surface, which are required to be at least effective, and core, which distinguishes superior performance from average performance. The surface competencies are knowledge (information regarding content), and skills (ability to perform a task). The core competencies, which are generally characteristics, are self-concept (values, aptitude, attitude, and self-image), traits (self-confidence, team player, and handles ambiguity), and motives (focus on client success, and preserves organisation / personal integrity).

Nine knowledge areas must be addressed in the report submitted upon application to register as a CHSO with the SACPCMP: Procurement Management; Cost Management; Hazard Identification Management; Risk Management; Accident or Incident Investigation Management; Legislation and Regulations; Health, Hygiene and Environmental Management; Communication Management, and Emergency Preparedness Management (SACPCMP, 2013a). The CHSO Scope of Services in turn states that CHSOs are expected to be experienced and knowledgeable relative to the following areas: construction project specific H&S management systems; construction H&S; H&S performance measurement and monitoring management, and continual improvement (SACPCMP, 2013b).

However, a study conducted prior to the registration of CHSOs initiative by Smallwood and Haupt (2008) investigated the importance of 79 knowledge areas and 50 skills to CHSOs. These were then consolidated in terms of eight and seven composite knowledge and skills areas respectively. The eight composite knowledge areas include: construction technology / technology; design; financial management; H&S; law; management / management of parameters; planning, and project administration. The seven composite skills areas include: financial; general management; interpersonal / developmental; leadership; negotiating; planning, and technical. The nine knowledge areas, and the 'scope of services' areas which CHSOs are required to be experienced and knowledgeable relative to as per the SACPCMP (2013a; 2013b), are included in the eight composite knowledge and seven composite skills areas as per Smallwood and Haupt (2008).

METHOD

Due to the nature and extent of the data required, the quantitative method was adopted, which entailed the use of a self-administered questionnaire consisting of fifteen questions. Questions one to six included five-point Likert scale type questions directed at determining the importance of surface and core competencies to CHSOs, and the rating of CHSOs relative thereto. The composite knowledge areas and composite skills, which constitute the surface competencies, and which were included in the questionnaire, have their origin in the study conducted by Smallwood and Haupt (2008), and were used in several subsequent related studies. The core competencies included in the questionnaire are according to Singh (2004) and are applicable to all construction management and related functions, and for that matter, built environment professionals. Question seven enabled the respondents to record any general comments, and questions eight to fifteen were aimed at extracting demographic data. The questionnaire was pre-tested among ten randomly selected H&S practitioners to ensure that the questionnaire did not contain errors or ambiguities, before administering the primary questionnaire.

The sample included a national construction H&S association in South Africa. A total of 195 questionnaires were distributed, 69 were returned, 17 were recorded as undelivered, and 109 were not returned, which equates to a response rate of 38.8% i.e., 69 / (195 - 17).

The analysis of the data entailed the computation of descriptive statistics, and a measure of central tendency in the form of a mean score (MS) between 1.00 and 5.00, based upon percentage responses to the points on the respective scales to enable interpretation of the responses, and to rank variables where necessary. To enable interpretation of the MSs, ranges were created. The ranges span 0.80 based upon the difference between 5.00 and 1.00 being 4, divided by the number of points, namely 5, which equals 0.80 i.e., ≥ 1.00 ≤ 1.80; > 1.80 ≤ 2.60; > 2.60 ≤ 3.40; > 3.40 ≤ 4.20, and > 4.20 ≤ 5.00.

FINDINGS

CHSOs (56.5%) predominate among the respondents, followed by CHSMs (34.8%), Construction Manager (4.3%), Construction Project Manager (2.9%), and CHSA (1.4%).

Table 1 presents a comparison of the importance of ten core competencies relative to CHSOs and the rating of them relative thereto, in terms of MSs and ranks, based upon percentage responses to scales of 1 (not important) to 5 (very important) (importance), and very poor to excellent (rating), respectively.

All the ‘importance’ MSs are > 4.20 ≤ 5.00, which indicates that the core competencies are more than important to very important / very important. Team player is ranked first, followed by preservation of personal integrity, and values. In terms of the ‘importance’ category MSs, motives are ranked first, marginally ahead of traits, followed by self-concept.

Only 3 / 10 (30.0%) ‘rating’ MSs are > 4.20 ≤ 5.00, which indicates that the rating is good to excellent / excellent - preservation of personal integrity, focus on client success, and preservation of organisation integrity.

The remaining 7 / 10 (70%) ‘rating’ MSs are > 3.40 ≤ 4.20, which indicates that the rating is average to good / good - team player is followed by self-confidence, self-image, values, attitude, aptitude, and handle ambiguity. In terms of the ‘rating’ category MSs (emboldened), motives are ranked first, followed by traits, and self-concept.

In terms of ratings as expressed as a percentage of importance, the percentages range from 89.3% to 80.2%. Focus on client success (89.3%) is clustered along with self-image (88.6%), preservation of personal integrity (88.4%), aptitude (87.8%), and preservation of organisation integrity (87.5%).

Table 1: Comparison of the importance of ten core competencies relative to CHSOs and the rating of them relative thereto

Category / Core competency	Importance (I)			Rating ®			R/I
	MS	R	OR	MS	R	OR	
Self-concept:	4.54	3		4.00	3		84.7
Values	4.70	1	3	4.00	2	7	81.1
Aptitude	4.35	4	10	3.94	4	9	87.8
Attitude	4.67	2	6	4.00	3	8	81.7
Self-image	4.43	3	9	4.04	1	6	88.6
Traits:	4.67	2		4.02	2		82.3
Self-confidence	4.70	2	4	4.07	2	5	83.0
Team player	4.83	1	1	4.19	1	4	83.3
Handle ambiguity	4.49	3	8	3.80	3	10	80.2
Motives:	4.71	1		4.28	1		88.4
Focus on client success	4.64	3	7	4.25	2	2	89.3
Preservation of organisation integrity	4.68	2	5	4.22	3	3	87.5
Preservation of personal integrity	4.80	1	2	4.36	1	1	88.4

Table 2 presents a comparison of the importance of eight combined knowledge areas relative to CHSOs and the rating of them relative thereto, in terms of MSs and ranks, based upon percentage responses to scales of 1 (not important) to 5 (very important), and very poor to excellent, respectively.

Combined knowledge area	Importance		Rating		R/I
	MS	R	MS	R	
Project administration	4.32	3	3.77	5	83.4
Financial management	3.77	7	3.42	7	87.4
Design	3.61	8	3.22	8	85.1
Law	4.36	2	4.13	2	93.2
Construction technology / Technology	3.94	6	3.59	6	88.1
H&S	4.80	1	4.43	1	90.3
Planning	4.14	5	3.91	3	92.7
Management / Management of elements	4.30	4	3.88	4	87.3

Table 2: Comparison of the importance of eight combined knowledge areas relative to CHSOs and the rating of them relative thereto

Half of the 'importance' MSs are > 4.20 ≤ 5.00, which indicates that the combined knowledge areas are more than important to very important / very important. H&S is ranked first, followed by law, project administration, and management / management of elements. The remaining 4 / 8 (50.0%) MSs are > 3.40 ≤ 4.20, which indicates that the combined knowledge areas are important to more than important / more than important.

Only 1 / 8 (12.5%) 'rating' MSs is > 4.20 ≤ 5.00, which indicates that the rating is between good to excellent / excellent - H&S.

A further 6 / 8 (75%) 'rating' MSs are > 3.40 ≤ 4.20, which indicates that the rating is average to good / good - law, planning, management / management of elements, project administration, construction technology / technology, and financial management.

The remaining 1 / 8 (12.5%) 'rating' MSs is > 2.60 ≤ 3.40, which indicates that the rating is poor to average / average.

In terms of ratings as expressed as a percentage of importance, the percentages range from 93.2% to 83.4%. Law (93.2%), planning (92.7%), and H&S (90.3%) have percentages > 90.0%, which are followed by the remaining five combined knowledge areas.

Table 3 presents a comparison of the importance of seven combined skills areas relative to CHSOs and the rating of them relative thereto, in terms of MSs and ranks, based upon percentage responses to scales of 1 (not important) to 5 (very important), and very poor to excellent, respectively.

4 / 7 (57.1%) 'importance' MSs are > 4.20 ≤ 5.00, which indicates that the combined skills areas are more than important to very important / very important - leadership, interpersonal / developmental, planning, and general management. The remaining 3 / 7 (42.9%) MSs are > 3.40 ≤ 4.20, which indicates that the combined skills areas are important to more than important / more than important - negotiating, technical, and financial.

No 'rating' MSs are > 4.20 ≤ 5.00, however, 6 / 7 (85.7%) 'rating' MSs are > 3.40 ≤ 4.20, which indicates that the rating is average to good / good - leadership, interpersonal / developmental, general management, negotiating, planning, and technical. The remaining 1 / 7 (14.3%) 'rating' MSs is > 2.60 ≤ 3.40, which indicates that the rating is poor to average / average - financial.

In terms of ratings as expressed as a percentage of importance, the percentages range from 93.4% to 82.7%. Negotiating (93.4%), interpersonal / developmental (92.1%), and Technical (91.9%) have percentages > 90.0%, which are followed by the remaining four combined skills areas.

Table 3: Comparison of the importance of seven combined skills areas relative to CHSOs and the rating of them relative thereto

Combined skills area	Importance		Rating		R/I
	MS	R	MS	R	
Interpersonal / Developmental	4.29	2	4.03	2	92.1
General management	4.25	4	3.91	3	89.5
Financial	3.72	7	3.25	7	82.7
Leadership	4.51	1	4.09	1	88.0
Negotiating	4.01	5	3.81	4	93.4
Planning	4.28	3	3.74	5	83.5
Technical	3.96	6	3.72	6	91.9

Table 4 indicates the degree of concurrence with four statements related to the practice of H&S management by CHSOs in terms of percentage responses to a scale of strongly disagree to strongly agree, and MSs between 1.00 and 5.00.

The MSs of 2 / 4 (50%) statements are > 4.20 ≤ 5.00, which indicates that the concurrence is between agree to strongly agree / strongly agree - 'CHSOs require leadership skills to practice H&S management', and CHSOs require a formal education as a prerequisite to practice H&S management'.

The MSs of the remaining 2 / 4 (50%) statements are > 3.40 ≤ 4.20, which indicates that the concurrence is between neutral to agree / agree - 'CHSOs require technical skills to practice H&S management', and 'CHSO intervention and participation is fostered through construction H&S legislation'.

Table 4: Degree of concurrence with four statements related to the practice of H&S management by CHSOs

Statement	Response (%) Unsure	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	MS
CHSOs require leadership skills to practice H&S management	0.0	1.5	4.4	1.5	39.1	53.6	4.39
CHSOs require a formal education as a prerequisite to practice H&S management	1.5	1.5	2.9	7.3	31.9	55.1	4.32
CHSOs require technical skills to practice H&S management	0.0	1.5	1.5	13.0	53.6	30.4	4.10
CHSO intervention and participation is fostered through construction H&S legislation	0.0	2.9	8.7	13.0	63.8	11.6	3.72

Table 5 indicates the degree of concurrence with ten statements relative to the influence of CHSOs during construction in terms of percentage responses to a scale of strongly disagree to strongly agree, and MSs between 1.00 and 5.00.

It is notable that no MSs are > 4.20 ≤ 5.00, however, the MSs of 6 / 10 (60%) are > 3.40 ≤ 4.20, which indicates that the concurrence is between neutral to agree / agree - ‘CHSOs are compliance drivers’, ‘site management commitment is the main driver for CHSOs influencing H&S initiatives’, ‘CHSOs mostly influence organisations through a reactive approach using inspection or audit findings, and accident data’, ‘CHSOs are competent in terms of construction methods’, ‘CHSOs are competent in terms of construction materials’, and ‘CHSOs are competent in terms of plant and equipment’.

The MSs of 2 / 10 (20%) are > 2.60 ≤ 3.40, which indicates that the concurrence is between disagree to neutral / neutral - ‘CHSOs are side-lined in terms of decision making’, and ‘CHSOs do not have the status to influence change in the organisation’. These findings are contrary to those reflected in the literature.

The MSs of 2 / 10 (20%) are > 1.80 ≤ 2.60, which indicates that the concurrence is between strongly disagree to disagree / disagree - ‘CHSOs do not influence behaviour’, and ‘CHSOs do not engage workers to gather H&S advice’. Ideally the MSs should be 1.00 as CHSOs should influence behaviour and should engage workers to gather H&S advice.

Table 5: Degree of concurrence with ten statements relative to the influence of CHSOs during construction

Statement	Response (%) Unsure	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	MS
CHSOs are compliance drivers	0.0	1.5	10.1	10.1	52.2	26.1	3.91
Site management commitment is the main driver for CHSOs influencing H&S initiatives	1.5	2.9	5.8	17.4	42.0	30.4	3.87
CHSOs mostly influence organisations through a reactive approach using inspection or audit findings, and accident data	0.0	7.3	11.6	8.7	43.5	29.0	3.75
CHSOs are competent in terms of construction methods	0.0	1.5	2.9	8.7	23.2	43.5	3.65
CHSOs are competent in terms of construction materials	0.0	2.9	11.6	24.6	43.5	17.4	3.61
CHSOs are competent in terms of plant and equipment	0.0	2.9	14.5	20.3	44.9	17.4	3.59
CHSOs are side-lined in terms of decision making	0.0	14.5	13.0	17.4	40.6	14.5	3.28
CHSOs do not have the status to influence change in the organisation	0.0	18.8	30.4	11.6	29.0	10.1	2.81
CHSOs do not influence behaviour	0.0	29.0	44.9	11.6	11.6	2.9	2.14
CHSOs do not engage workers to gather H&S advice	0.0	31.9	49.3	5.8	13.0	0.0	2.00

Table 6 indicates the degree of concurrence with eight statements relative to the management of H&S in CHSOs' organisations in terms of percentage responses to a scale of strongly disagree to strongly agree, and MSs between 1.00 and 5.00.

It is notable that only 1 / 8 (12.5%) MSs is > 4.20 ≤ 5.00, which indicates that the concurrence is between agree to strongly agree / strongly agree - 'H&S officers actively monitor H&S', which is a legal and function-related requirement.

The MSs of 4 / 8 (50%) are > 3.40 ≤ 4.20, which indicates that the concurrence is between neutral to agree / agree - 'audits are required for H&S management to be successful', 'production pressure contributes to poor H&S performance', 'the organisation uses legislation requirements as a minimum to address H&S management', and 'poor H&S performance is due to inadequate supervision'. Audits are a legal requirement (RSA, 2014), and enable identification of H&S management system and H&S programme issues. The negative impact of production pressure and inadequate supervision on H&S are well documented in the literature (cidb, 2009). Then, H&S legislation constitutes the minimum requirements, and it is notable that the respondents indicate that their organisations target better practice.

The MSs of 2 / 8 (25%) are > 2.60 ≤ 3.40, which indicates that the concurrence is between disagree to neutral / neutral - 'workers monitor their fellow workers in terms of H&S', and 'site management actively monitors H&S'. Ideally the concurrence should be greater as management commitment and worker participation are the 'two pillars' of an H&S programme.

The MS of 1 / 8 (12.5%) statements, namely 'a formal H&S programme is not needed in the organisation' is > 1.80 ≤ 2.60, which indicates that the concurrence is between strongly disagree to disagree / disagree. This statement is untrue, and the MS should have been 1.00.

Table 6: Degree of concurrence with eight statements relative to the management of H&S in CHSOs' organisations

Statement	Response (%)						MS
	Unsure	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	
H&S officers actively monitor H&S	0.0	1.5	0.0	2.9	47.8	47.8	4.41
Audits are required for H&S management to be successful	0.0	2.9	7.3	10.1	40.6	39.1	4.06
Production pressure contributes to poor H&S performance	0.0	4.4	7.3	7.3	49.3	31.9	3.97
The organisation uses legislation requirements as a minimum to address H&S management	1.5	1.5	10.1	17.4	43.5	26.1	3.78
Poor H&S performance is due to inadequate supervision	1.5	1.5	7.3	24.6	40.6	24.6	3.75
Workers monitor their fellow workers in terms of H&S	7.3	14.5	37.7	26.1	14.5	7.3	3.26
Site management actively monitors H&S	0.0	8.7	20.3	21.7	37.7	11.6	3.23
A formal H&S programme is not needed in the organisation	0.0	59.4	37.7	0.0	1.5	1.5	1.48

DISCUSSION

The importance of the ten core competencies relative to CHSOs, namely more than important to very important / very important underscores the contention of Singh (2004), namely that core competencies distinguish superior performance from average performance. Furthermore, a study conducted by Smallwood and Emuze (2011) determined that 8 / 10 core competencies are more than important to very important /

very important in terms of the practice of construction management, which includes the management of H&S. Given that CHSOs were rated good to excellent / excellent in terms of 3 / 10, and average to good / good in terms of 7 / 10 core competencies, potential exists for an improvement in the latter seven core competencies. In terms of importance versus rating, the 'importance' MSs range from 4.83 to 4.35, the 'rating' MSs range from 4.36 to 3.80, and that the percentages in terms of ratings / importance range from 89.3% to 80.2%. It is notable that the percentages relative to core competencies, composite knowledge areas, and composite skills areas are relatively consistent. Furthermore, although the percentages can be deemed high, they indicate potential for improvement.

Half the eight combined knowledge areas are more than important to very important / very important, and the other half are important to more than important / more than important. This finding indicates greater importance than those courtesy of a study conducted by Smallwood and Haupt (2008), which determined 2 / 8 were more than important to very important / very important, 5 / 8 were important to more than important / more than important, and 1 / 8 were less than important to important / important. H&S, law, and project administration are the top three in the current study, as opposed to H&S, project administration, and design in the 2008 study. Given that CHSOs were rated good to excellent / excellent in terms of 1 / 8, average to good / good in terms of 6 / 8, and poor to average / average in terms of 1 / 8 combined knowledge areas, potential exists for an improvement relative to the combined knowledge areas. Furthermore, these findings differ from those courtesy of a study conducted by Smallwood and Deacon (2017), which determined that CHSOs were rated below average relative to 7 / 8 combined knowledge areas. In terms of importance versus rating, the 'importance' MSs range from 4.80 to 3.61, the 'rating' MSs range from 4.43 to 3.22, and that the percentages in terms of ratings / importance range from 93.2% to 83.4%. It is notable that the 'importance' MS range is greater than that relative to core competencies. Furthermore, although the percentages can be deemed high, they indicate potential for improvement.

4 / 7 combined skills areas are more than important to very important / very important, and 3 / 7 are important to more than important / more than important. This finding reflects the finding of a study conducted by Smallwood and Haupt (2008), which determined 4 / 7 were more than important to very important / very important, 2 / 7 were important to more than important / more than important, and 1 / 7 was less than important to important / important. In terms of importance versus rating, the 'importance' MSs range from 4.51 to 3.72, the 'rating' MSs range from 4.09 to 3.25, and that the percentages in terms of ratings / importance range from 93.4% to 82.7%. It is notable that the 'importance' MS range is greater than that relative to core competencies. Furthermore, although the percentages can be deemed high, they indicate potential for improvement.

Given that CHSOs were rated average to good / good in terms of 6 / 7, and poor to average / average in terms of 1 / 7 combined skills areas, potential exists for an improvement relative to the combined skills areas. Furthermore, these findings differ from those courtesy of a study conducted by Smallwood and Deacon (2017), which determined that CHSOs were rated below average relative to 7 / 7 combined skills areas.

The degree of concurrence with ten statements relative to the influence of CHSOs during construction highlights that CHSOs influence H&S through driving compliance using inspection or audit findings, and accident data, and that site management commitment is the main driver for CHSOs influencing H&S. Furthermore, they do have status to influence change and behaviour, and they do facilitate worker participation in H&S despite being side-lined to a degree in terms of decision making. CHSOs are also competent in terms of construction materials, methods, and plant and equipment.

The degree of concurrence relative to the need for CHSOs to possess leadership and technical skills, and undergo formal education is underscored by previous studies (Smallwood and Haupt, 2018; Smallwood and Deacon, 2017).

The degree of concurrence with eight statements relative to the management of H&S highlights the importance of formal H&S programmes, and H&S legislation, the latter constituting a guide for the management of H&S, and audits. H&S officers are focused on monitoring H&S, site management monitors H&S, workers monitor their fellow workers in terms of H&S, optimum supervision is a pre-requisite for optimum H&S performance, and production pressure contributes to poor H&S performance.

CONCLUSIONS

Given that 56.5% of respondents were CHSOs it can be argued that the findings are biased to a degree, however, 43.5% were primarily ‘managers’ and exposed to CHSOs and thus ‘observers’ and ‘reviewers’ of CHSOs. Furthermore, given that most of the respondents (90.3%) are CHSOs and CHSMs and are thus employed by contractors, their employers are likely to be committed to H&S and thus compatible to CHSO and CHSM interventions, participation, and influence in terms of H&S. This enhances the validity and reliability of the findings.

The findings reinforce the need for CHSOs to be competent in terms of eight combined knowledge areas, and not just H&S as a knowledge area, and to be competent in terms of seven skills areas. The CHSOs in general are above average in terms of competency relative to the combined knowledge and skills areas, however, there is potential for improvement.

CHSOs should undergo formal education in terms of either diploma or degree programmes, as opposed to ad hoc short courses. This is underscored by the importance of the combined knowledge and skills areas.

H&S management does not occur in a ‘vacuum’ and is an integral part of site management and contracts management, and H&S should be afforded status at least equal to that afforded to the other project parameters and integrated into the construction process and activities. Given this site management, supervision, workers, CHSMs, and CHSOs should be committed to and empowered to contribute to H&S. Furthermore, CHSOs should be an integral part of site management and included in decision making.

Therefore, the proposed framework includes: predictors of performance in the form of the core competencies, combined knowledge and skills areas, professional registration, and professional association, and enablers of performance in the form of H&S should be afforded status at least equal to that afforded to the other project parameters and integrated into the construction process and activities, and CHSOs should be an integral part of site management and included in decision making.

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INCORPORATING PUBLIC HEALTH IMPACTS IN THE IMPACT ASSESSMENT PROCESS DURING ROAD PROJECTS: WEAKNESSES AND CHALLENGES

U T G Perera[1], Richard Haigh and Dilanthi Amaratunga

[1] *Global Disaster Resilience Centre, University of Huddersfield, Queensgate, Huddersfield HD1 3DH, UK*

Road construction projects have various effects on human health, with nearby communities in populated areas being particularly vulnerable. In Sri Lanka, an Impact assessment (IA) is the primary obligatory tool for incorporating information on human health during the projects. However, the attention to health impacts is limited and it is unclear about the challenges and weaknesses that might be hindering a fuller consideration of health in current practices. Therefore, this study conducted 42 semi-structured interviews in Sri Lanka to obtain the experts' opinions on the inclusion of health impact during the road projects. A thematic analysis was performed to identify the key impacts, challenges, and weaknesses during the projects. The findings revealed few major impact categories including air, noise, and vibration nuisance as well as few other impacts including communicable diseases and behavioural risks. Findings suggest that there is a need to promote more comprehensive inclusion of health in IAs during road projects in developing countries.

Keywords: health; impact assessments; nearby community; road projects

INTRODUCTION

Roads are expanding at an unparalleled pace across the world, both in total length and extent. By 2050, approximately 25 million kilometers of new roads are planned, representing a 60% rise in total road length over **2010(**Dulac, 2013). Also, road infrastructure investment is projected to increase at an average annual rate of about 5% worldwide over the period of 2014 to 2025 (Smith, Weyber and Harrison, 2015). Alamgir *et al. (*2017) revealed that 90% of new roads will be developed in the developing countries, most of which will be in tropical and subtropical areas. As a result of factors such as fast population growth, urbanisation, and economic development, roads will likely remain the biggest area of investment, especially for growth markets in these countries. Most governments in the developing countries are using road construction to scale up their cities ‘competitiveness, requiring structuring and re-structuring of their road networks, and in return, attract investments. Also, such development has been a crucial factor in the region development strategies in these countries.

[1] thisara.uduwarage@hud.ac.uk

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Road development has been found to improve mobility enhancing accessibility to jobs, social facilities and services such as schools and hospitals as well as an increased market for agricultural goods and services (Pradhan and Bagchi 2013).It has a major role in urban and regional development, because it provides accessibility options for markets, education occupation, health and other key services (Makarova *et al.,* 2017).Moreover, road development has significantly improved the livelihoods of rural areas. These developments facilitate the timely and reasonable delivery of basic health, education, water, and sanitation services, which can empower vulnerable groups (Laurance and Balmford, 2013).

Despite its many perceived and actual benefits, road development may also have negative impacts on people, especially related to public health. Given the unparalleled speed and scope of these activities, it is critical to properly examine the potential outcomes of large-scale road and highway developments in developing countries. Yet these are the countries that have less emphasis on those health impacts, where impact assessments are limited to the documentation process of the project without any monitoring or evaluating process on these adverse health impacts (Kolhoff *et al.,* 2016). This was further identified by Cheriyan *et al. (*2020) on their research on PM pollution. For example, they pointed out that environmental standards on impact assessment for PM2.5 are significantly weaker in developing countries compared to the World Health Organization (WHO) guidelines. The public health impacts could be easily neglected during project implementation as there was not a dedicated section for public health in most of these impact assessment reports. Previous studies have also highlighted this ignorance of public health aspect in impact assessment reports where traditional road planning tends to consider only some of the long-term impacts from road construction, such as accidents and environmental pollution factors (Chauhan *et al.,* 2010; Lee *et al.,* 2013; Moretti *et al.,* 2018).

Some studies have found that the construction phase of road projects has a greater effect on public health than other stages of road development (Ngwepe and Aigbavboa, 2015). Several studies have also highlighted the impact of construction materials and equipment, which can cause high levels of air pollution and noise during working hours (Li *et al.,* 2017; Moretti *et al.,* 2018). These studies also highlight the impact to public health, which are not clearly addressed in existing construction projects. These risks are especially significant in urban areas, where the population density is high alongside the roads, and the resident population are highly exposed to these impacts (Celik and Budayan, 2016; Moretti *et al.,* 2018). However, a few studies have identified the lack of a holistic approach to assess these public health impacts as a major gap in the existing literature (Diallo *et al.,* 2018; Pham, Riley and Harris, 2018).

Riley - Powell *et al. (*2018) and Zolfagharian (2012) claimed that enhancing the identification of major health impacts of road construction processes will help to improve the effectiveness of environmental management systems. Therefore, developed countries have implemented an integrated health impact assessment or a separate health impact assessment during the road construction process. Studies have highlighted the effectiveness of such assessment where environment and public wellbeing considered as a key aspect throughout the construction process (Tobollik *et al.,* 2016; Gálvez-Martos *et al.,* 2018). However, studies have found that developing countries are suffering from the limited scientific data about the impacts of road construction materials and technologies on health, and therefore it is difficult to make informed choices aimed at reducing such impacts through the impact assessment process (Chauhan *et al.,* 2010; Men *et al.,* 2022). Therefore, a better understanding of the impact on public health during road construction projects will be vital in tackling this adverse situation.

As a developing country, this lack of attention to health impacts has also been evident in Sri Lanka, a country where successive governments have committed substantial investment into constructing, developing, rehabilitating, widening, and maintaining road transport infrastructure (Arunashantha, 2019). During the rapid growth of road development, health issues related to construction workers have been addressed under the factories Ordinance No. 45 of 1942, which is the main existing national law related to the occupational safety and health in the country. However, there is little evidence of attempts to identify potential public health impacts. Although the existing environment impact assessment process has tended to focus on public health, that health evaluation has been limited to a few environmental health aspects, such as air pollution dust and noise (Perera *et al.,* 2021). There also appears to be the lack of a common framework to identify the overall public health impacts in road construction (Hapuarachchi *et al.,* 2016).

To address this gap, this study aims to assess the potential health impacts due to the road construction projects activities in a developing country, Sri Lanka, and to identify the most harmful activities and vulnerable groups during the construction stage of the road projects. The opening sections of this paper provide a brief literature review of recent studies related to health impacts and the construction sector, including roads. This review illustrates the lack of studies on public health during the road construction projects and its impacts on the nearby communities. The subsequent sections set out the methodology and results from a qualitative study in Sri Lanka.

METHOD

Empirical investigations were carried out in Sri Lanka in March - April 2022 using a semi structured interview format to investigate the potential public health impacts occurs during the construction phase of the road projects. As noted by Silverman (2001) the interviews in social science strive to generate data which give an authentic insight into people's experience. Further, the semi-structured format encourages two-way communication and allows interviewers to learn answers to questions as well as the reasons for the answers, as well as giving respondents time to open up about other issues (DeJonckheere and Vaughn, 2019). Several studies have also adopted the semi structured interviews to investigate the public health impacts in development projects (Marttunen and Hämäläinen, 1995; GYI, GIBB and HASLAM, 1999; Altman *et al.,* 2020)

Twelve categories of expert were identified through the reviewed literature sources as the potential key informants for the first phase of the interviews (Table 1). From the selected categories, forty-two (42) interviews were conducted in Sri Lanka with representatives from agencies in road construction, public health and environment management using the purposive sampling method.

The interview protocols were developed around the three guiding research questions. And further analysis for the expert interviews was developed based on a thematic extraction, where key themes of each interview were extracted. Then, the themes were classified based on the research questions, and these key findings of the classification are highlighted in the results and discussion section. Findings from the expert interviews provided a deeper understanding of potential public health impacts that occur during the construction phase of the road projects and beyond the theoretical discourse. They showcased the research gaps and potential discrepancies with observations from practice as well.

Table 1: 12 Categories of the selected key informants

Category	Code	Number of interviews
Academia on Environment Science	ES	05
Academia on Construction and Civil Engineering	CC	04
Environment practitioners (Government)	EPG	04
Environment practitioners (Private)	EPP	04
Central Environment Authority	CEA	02
Road Development Authority	RDA	03
Road Contractors	RC	03
Health and Safety officers	HS	04
Consultant - Road Construction	CRC	04
General Practitioners	GP	03
Health officials (Ministry of Health)	HO	03
MOH- Public Health Inspectors	PH	03

FINDINGS

All interviewed experts reported increased frequency and severity of public health impacts during road construction projects and were very concerned about short - term and long - term impacts of these projects. Some experts reported that they observed severe health impacts in recent years due to the increased frequency of road infrastructure development projects. Such statements were made by the interviewees whose expertise and professional experience was in health and safety and public health. The most prominent types of health impacts described by the respondents were air quality and dust nuisance, noise nuisance, water pollution and mosquito borne diseases.

Dust Nuisance

Among these four impacts, almost all respondents agreed on the impact of air pollution and dust nuisance on nearby communities. As stated by two of the interviewees ES 5 and CRC 4 the dust issue was the major public health impact in most of the road construction projects in Sri Lanka.“ When we are going to the ground level, the most frequent complaint is the dust, so we have to control dust in road construction, but it is not practiced”.“90% of the complaints received about the impacts were about this dust issue. But this depends on the project. In an expressway project, we can establish a dust barrier. But if it is a B grade one, minor road, there is a practical issue of implementing a barrier in such cases. Because these are short term effects”.

It was clear through the statements made by the respondents that most of the existing preventive measures which should be considered under public health and safety had been largely overlooked the air quality and dust nuisances during these road construction projects. A respondent from the road development authority (RDA 1) revealed that most road contractors ignore public health concerns, and it has led to many public complaints to the road development authority, especially concerning dust and the noise. This was further confirmed by general practitioners (GP1 and GP2), who suggested that respiratory health issues were more prominent than the other public health impacts during road construction stage. As stated by GP1"So many chronic patients coming on every week for treatments due to asthma and panting."

The interviewee also highlighted the long-term effects on a persons' health due to the exposure on low air quality and dust related issues. "If the person, currently suffering from wheeze, after one year they will end up as an asthma patient. And their frequent cough made a social issue to the other members of that family. If this asthma issue prevails for a long time, it can be ended up as a cancer. Another risk occurred due to the frequent exposure to dust is asbestosis. These patients are directly admitted to the cancer hospitals or general hospitals."

Noise and Vibration Nuisance

The second most highlighted impact was the noise and vibration which occurred due to the heavy machinery and vehicle transportation. The night-time work also emphasized by the interviewees as a critical factor on noise nuisance. As stated by an environment officer (EPG2) "During the operational phase, certain communities face some problems, especially near the Colombo area. There were noise complaints during the night near the neighbouring area of the highway, so they started constructing sound barriers. That's a new experience for many of us".

The lack of monitoring on standard noise level was highlighted by the interviewees as a main concern during the road construction. During the construction of southern expressway, the officers have received complain from the community regarding the higher noise level. This was explained by one of the health and safety officer of the project (HS3). "Some are complaining about issue with studying. These people were beyond the permitted noise impact zone. But they were still complaining. Sometimes I felt that was an allergy for some of the people. Our standard level was 75 decibels. When we measured that location, it was 55 decibels. But there were people who sensitive for that limit and it was a direct impact for them. But we were unable to measure this. This was a subjective issue during that period".

Other Health Impacts - Communicable Diseases

Apart from these main four categories, there were other health impacts mentioned by the respondents which were not significant in previous studies. For example, sexually transmitted disease, COVID-19, Dengue and Malaria. Other, less common impacts mentioned by a small number of respondents included leptospirosis and tuberculosis.

Both health and safety professionals (HS) and environment practitioners (EPG and EPP) also stated that some of the emerging health impacts were excluded in road construction projects as existing health and safety guidelines were limited to the impacts of air pollution and noise pollution. As an example, one of the Environment professional (EPP1) in an existing road project emphasized on how most projects tend to ignore the potential increase in sexually transmitted diseases. "Most of the time you can see HIV prevention programmes without any consideration on other sexually transmitted diseases during construction, but these prevention campaigns have to be converted as HIV and other Sexually transmitted Diseases".

According to the HS1 the existing health and safety guidelines have been prepared to tackle HIV as a health issue in road construction projects. However other sexually transmitted diseases such as Gonorrhoea, Hepatitis and Herpes have not received much attention despite them being a major challenge in the present situation. This scenario was also confirmed by one of the road contractors (RC1) whereby it was stated that HIV or other sexually transmitted diseases had never been monitored during the construction phase of the road projects.

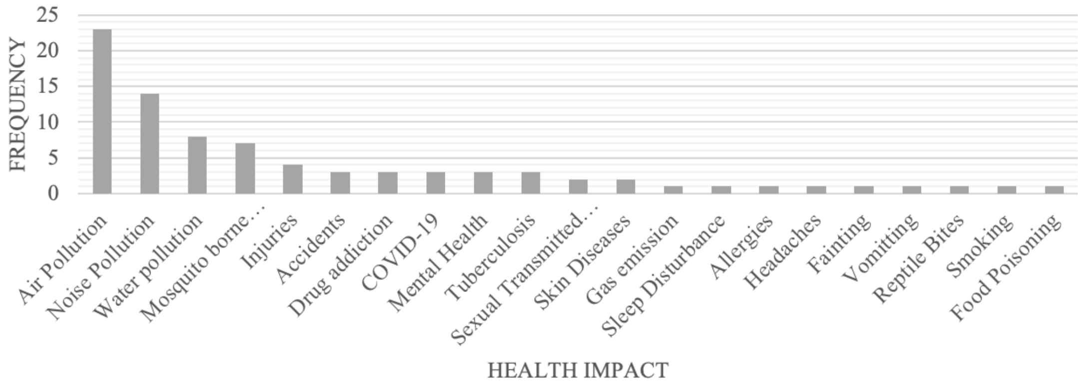

Figure 1: Potential health impacts on road construction

Some respondents also revealed that that the COVID-19 pandemic in Sri Lanka has created more complex scenarios in the road construction sector due to changes in the working environment and exposure of the public during the construction phase. Almost all the experts stressed on the practical difficulty of using safety measures during the working period, for example, the hot and humid climate in the country made it difficult to wear gloves and masks while working in construction sites. As stated by one of the health and safety officers (HS2) of an ongoing road project: " It is the most difficult industry to adhere with the COVID-19 precautions due to the work environment"

HS2 also highlighted that the environment was unsafe for the nearby community due to frequent interactions between workers and the public in occasions such as shopping, accommodating, commuting, and roaming. HS 2 also noticed several COVID -19 hotspots around the road construction sites and felt that the nearby community is also at a significant risk of the disease due to the interaction with road workers in the specific area. This was identified in relation to other vector borne disease such as Dengue and Malaria, where cases have surged in proximity to road construction sites. The public health inspectors (PH1 and PH2) have noticed these scenarios and named some of the road construction sites as dengue hotspots, especially in the Western Province. This was further confirmed by a health professional (HO1) in the Ministry of Health, Sri Lanka where recent Dengue outbreaks in the year 2021 were reported from the existing construction sites.

Apart from such health impacts on neighbouring communities, some experts revealed that few underrated scenarios occurred during their previous working experiences with respect to leptospirosis and tuberculosis. As mentioned by a health and safety officer (HS2), he was able to notice and prevent the outbreak of leptospirosis during an expressway project in Sri Lanka. Similarly, tuberculosis was experienced by a public health inspector (PH2) in an ongoing road widening project in Sri Lanka and he was able to reduce the risk with the involvement of other public health inspectors in the respective region.

Other Health Impacts

As highlighted by Dahlgren and Whitehead (Dahlgren and Whitehead, 1991), different social and cultural factors in influencing a person's health and well-being. The road construction project has a negative impact on these wider health determinants on the nearby communities too. This includes social factors such as accessibility disruptions, education and employment disruptions and the person's individual characteristics and behaviour risk such as drug popularization, and smoking and harmful use of alcohol too.

Social factors were the prominent risk category than the individual characteristics during the road construction. As highlighted by the experts there were many complaints regarding the accessibility and employment disruptions. An environment officer of small-scale road projects in Sri Lanka (EPP3) have experienced this situation in minor and B grade roads. "If it is a minor road or B grade road, there can be a temporarily accessibility issue due to the drainage construction. Because there are various activities in such construction, and it takes some time. Social isolation also experienced by few of the interviewees (CRC2) especially during the expressway projects in Sri Lanka. Interviewees highlighted the fragmentation issues were frequent during the Southern expressway and Central expressway projects where large-scale constructions separated the nearby communities which affect badly on mental health on certain families.

The interconnection between the workers and the community also impacted badly on certain groups of the community. The alcohol consumption, smoking, Beetle chewing, illegal drug usage among the main risk factors identified by some the interviewees (EPG1, EPG3, RC1, PH2) directly involved in the road construction. As stated by one of the health and safety officers (HS3) "People who are working in the constructing side, their behaviours. Like they can have some impact on the neighbouring people. Like, you know, the women and girls and small kids. And, it can be again related with the sexual harassment and also the drug popularisation. "Interviewees also highlighted the Sexual and gender-based violence and harassment on women and children as another underrated health impact on road construction projects.

CONCLUSIONS

It was revealed through the experts' interview that the potential health impacts go beyond the typical health impacts that were commonly discussed on impact assessment reports. More than twenty impacts have been discussed by the interviewees, including those not widely discussed in the scientific literature. Table 2 indicates the wider health determinants and risk factors on health which were highlighted by the experts such as air quality nuisance, noise nuisance, water quality, behavioural risk etc. Air quality and noise nuisance were the mainly discussed categories during the interviews whereas the determinants such as Interconnection with workers, Water quality and Risk-taking behaviour categories were the least discussed categories highlighted through the interviews. Moreover, the inadequate attention to proper mitigation measures by road contractors and government agencies was also revealed as a main weakness in Sri Lanka. Further, the results revealed the importance of a comprehensive health impact assessment process which covers the whole range of public health impacts during road construction projects.

Given the Sri Lankan government's commitment to sustainable development goals and the enhancement of public health and road development projects, Sri Lanka serves as a platform for determining the quality of health sustainability during road infrastructure projects. According to the findings, health concerns were not fully investigated during the road construction process. This suggests there is a lack of understanding and grasp of the inclusion of health in the road development sector in

Sri Lanka. A similar situation could be identified in most of the other developing countries whereas developed countries have implemented health impact assessments and health and safety guidelines during the pre-construction as well as the construction stages of the road projects.

Table 2: Summary of the public health impact categories with risk factors

Determinant of health	Risk factors in health
Environment	Air quality and Dust nuisance, Noise nuisance, Vibration nuisance, Water quality and water usage, Water safety, Odour nuisance, Visual disturbance, Habitat degradation (Reptile bites, Insect attacks, Human - Elephant conflict), Natural hazard risk (Floods, Landslides)
Social	Community cohesion, educational disruption, Access disruption (Road accessibility), Road safety (Accidents and injuries), Crime and fear of crime
The person's individual characteristics and behaviours	Drug and Alcohol consumption, Injuries with Aggressive behaviour, Sexual and gender-based violence and harassment, Communicable diseases /Infectious disease, and sexually transmitted diseases (HIV Aids/COVID 19/Tuberculosis)

In this research empirical evidence also suggest that there were major gaps in the existing knowledge where traditional health impacts were the main concern in the road construction sector in developing countries. The analysis does have certain limitations as any health or accident-related data were not considered for the analysis and the expert interviews were the major source of data analysis. However, the qualitative analysis of the expert opinions provides an insight into the current understanding of such issues among the road construction industry and other relevant authorities. Also, the identification of public health impacts with relation to the construction activities and vulnerable groups will be a challenge due to the current impact assessment process in the country.

Further studies should be conducted to gain a wider knowledge about the potential health impacts, sources, and vulnerable groups. There is a need to support local health systems to deal with these potential health impacts and vulnerable groups. The proper integration of health professionals into the road construction sector could enhance these aspects during road construction projects. This paper will contribute a holistic picture of public health impacts and illustrates the future research directions and possible factors to be considered while executing the research. The finding of this paper can inspire researchers to progress further in this area, where the identification of contextual differences of health impacts and assessment process across emerging and developed countries could enhance the existing impact assessments process in road projects. The renewed construction policies can address issues associated with public health impacts and produce an environment-friendly and sustainable road construction practice.

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MONEY AND MENTAL HEALTH MATTERS IN UK CONSTRUCTION WORKERS

Katharine van Someren[1] and Graeme Larsen

[1] *Arup, 8 St Thomas Street, Winchester, SO239HE*

[2] *University College of Estate Management, Horizons, 60 Queen's Rd, Reading, United Kingdom RG1 4BS, UK*

The research aim was to combine topics to explore the holistic well-being of UK construction workers. Mental health, depression, financial insecurity, food insecurity, and access to mental health resources topics were part of the study. A critical review of the well-being literature led to the adoption of published and established methods from relevant literature for the research design. The primary hypothesis explored; high job insecurity and low financial well-being will impact and increase a person's mental health depression score. A total of 38 UK participants were included in the research, findings showed 32% of male participants self-reported moderate or severe depression compared to 14% of the general population. Females had lower levels of self-reported depression compared to males and were more likely to feel food insecure compared to male participants. Significantly, the findings indicated job insecurity and financial well-being could potentially predict participants' depression in the study sample.

Keywords: HRM; equality; diversity; performance; gender; mental health; career

INTRODUCTION

The built environment sector faces many competing challenges. The dominant discourse remains based upon themes of competitiveness, productivity, efficiency, and environmental sustainability. Yet, all those themes require one key ingredient, human resources. Constructing the Future for both places and infrastructure - requires people to be healthy and safe both on an individual basis and in teams. People are the core of 'Constructing the Future' and to work with skill, craftmanship and experience, we need to reflect on the views of people in skilled physically labour-intensive employment. Human resource management, equality, diversity, and performance themes are explored through mental health metrics and this work acknowledges these are mostly defined by other stakeholders before skilled workers enter a construction site.

The research aim was to explore the holistic well-being of workers, this included understanding the themes of human resource management, equality, diversity, and performance. Combining mental health, depression and access to support services, an

[1] kate.vansomeren@arup.com

van Someren, K and Larsen, G (2023) Money and Mental Health Matters in UK Construction Workers *In:* Tutesigensi, A and Neilson, C J (Eds) *Proceedings of the 39th Annual ARCOM Conference,* 4-6 September 2023, University of Leeds, Leeds, UK, Association of Researchers in Construction Management, 354-363.

aim was to see if acculturation was taking place with a greater saturation of mental health support.

LITERATURE REVIEW

Mental health - United Kingdom

In England, suicide is the leading cause of death by adults below the age of 50 (ONS 2017). Within the construction industry compared to the male national average, the risk of suicide is three times higher for low-skilled male labourers (ONS 2017). The sub-groups in construction with the highest risk are among the building finishing trades: decorators, painters, plasterers, and roofers (ONS 2017). In the assessment of depression, the Patient Health Questionnaire (PHQ)- 9 is widely used for self-report data and is available globally for distribution and reproduction. In the UK construction sector workplace poverty is a rising concern and a subject with limited data. In 2019/2020, 12% of construction workers in London were in workplace poverty (Trussell Trust 2016), workplace poverty is defined by the UK Government by those households with below average income. Notably, the key risk factors for mental illness are low income and debt as part of the poverty narrative alongside food insecurity, job insecurity and career choices available (Yazd *et al.,* 2019, Money and Mental Health Policy Institute 2019)

A key driver for this research stemmed from the question:
Are UK construction workers struggling to make ends meet financially, do they feel insecurity in their job, and could this negatively affect their mental health?

Definition and global context: Work is good for mental health, but a negative working environment can lead to physical and mental health problems (World Health Organization 2022).

Mental health relates to a person's ability to cope and deal with daily life. A person with a positive sense of self, who they are and ability to manage on a daily basis is a good example of someone in good mental health. It includes being able to meet the demands of everyday life, connect with people to form relationships, make sense of the work around you, think clearly and express feelings and emotions (Council for Awards in Care 2020). Whilst this research focuses on the UK, it is important to recognise that the issues raised thus far are not UK centric, they are in fact being played out differently across different parts of the world. Global studies that relate to mental health and construction have been conducted in different regions. In Australia, 1124 mining and construction workers that were Fly In Fly Out (FIFO) workers in remote sites were found to have higher rates of psychological distress, this was more prevalent among those under 44 years of age (Bowers *et al.,* 2018).

A mixed methods study with two different surveys and methods was used for a construction site, with 18 and 91 participants respectively, findings from the studies found that work-life balance and financial concerns were the highest-rated stressors (Langdon and Sawang 2018). In Nigeria, 110 tradesmen completed questionnaires in a cross-sectional study across 65 construction sites where they were registered with the Federation of Construction Industry, Nigeria (Nwaogu *et al.,* 2021). The logistical regression findings of (Nwaogu *et al.,* 2021) included protective factors of resilience and both problem and emotion focussed coping strategies, and that depression was seen in 72.5% of the participants when completing the PHQ-9 self-assessment for depression (Nwaogu *et al.,* 2021). Demographic characteristics according to mental health and resilience found that those tradesmen with less than 20 years of experience were more likely to have depressive symptoms (Nwaogu *et al.,* 2021).

Financial well-being

"Financial well-being is a state of being wherein a person can fully meet current and ongoing financial obligations, can feel secure in their financial future, and is able to make choices that allow them to enjoy life." (Consumer Financial Protection Bureau 2017: 7). The financial well-being scale is a useful measure of a person's ability to cope financially and prosper. The financial well-being scale, when in development, was tested on over 14,000 participants during three rounds of surveys to validate its use (Consumer Financial Protection Bureau 2017). Rigorous statistical testing by the Consumer Financial Protection Bureau (2017) showed the scale to be a comprehensive tool and it is freely available for researchers, as such it was adopted. A mental health problem can make it feel harder to manage finances and ask for support which leads to being financially vulnerable. The financial difficulties can cause mental ill health where essentials such as food and shelter are compromised, which can lead to mental health problems (Money and Mental Health Policy Institute 2019).

Insecurity in the Workplace - Insecurity in Construction Jobs

In July 2021, the Living Wage Foundation (Richardson and Howard 2021) analysed data from two studies in the UK Government Office for National Statistics studies - quarterly Labour Force Survey and annual Family Resources Survey. Richardson and Howard, (2021) found that 6.6million workers experienced work insecurity in the UK. As with most socio-economic factors there is discrimination at play, where "social inequalities are associated with increased risk of many common mental disorders" (World Health Organization, 2014). Construction as an industry was found to have 18% of insecure workers, and those that were in both insecure work and living below the Living Wage was found to be 16% (Richardson and Howard, 2021).

Definition
To define insecure work, the Living Wage Foundation (Richardson and Howard, 2021) used four criteria, a worker had to meet at least one to be included in the insecure work category from: 1) people in non-permanent work (excluding those who said they did not want a permanent job); 2) self-reported volatile pay and hours (zero hours contracts); 3) self-reported volatile hours, constant pay; and finally 4) low paid self-employed workers. Recent findings from a study by Lingard *et al.,* (2021) showed that Australian construction workers mental health have both a positive and significant association between mental health and job security.

This association was found in all age groups and was stronger among younger participants (Lingard *et al.,* 2021). In the young workers age group (18-24), perceived fairness of effort and reward (pay) was positively and significantly associated with mental health (Lingard *et al.,* 2021). In both the middle-aged (25-45) and older (>45) age groups a statistically significant positive association was found between job control and mental health and a negative association between job demands and complexity and mental health (Lingard *et al.,* 2021). A measure of job insecurity through qualitative survey methods was tested and validated by (Blotenberg and Richter, 2020).

A critical review of the well-being literature led to drawing upon published and established techniques from relevant literature for the research design and methods, this enabled the primary hypothesis. UK construction workers who are feeling job insecure and financially unwell are more likely to be suffering from self-reported depression.

METHOD

An online questionnaire survey was piloted during January 2022, this pilot survey initially asked broader questions around mental health and workplace poverty as shown in Table 1. The online survey comprised a combination of photos and questions, these were based on other published works to allow for comparison and disparity in findings. The survey was shared initially with colleagues from the author's academic institute. The survey was posted on LinkedIn and shared via construction contacts directly through individual messages. A link at the end of the survey prompted participants to share the survey to others to encourage snowball sampling and provided links to mental health services.

The final survey was designed by drawing upon recognised and established surveys in each of the research topic areas already described: mental health, financial well-being, and insecurity of work. The mental health section utilised the PHQ9 survey, it allows a participant to self-report their own depression. The PHQ9 survey (Kroenke *et al.,* 2001) uses a numerical scale to convert each of the 9 questions and totals these out of 27. Different categories are then assigned based on this score, a lower score means the person has a lower level of self-reported mental ill health and the nearer the score is to 27 the more severe the depression. The financial well-being section utilised the CFPB (2017) Financial Well-Being Scale and scoring structure. The insecurity of work section used the Blotenberg and Richter (2020) measure of job insecurity questions. The Economic Research Service US Department of Agriculture (2022) food security measurement was used for food insecurity questions. Additional questions included gender, working hours per week, number of workplace locations, income and the type of mental health help people had sought.

Analysis - Regression Modelling

The data was sorted and made into numeric values - for example, where an answer to a question was a categorical range, such as Working Hours per week this was coded to differentiate each possible outcome. The multiple linear regression model was uploaded to R an open-source data analysis tool.

Hypotheses
The null hypothesis is H0:

There is no relationship between the independent variables (financial well-being, qualitative job insecurity measure, working hours per week, total number of workplace locations or income) and a person's self-reported depression rating.

The alternative hypothesis is H1:
There is a relationship between the independent variables and a person's self-reported depression rating.

Theoretical and Methodological Justification
The field of holistic well-being is vast and draws upon a range of social sciences, it is therefore theoretical fragmented and methodological fractured with no definitive theory. Essentially, holistic well-being began as defined through the positivist traditions, seen as objective, external and universal. However, traction has been

gained by more subjective well-being theories with the Tripartite model (Galiha *et al.,* 2011) used as a touchstone to inform the argument posed and the research undertaken.

Table 1: Research methods based on peer reviewed published methods

Theme	Source and background
Mental Health	PHQ-9 (Kroenke *et al.,* 2001)
Financial well-being - part 1 and part 2	Consumer financial protection bureau financial well-being scale (Consumer Financial Protection Bureau 2015)
Security of work	Qualitative Job Insecurity Measure (Blotenberg and Richter 2020)
Security of food	Food security measures (Economic Research Service US Department of Agriculture 2022)
Demographic information	Based on other mental health in construction studies: (Kotera *et al.,* 2019, Bowers *et al.,* 2018)

FINDINGS

Gender

A total of 38 participants over 18 years of age completed the survey, actual count data reveals that 18 participants were female, 19 male and one was non-binary or preferred not to state their gender.

Depression and Mental Ill Health

Depression Severity is defined by PHQ-9 as: 0-4 none, 5-9 mild, 10-14 moderate, 15-19 moderately severe, 20-27 severe; here these are shown as count data for each category in Table 2.

Table 2: Depression rating as two discrete categories, count of how many participants in each

	Moderate to severe	None or mild
PHQ9 count	8	30

Depression and General Population

Table 3: Gender and PHQ9, moderate to severe symptoms as percentages of study sample

	General Population (ONS 2021) Moderate to severe symptoms	van Someren study (2022) Moderate to severe symptoms
Men	14	32
Women	20	11

No Depression or Mild Symptoms

Firstly, the women in the current study, had a proportion of 89% with no or mild depression symptoms, this is greater than the 80% of the women in the general population, which is a welcome finding.

Moderate to Severe Symptoms

Participants who self-reported moderate or severe depression are shown in Table 3 this reveals more males in the survey reported moderate or severe depression symptoms when compared to the general population. The results showed 32% of male participants self-reported moderate or severe depression compared to 14% of the general population. The prevalence of male depression in construction is a finding from the van Someren (2022) survey and aligns with (ONS 2021) findings relating to male mental health in construction having higher depression rates than the general population.

Financial Well-Being

What are the levels of financial well-being in UK construction workers? The scores range from 29% financially unwell to 86% (financially well), those with a higher score are more financially well and less likely to feel insecurity relating to their financial situation.

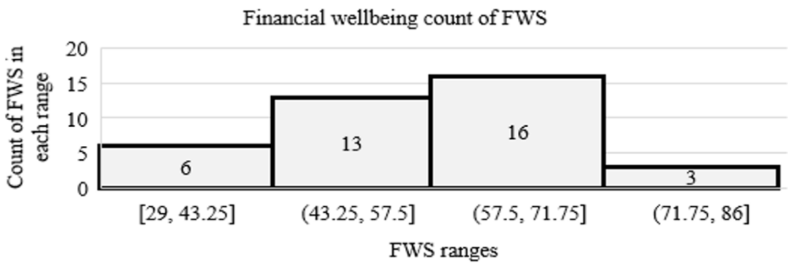

Figure 1 Financial well-being of participants

Figure 1 data shows there are 6 participants with a financial well-being score of 43.25 and lower, this indicates this group are potentially financially insecure. The top ranges of financial well-being showed both the 3rd quartile and 4th quartile totalled 19 participants.

Depression Rating and Financial Well-Being

What are the mental health consequences? To analyse this question, PHQ-9 depression scores and financial well-being scale scores for each participant were plotted using a dot violin plot as shown in Figure 2.

Figure 2: Financial well-being of participants

This type of plot shows the distribution of the data and the individual data points, allowing greater granularity of understanding when interpreting the findings. A trend appears to develop that shows for most participants the higher their financial well-being the lower their self-reported depression. There are however outliers, the lowest financial well-being score at 28% where the participant reported no adverse effect on their self-reported depression or mental health.

Multiple Linear Regression Model

The fitted multiple linear regression model is:

PHQ9 score = 14.09 - 0.14 *(Financial well-being) + 0.12 *(Working hours per week) - 1.51 *(Total number of workplace locations) +/- *(income) -5.63 *(job insecurity).

There was a significant relationship between PHQ9 and FWS ($p < 0.05$) and PHQ9 and the qualitative job insecurity measure ($p < 0.001$).

For financial well-being score, there was a decrease by -0.14 for each increase in depression rating, as someone becomes financially unwell their depression score increases. For job insecurity, as a person becomes more insecure -5.63 the higher their depression rating. The adjusted R2 value was 0.575 so 58% of the variation in depression rating using the self-reported PHQ9 can be explained by the model containing financial well-being, qualitative job insecurity measure, working hours per week, total number of workplace locations or income). Overall, these results indicate that there is a relationship between financial well-being and job insecurity as predictors of self-reported depression in this sample of participants.

Food Insecurity

Table 4: Food insecurity and gender, counts of participants

	Food insecure	Food secure	Grand Total
Female	4	14	18
Male	1	18	19
Prefer not to say/ don't know		1	1
Grand Total	5	33	38

Female participants were more likely to feel food insecure compared to male participants. As there is a strong interrelationship between food insecurity and gender (Dempsey, 2020) the final analysis investigated if this was also found in the UK construction sector. Table 4 shows a greater count of females in food insecurity, all participants to the survey were in employment and all of those in food insecurity were in paid employment (not self-employed). This finding supports prior work of Dempsey (2020), in this relationship. Alongside a greater understanding of depression in the context of UK construction this study also asked what mental health support and treatments were being sought by participants.

Mental Health Support

In addition to understanding a person's depression rating, this study also wanted to determine what self-reported mental health support a respondent was receiving in the past 12 months. Mental health support was an essential factor in this study as it provided the opportunity for participants to report access to services and their self-agency in reaching out for support. A cumulative sum of those in support or seeking mental health support across each category is shown in (Figure 3) revealed that 74% of participants were actively or previously engaged in mental health support.

The sample population for this study comprised 87% of participants that were in paid employment and 13% that were self-employed. Prior studies have found a relationship between UK construction sole traders (self-employed) in mental ill health and that specific group experiencing feeling shame towards seeking help compared to

Small- Medium Enterprise workers (Bevan *et al.,* 2022). This finding is therefore consistent with prior studies and supports the concept that workers in employment are more likely to access mental health support services.

Limitations

The limitations of this research include the sample size and a wider study with greater industry participation would be preferential to test and validate the multiple linear regression model. This would provide further insight into the interrelationship of variables of financial insecurity and job insecurity being predictors of depression to better understand human resource management of mental health.

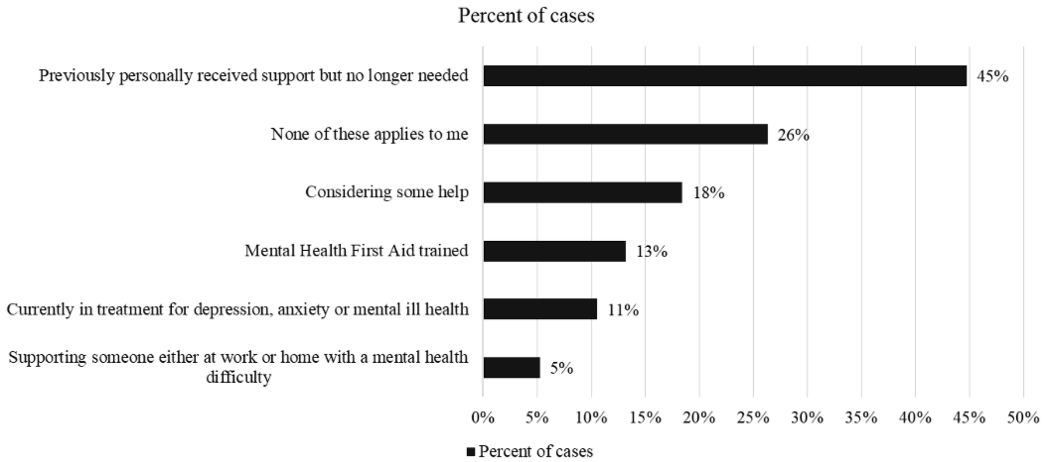

Figure 3: Mental Health Support, Cumulative Sum of Those in Each Category

The method followed was appropriate for a public based open accessible online survey, however, this could have led to a multitude of barriers of those who could access the survey including those with technology deprivation.

The avenues for further study are vast, including large dataset in the UK, slicing data samples between operatives/trade and professionals, different levels of focus from projects, firms, professions, to comparing different companies or different UK regions. There is of course also the international dimension, whereby the phenomena discussed in the research occurs globally, arguably being played out differently across different international settings. Whilst this research is limited to the UK only, the authors would welcome future international collaboration to better understand and even compare how these issues are played out between countries and their approaches. Semi structured interviews, yielding qualitative data for interpretation, would provide an additional dimension to the research to future research. This could offer a deeper and richer insight to the circumstances and conditions people in UK construction and elsewhere are facing during economically challenging times.

CONCLUSIONS

Human resource management, equality, diversity, and performance themes were explored through mental health metrics and this work acknowledges these are mostly defined by other stakeholders before skilled workers enter a construction site. Results suggest a statistically significant relationship between financial well-being and job insecurity as predictors of self-reported depression in the UK construction workers studied. 32% of male participants working in the UK construction industry self-reported moderate or severe depression compared to 14% of the general population. Food insecurity was higher in female participants than males, all were in employment in the UK construction sector. 74% of participants had accessed mental health support, were considering it or had supported a friend or colleague, which is welcome news. Theory and methodological justification were provided by using the research frameworks provided from prior peer reviewed publications. A workforce that is diverse, built upon health, well-being, equality, and sustainable financial mechanisms, can offer the built environment real benefits to construct the future places and infrastructure. Attracting, and importantly retaining, workers is paramount to include an open discourse around finances, mental health, food, and job-insecurity.

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DETERMINANTS OF DEPRESSIVE SYMPTOMS AMONG MALE CONSTRUCTION WORKERS IN CAPE TOWN, SOUTH AFRICA

Rita Peihua Zhang[1], Paul Bowen[1&2] and Peter Edwards[1]

[1] *School of Property, Construction, and Project Management, RMIT University, Melbourne, Victoria 3000, Australia*

[2] *Department of Construction Economics and Management, University of Cape Town, Private Bag X3, Rondebosch 7701, Cape Town, South Africa*

Individuals working in the construction industry are at a high risk of depression. This study investigates which groups of construction workers are more susceptible to depression through examining the associations between the prevalence of depressive symptoms and demographic factors, social and work-related factors, and behavioural factors. Data were collected from 496 male construction workers drawn from 18 construction sites in the Western Cape. Binomial logistic regression analysis was used to analyse the data. The results show that Black African construction workers experience lower levels of depressive symptoms compared to 'Other' ethnicities. Workers who are single or live with other adults without children experience significantly higher risk of depression compared to workers who are married or in a long relationship or live alone. The study also revealed that substance use is associated with lower levels of depressive symptoms, suggesting that construction workers use substance as a coping strategy for short-term depression reduction. Practical suggestions are provided to protect the mental health of construction workers who are more vulnerable to depression.

Keywords: depression; determinants; male construction workers; South Africa

INTRODUCTION

Depression is a common mental disorder, a leading cause of disability, and a major contributor to the global burden of disease (WHO, 2021). Depressive disorders have a significant impact on all aspects of an individual's life, including work productivity, social relationships, and community participation (WHO, 2023).

Construction is an industry with a particularly high risk of mental ill-health (Boschman *et al.,* 2013). Studies have shown that people working in construction experience a much higher risk of depression than those working in other industries (Al-Maskari *et al.,* 2011). Depression has been reported as a significant cause of suicide (Pincus and Pettit, 2001) and should be noted in the construction industry, where suicide rates for construction workers are significantly higher than for the

[1] rita.zhang@rmit.edu.au

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general work population. Male construction workers are twice as likely to commit suicide as non-construction workers (Mates in Construction, 2016).

Research has shown a strong association between construction workers' mental ill-health and a construction work environment characterised by high job demands, low job control, job insecurity, workplace inequity, and poor workplace social support (Chan *et al.,* 2020; Duckworth *et al.,* 2022). While these studies are important in terms of understanding how work contributes to mental disorders in construction workers, they do not suggest which individual or demographic characteristics make specific groups of construction workers more susceptible to mental disorders.

The model of health and disease proposed by the Western Cape Department of Health and Welfare (2007) in South Africa has been adapted to explain mental health as illustrated in Figure 1. The model shows that that an individual's mental health is shaped by a range of upstream and downstream factors. Upstream factors are root causes of mental ill-health including social factors (e.g., living and working conditions) and structural factors (e.g., socio-economic status); while downstream factors are proximal or direct causes of mental ill-health including biological factors (e.g., age and ethnicity) and behavioural factors (e.g., substance abuse). In line with this adapted model, this study investigates the prevalence of depressive symptoms and its association with various demographic factors (i.e., age, ethnicity, education), social and work-related factors (i.e., relationships, living arrangements, work status) and behavioural factors (i.e., alcohol consumption, drug use). The objectives of this study were to focus on the prevalence and nature of depressive symptoms in the South African construction industry, to identify factors contributing to this mental disorder, and to consider strategies by which it may be addressed.

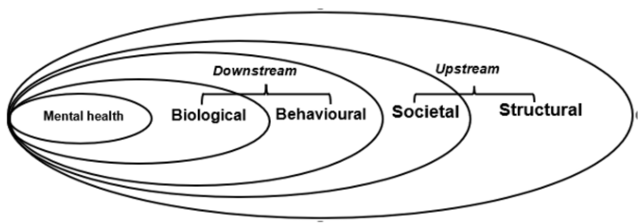

Figure 1: Conceptual mental health model (Western Cape Department of Health and Wellfare, 2007)

Depression and Contributory Factors

Depression and depressive symptoms

Depression falls into two main sub-categories: 1) major depressive disorder or depressive episodes, involving symptoms such as depressed mood, loss of interest or pleasure and lack of energy; depressive episodes can be classified as mild, moderate or severe, depending on the number and severity of symptoms; and 2) dysthymia, a persistent or chronic form of mild depression; symptoms of dysthymia are similar to depressive episodes but tend to be less intense and last longer (WHO, 2017). Depression can recur or become chronic, contributing to functional impairment and inability to adequately perform work, family, and social roles (Pincus and Pettit, 2001).

In the construction industry, mental disorders such as depression have a significant impact on work productivity and safety (Haslam *et al.,* 2005). Construction sites are hazardous, and workers need to have sufficient mental capacity to maintain focus and keep alert to manage site safety hazards (Boschman *et al.,* 2013). When workers experience depression, these capacities may be impaired, increasing the risk of workplace accidents and injuries.

Age, Ethnicity, and Education

The prevalence of depression varies by age in the general population, peaking in older adults (55-74 years) (WHO, 2017). The same trend has been noted in the construction industry. For example, Park and Jeong (2021) studied a sample of construction workers in South Korea and reported the highest rates of depressive symptoms in the 60-year-old age group compared to the 50s and under-50 age groups. This trend may be related to age-related changes in workers. As people age, they naturally experience physical and cognitive changes, such as declined physiological functions, reduced physical strength, slower information processing speed and decreased ability to respond effectively to stressful events (Varianou-Mikellidou *et al.,* 2019). These changes have a clear impact on workers' mental health in demanding construction work environments. Therefore, it is hypothesised that:

H1: Older workers are more likely to present with more depressive symptoms compared to younger workers in the South African construction industry.

Ethnicity has been identified as a risk factor for mental ill-health (Bailey *et al.,* 2019; Riolo *et al.,* 2005). Ethnically disadvantaged groups are more likely to experience racism, lower socio-economic status, and stressful life events, all of which contribute to an increased risk of depression (Bailey *et al.,* 2019). Studies in the construction industry show that ethnically disadvantaged workers are more likely to experience the challenges of financial hardship and have less access to health resources and services, which increases their risks of psychological distress and depression (Ang *et al.,* 2017; Palaniappan *et al.,* 2022). Therefore, it is hypothesised that:

H2: Black African workers are more likely to present with more depressive symptoms compared to “Other” ethnicities in the South African construction industry.

Education as a socio-economic status indicator is associated with the risk of depression experienced by individuals (Freeman *et al.,* 2016). Ross and Mirowsky (2006) explained that education is an individual resource that influences other socio-economic status indicators such as employment, occupation, and income, which are important protective factors for mental health. However, Palaniappan *et al. (*2022) reported that construction workers with higher levels of education tend to experience higher levels of depressive symptoms than construction workers with lower levels of education. This is because some construction work tasks are manually intensive and require low skills levels. Construction workers with higher education may find that the work tasks they perform are not commensurate with the level of training they have received, contributing to a higher risk of feeling depressed (Palaniappan *et al.,* 2022). Thus, it is hypothesised that in the South African construction industry:

H3: Workers with higher levels of education are more likely to present with more depressive symptoms compared to less educated workers.

Relationship Status, Living Arrangements and Work Status

Research has repeatedly shown that married people have lower levels of depressive symptoms than separated, divorced, widowed and never-married counterparts (LaPierre, 2009). The marital resource model posits that marital status shapes access to resources and exposure to strains, resulting in differences in depressive symptoms between people of different marital status (Cotten, 1999). Being married has also been identified as a protective factor for construction workers' mental health. In the USA, Dong *et al.* (2022) reported that construction workers who are not married are 1.7 times more likely to experience serious psychological problems and 1.8 times more likely to experience suicidal thoughts than those who are married. It is therefore hypothesised that in the South African construction industry:

H4: Workers who are single are more likely to present with more depressive symptoms compared to workers in married/long-term relationships.

During the apartheid era in South Africa, single-person households were designed to prevent the urbanisation of African families (Posel, 2021). Africans (mainly males) who migrated from their rural homes to cities for work, were often housed in single-person accommodations to ensure that their families remained in their homes. However, post-apartheid, individual migrant labour patterns have continued due to the scarcity of affordable family accommodation in urban areas (Posel, 2021) and a significant increase in poorly conditioned informal settlements that are unsuitable for family living (Hunter and Posel, 2012). Living alone has increased in post-apartheid South Africa. People living alone are more likely to experience social isolation and receive less emotional and instrumental support than those living with others, which may increase their risk of depression (Stahl *et al.,* 2017). Therefore, it is hypothesised that in the South African construction industry:

H5: Workers who live alone are more likely to present with more depressive symptoms compared to workers cohabiting with others.

Work status or employment arrangement is strongly linked to workers' mental health. Over the past few decades, there has been a noticeable increase in precarious employment in the global labour market, including short-term contracts, casual and part-time work (Quinlan *et al.,* 2001). Precarious employment is characterised by uncertainty, instability and insecurity, and workers in precarious employment often receive limited social benefits and legal entitlements (Kalleberg and Hewison, 2013). Among different employment arrangements, research shows that casual full-time workers have the worst exposure to poor psychosocial work conditions and experience the worst mental health (LaMontagne *et al.,* 2012). It is therefore hypothesised that in the South African construction industry:

H6: Workers on casual or temporary contracts are more likely to present with more depressive symptoms compared to permanent workers.

Alcohol Consumption, Drug Use / Abuse and Depressive Symptoms

The literature points to a reciprocal association between substance use and depression. On the one hand, individuals tend to use substances (e.g., alcohol and / or drugs) as a coping mechanism to relieve the mental tension and strain experienced, as explained by the tension reduction theory (Frone, 2008). Substance use, on the other hand, further promotes or exacerbates depression and anxiety problems, leading to poorer mental health (Awaworyi and Farrell, 2017). This reciprocal association can also find evidence in the construction industry (Dong *et al.,* 2022; Langdon and Sawang, 2018). Therefore, it is hypothesised that in the South African construction industry:

H7: Workers who are scored as being at moderate to high alcohol risk of harm are more likely to present with more depressive symptoms compared to workers who are scored as being at low risk of alcohol harm.

H8: Workers who are scored as being at possible risk of drug-related problems or heavily dependent on drugs are more likely to present with more depressive symptoms compared to workers who are scored as having no drug-related.

Method

Survey Instrument and Measures

A survey instrument was employed for primary data collection. It incorporated questions eliciting demographic, social and work-related information, as well as three standardised tests, i.e., the CES-D-10 scale for depressive symptoms (Andresen *et al.,* 1994), the Alcohol Use Disorders Identification Test (AUDIT) for alcohol use (Saunders *et al.,* 1993) and the Drug Use Disorders Identification Test (DUDIT) for drug use (Berman *et al.,* 2003). All three tests are well-validated scales, with higher scores on each indicating higher levels of the construct of interest. Given the education level of most on-site construction workers, the use of open-ended questions was avoided to facilitate ease of data collection.

Participants

The study population was drawn from 18 construction sites in the Western Cape and involved seven construction companies. Convenience sampling was used to select construction sites and survey participants. The participant sample consisted of all male employees who were on site on the day the field researchers were scheduled to visit. Questionnaires were completed in three of South Africa's 11 official languages - Afrikaans, English and isiXhosa (as these are the most often spoken languages in the Western Cape region).

Data Analysis

Data cleaning
Of the 574 responses received, 18 were excluded as participants did not answer key decision-making questions on alcohol and drug use and 60 were deleted as the missing values exceeded 15% (Graham, 2012), resulting in a final dataset of 496 responses. Missing data were imputed using the EM (expectation maximisation) algorithm.

Analysis method
The CES-D-10 depression scale had 10 items, each of which was scored with four response options ranging from 0 = Rarely or none of the time (less than 1 day) to 3 = All of the time (5-7 days). Therefore, the range of CES-D-10 scores was 0-30 and two categories (absence and presence) were created i.e., those below the clinical cut-off level of 10 and those equal to or above 10 (Andresen *et al.,* 1994). The AUDIT scale also had 10 items, with response options for each item ranging from score 0 to score 4. Thus, the score range of AUDIT was 0-40 and scores were placed in one of four categories: 0-7 (low risk of harm), 8-15 (medium risk), 16-19 (high risk or harmful level), and 20 or more (dependence likely). The DUDIT scale had 11 items and the score range was 0-44. The DUDIT scores were categorised as follows: 0-5 (no drug-related problems), 6-24 (possible drug-related problems), 25 and above (probably highly drug dependent).

Descriptive analysis was used to describe categorical data of demographic, social and work-related characteristics. Binomial logistic regression was then used to examine the strength of the relationship between the predictor variables (demographic, social and work-related, and behavioural) and the dependent variable representing depressive symptoms in construction workers.

FINDINGS

Participant Characteristics (N=496)

All participants were male, aged between 18 and 67 years (M=35, Md=34). Almost two-thirds (59%) of the participants were black 'Africans'. Nearly 20% of participants had primary education and 65% had had secondary education or been exposed thereto. Nearly half (48%) were married or in a long-term relationship. In terms of employment status, 53% were in casual or contract employment.

Ninety participants (18%) scored at least 10 on the CES-D-10 depression scale, indicating depressive symptoms. For alcohol consumption, 25% (n=123) showed at least moderate risk of alcohol harm (score 8 or above) on the AUDIT test whilst 7% (n=37) showed high risk to possible dependence (score 16 or greater). For the DUDIT test, 6% (n=29) of the study participants showed possible presence of a drug problem and 1% (n=4) showed high levels of drug dependence.

Binomial Logistic Regression Analysis

Table 1 depicts the significance of the relationship between the various categories of the predictor variables and the depression profile, contrasted against their respective reference categories.

Table 1: Binomial logistic regression model

Characteristics	Adjusted odds ratios (aOR)⁺	
	aOR	**95%CI**
Demographic characteristics		
Age (years)	.97	.94 – 1.00
Race / ethnicity		
'Black' African	-	-
'Others'	1.90*	1.04 – 3.47
Social and work-related characteristics		
Education (exposed or completed)		
Primary	-	-
Secondary	2.99*	1.21 – 7.41
Tertiary	1.26	.57 – 2.79
Relationship status		
Single	-	-
Married / Long-term relationship	.41**	.21 - .81
Living arrangements		
Live alone	-	-
Live with other adults; no children	12.11*	1.47 – 99.96
Live with other adults and children < 18 yrs.	7.25	.88 – 59.65
Live only with children <18 yrs.	3.92	.50 – 30.93
Work status		
Casual or contract	-	-
Permanent	.65	.37 – 1.14
Behavioural characteristics		
AUDIT score (alcohol consumption) (AC)		
Low risk of harm	-	-
Moderate risk of harm	.20**	.06 - .60
High risk of harm	.23*	.07 - .78
Likely dependence	.25	.04 – 1.60
DUDIT score (drug use / abuse) (DU)		
Absence of drug-related problems	-	-
Possible drug-related problems	.03**	.003 - .04
High level of drug dependency	.03*	.002 - .51

⁺Model adjusted for all covariates; *$p< .05$; **$p< .01$; ***$p< .001$

The associated probabilities (p-values) provide an index of the significance of each category of predictor variable in relation to their reference categories. The odds ratio (OR) is a measure of effect size.

From Table 1, the odds ratio for 'Others' ethnicity is 1.9, indicating that this ethnic grouping is 1.9 times more likely than 'Black' African workers to present with depressive symptoms. Workers having attained or having been exposed to secondary school education were 2.99 times more likely to present with depressive symptoms than were workers who had experienced at most primary school education. There was no difference between workers with primary or less education and those having obtained or been exposed to a tertiary education.

Married and long-term relationship employees are less likely (odds ratio of .41) than single employees to present with depressive symptoms. Regarding living arrangements, workers living with other adults without the presence of children were 12 times more likely to present with depressive symptoms than were workers who lived alone. There was no difference between workers living with adults and children, or with children only, and those living alone.

In terms of alcohol use, the odds ratios indicate that workers at either moderate risk of harm (.20) or high risk of harm (.23) are less likely than workers at low risk of harm to present with depressive symptoms. Regarding drug use, the odds ratios indicate that workers experiencing either possible drug-related problems (.03) or a high level of drug dependency (.03) are less likely than workers with an absence of drug-related problems to present with depressive symptoms.

There was no association between age and the absence or presence of depressive symptoms. Additionally, no significant differences were noted between the categories of work status and the depressive symptoms classification (see Table 1).

Therefore, Hypotheses 1, 2, 5, 6, 7 and 8 are not supported, Hypothesis 3 is partially supported, while Hypothesis 4 is supported.

DISCUSSION

Contrary to expectations, 'Black' African workers were found to be less likely to exhibit depressive symptoms compared to 'Other' ethnic groups. Research has shown that the association between ethnicity and depression may be influenced by the nature of the scales used to assess depressive symptoms. For example, Riolo *et al. (*2005) reported that the prevalence of major depressive disorder (MDD) was significantly higher in Whites than in Black groups, but the opposite pattern was found for dysthymia or chronic depressive disorder. This is because black people with MDD are less likely to seek and receive treatment. In the present study, the CES-D-10 scale aimed to assess symptoms associated with MDD, which may explain the finding that Black African construction workers experience fewer depressive symptoms than 'Other' ethnic groups.

Different from previous research finding (Stahl *et al.,* 2017), this study showed that construction workers living with other adults without children were at significantly higher risk of depression compared to construction workers living alone. As mentioned earlier, the migrant labour system is widespread in South Africa, with many migrant workers living in informal settlements (Posel, 2021). Construction workers who reported living with other adults without children may share accommodation with other male migrant workers. Informal settlements often lack basic facilities and amenities and are often in poor conditions. Sharing accommodation in such living conditions may contribute to crowding and conflicts and subsequently increase the risk of depression among construction workers.

Interestingly, the study showed that higher levels of substance use were associated with lower levels of depressive symptoms among construction workers. This can perhaps be explained by that substance use is commonly adopted as a coping method by construction workers for short-term reduction of mental disorder (Langdon and

Sawang, 2018). However, Kushner *et al.* (2000) suggest that substance use, and mental disorders can develop into comorbidity through a vicious feed-forward cycle. Therefore, substance use as a short-term strategy to reduce depression may have long-term negative impacts on the health and wellbeing of construction workers.

The present study found that the presence of depressive symptoms was not associated with age or employment status. These results are probably related to the rising unemployment rate in South Africa, which reached a peak of 35.3% at the end of 2021 (Statistics South Africa, 2022). In particular, unemployment is highest among young people. The high unemployment rate and associated insecurity may make younger workers as likely to experience depressive symptoms as older workers. Similarly, in such a labour market, workers who still have a job (regardless of their employment status) may be psychologically protected by the positive effects of being employed. Indeed, Borra and Gómez-García (2016) reported that 'others unemployment' had a positive impact on individuals' wellbeing at work in Spain, where economic recession and high unemployment rates were experienced.

CONCLUSIONS

This study investigates the prevalence of depressive disorders among site workers in the South African construction industry in relation to various demographic, socio- and work-related and behavioural factors. The study shows that sharing accommodation with other migrant males in informal settlements may increase stress levels and increase the risk of depression. The results emphasise the need for governments and construction organisations to provide adequate housing to protect the mental health of migrant construction workers. The study also found that substance use was associated with lower levels of depressive symptoms, suggesting that construction workers use substances as a coping strategy for short-term depressive symptom reduction. Construction organisations should implement initiatives to raise awareness among construction workers about the long-term harm that substance use may cause to their health and wellbeing.

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HUMAN RESOURCES MANAGEMENT

MORE THAN THE MONEY: FACTORS PERCEIVED AS IMPORTANT BY UNDERGRADUATES AND EARLY-CAREER GRADUATES REGARDING THE ATTRACTIVENESS OF EMPLOYMENT OPPORTUNITIES IN THE IRISH CONSTRUCTION SECTOR

Stephen Moore, Anthony Needham, John P Spillane and James G Bradley[1]

Irish Construction Management Research Centre, School of Engineering, University of Limerick, Limerick, V94 T9PX, Ireland

The Irish construction sector is seeing massive growth, with 167,300 people employed in the sector in Q2 2022 compared to 127,300 in the same period in 2021. This pilot study investigates factors that influence graduates' choice of employer, whether these factors mature over time and the talent acquisition strategies of construction companies. A mixed-methods approach is taken, with data gathered from 20 semi-structured interviews and 53 questionnaire surveys. While there is evidence in the literature indicating factors such as skills, attributes and characteristics influencing employer's view of graduates' employability, this work takes the alternate viewpoint in terms of identifying the factors that influence graduates' choice of employer in the Irish construction sector. Findings indicate various factors such as salary, social considerations, career development, challenge and responsibility are involved. There is a difference between factors that undergraduates see as attractive before their industrial placement compared to afterwards. The findings indicate how Irish construction companies could structure their offerings to attract graduates into the construction sector to ensure their place as successful organisations constructing the future.

Keywords: talent; recruitment; retention; undergraduate; early career; Ireland

INTRODUCTION

Since the Irish economy has rebounded from the economic downturn of 2008, the country's construction industry the numbers employed, and revenue generated in the sector have been steadily rising (Central Statistics Office, 2022). The number of Construction enterprises increased by 5.9% from 2019 to 2020 and Construction activity grew by 26.2% (Central Statistics Office, 2022). With the best employers battling for graduates' attention and the government's pledge to create 60,000 new jobs means the construction sector is very attractive to graduates of built environment

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[1] jim.bradley@ul.ie

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programmes. To hire the top graduates over their rivals, businesses are constantly looking to obtain a competitive edge over their rivals. (CareersPortal.ie, 2022) The motivations behind graduates choosing a particular employer will be examined in this research paper, along with factors that contribute to the attractiveness of roles in construction companies.

In today's employment market in Ireland, construction companies are struggling to locate and hire graduates to fill open roles, this will have a negative impact on construction companies' ability to successfully participate in constructing the future. Traditionally, employability factors such as graduate attributes (skills, training, and personal characteristics) are used by employers to select the best employees (Chhinzer and Russo (2018), Clarke (2018)). However, where employers must compete for graduates in a tight labour market, coupled with the opportunities for emigration, they must be able to attract employees in the first place. This research paper will focus on addressing the knowledge gap as to what makes companies' offerings attractive to construction sector employees currently, from undergraduates to graduates, within the Irish construction sector.

A literature review was undertaken to detail the current knowledge for this research area. Primary data was gathered through 20 semi-structured interviews via MS Teams and administration of 53 questionnaire-based surveys executed through the MS Forms platform. Participants included undergraduates from built environment programs at a third level institution commencing their industrial placement, graduates looking for entry level positions and experienced graduates working within the construction industry in Ireland. Data was also gathered from recruitment agencies that specialise in construction recruitment as well as large to medium sized construction companies within Ireland regarding the structure of their packages and how they are presented to potential employees.

LITERATURE REVIEW

This literature review examines current research on employee benefits packages, employee perceptions and preferences, strategies for attracting top talent, and methods for employee retention with a focus on understanding the impact benefits packages have on employee perceptions of and preference for roles. The review will also explore strategies for attracting top talent, such as employer branding and referral programs. Finally, the different approaches organisations take to retain their employees, focusing on the role of compensation, benefits, and variable pay in talent management will be examined. Overall, this literature review aims to provide a comprehensive overview of current research on employee benefits, perceptions, attraction, and retention strategies.

A study presented by McKinsey Global in 2017 suggested that employers in Europe and North America will require 16 to 18 million more college-educated workers in 2020, more than what will be available (Keller and Meaney, 2017). It is vitally important that resources and the necessary requirements are available to make potential employees willing to join an organisation. Kaewnaknaew *et al. (*2022) expressed that compensation, benefits, and high variable compensation attractive to knowledge workers should be included in the organisation's talent acquisition plan. Financial and non-financial benefits should be used as a means of attraction for employment within a company. Dassler *et al.,* (2022) stated that employer attractiveness, organisational commitment and organisational identification are somewhat related. This is because all employees should be seen as possessing strengths that can create value for an organisation (Cappelli and Keller 2014). The statement from Cappelli and Keller (2014), also indicates that attracting top talent is largely down to issues apart from security, as employers are no longer willing or able to provide any assurance of continued employment. As a result, employees are now more open to exploring external opportunities even when not seeking them directly. Keller and Meaney (2017) also shows that "failure to attract and retain top talent" was the number one issue in the conference board's 2016 survey of global CEOs.

Reis de Neves (2019) describes talent management as a recent practitioner-generated term covering a range of long-standing practices aiming to get the right person at the right time. Many different components interplay to attract top talent to an organisation with high levels of pay, the presence of benefits, and variable pay all seen by participants as essential job-attraction criteria in a reward package (Schlechter *et al.,* 2014). Although Dassler *et al.,* (2022) argued that benefits and compensation were the least influential dimensions of employer brands and showed work-life balance as the third most important dimension.

Employer branding aims to promote the firm's unique features to existing and potential employees (Arasanmi and Krishna, 2019). An organisation can retain employees by seeking a relationship that leverages brand loyalty and employee productivity (Backhaus and Tikoo, 2004). Chandra (2019) conducted a study in Dublin City University to measure employee engagement by identifying factors that contributed to engagement and factors that require improvement as employee engagement leads to employee retention. Employer branding rests on the assumption that human capital adds value for a firm and enhances the firm's performance (Dabirian *et al.,* 2019). Backhaus and Tikoo (2004) also agreed that employer branding reflects the organisational human capital philosophy. Recent studies by Koukpaki *et al. (*2019) show that Backhaus and Tikoo's findings in 2004 are still relevant today as human resource development, brand marketing and employer branding have been proposed as an effective organisational strategy to develop a firm's capabilities to differentiate from the competition. Waal (2018) states that when an organisation is high performing, it increases happiness at the work level and, therefore, will increase attraction to a company. Having organisational support indicates the firm's value for caring for employees' well-being, which connotes a good work environment (Arasanmi and Krishna, 2019). Brand perception is essential for retaining employees; an employee will also look at the individual aspect of a job description, such as the structuring of packages.

Once employed, people are more likely to respond to higher performance demands when they perceive their employer's willingness to invest in their needs, such as training and development, and provide financial and non-financial rewards (Chiang and Birtch, 2011; Zafar *et al.,* 2020). Kadir *et al. (*2019) found that the higher the compensation and benefits provided to employees, the higher their performance, with compensation and benefits having a greater effect on employee performance than other factors such as job satisfaction, job security, and organisational culture. Whereas Nurlina *et al.,* (2022) found that transactional leadership, organisational culture, commitment, and compensation all significantly impacted work satisfaction and performance, with work satisfaction having a positive effect on performance. Amundso (2007) noted that employees' perceptions of benefits may vary across security, relationship, recognition, work fit, flexibility, learning, responsibility, and innovation.

Non-financial rewards have been proven to enhance employee performance (Schlechter *et al.,* 2014). However, there is no evidence supporting that specific combinations of non-financial rewards determine job attraction (Schlechter *et al.,* 2014). Millennial construction management students value work-life balance, job security, job satisfaction, recognition, and praise more than monetary compensation (Smith *et al.,* 2018). There is a positive correlation between motivation and job satisfaction (Ali *et al.,* 2021). When employees are more motivated and satisfied with their jobs, their performance increases (Pananrangi, *et al.,* 2020). Wages and benefits are the most important factors for employee retention in the construction industry, followed by the amount of available work and the opportunity to learn new skills (Bigelow, *et al.,* 2019). Additionally, talent management activities such as training, development, and recruitment positively affect the performance of construction companies (Kaewnaknaew, 2022). Exclusion of non-financial rewards, therefore, can be detrimental to the level of job attractiveness.

Balancing financial and non-financial rewards is crucial in framing a rewards system (Azeez *et al.,* 2019). Tiwari (2015) also agrees, stating that it is a strategy that uses non-financial rewards as a method of motivating and engaging by showing the employee the total cost of their employment and the value they bring. It was suggested by Bryant and Allan (2013) as a retaining strategy for employees with high salaries to go above and beyond pay raises and cash bonuses as they may value non-financial aspects more. A design for rewards should not be conducted in a vacuum absent of other factors that might be impacted by its adjustments (Azeez *et al.,* 2019). This is due to employees having different needs and interests and will change at various stages of their careers (Tiwari, 2015). When an employer improves their benefits to employees, Azeez *et al.,* (2019) states that this can lead to health increases. It is also worth bearing in mind that Herzberg's Hygiene theory shows there are two levels of needs for an employee, the lower-level needs facilitating survival, and the higher-level needs facilitating growth as a person (Truyens, 2021) so an ideal package should meet both sets of needs.

METHOD

To further understand the topic, a review of previous research papers was carried out using a synthesis matrix populated with information found in relevant papers (Efron *et al.,* 2019). To find these papers, databases such as Scopus and Google Scholar were searched using key words related to the topic such as employer attractiveness, talent acquisition and employee attributes,

Participant selection criteria were as follows. The participants had to be adults, over 18, studying and/or working in the built environment in roles that include Construction Management and Engineering, Civil Engineering, Architecture, and Electrical Engineering. The experience of participants ranged from undergraduate students with no experience, to undergraduates with one year experience and finally graduates with one or more years' experience. The more experienced participants involved had from one to four years of work experience with companies in the built environment since leaving college. The final participant group involved talent retention managers and agency recruiters in the built environment sector that are responsible for finding, attracting, and holding on to employees. Each participant was to answer from the perspective of a jobseeker looking for a role within the Irish Construction Industry.

Twenty semi-structured exploratory interviews were completed on MS Teams, using questions based on themes identified during the literature review - Structuring of Offerings, Impact and Effectiveness of Offerings, Companies' Perspective, Market and Participants' Perspectives. Participants' suitability for the study was verified at the beginning of the interview prior to their data being collected. All suitable interviewees were briefed on the purpose, informed that they could withdraw at any time and their consent was confirmed prior to the commencement of the interview. When 18 interviews were completed, no new findings were emerging so a further two interviews were completed to confirm saturation. The semi-structured format allowed exploration of relevant topics not covered by the set questions, should the opportunity arise. All data gathered was anonymised and stored securely.

The confirmatory survey questionnaire was designed as a gated MS Form and administered remotely with questions designed from interview responses around the six themes mentioned. If the respondent did not confirm their consent, then they were blocked from accessing and completing the survey. From an ethics perspective the company names, profiles, and adverts (the components of the offerings), used in the survey were all fictitious, having been built from details taken from a media trawl of companies and employment adverts relevant to the construction sector. The survey was completed by 53 respondents and focused on determining the components of the offerings (tailored to portray certain company profiles and benefit packages covering financial and non-financial elements) that they found most attractive. The output from the interviews and the survey are analysed in the next section.

FINDINGS

For this pilot study in the Irish Construction sector, 20 interviews were conducted and there were 53 completed survey responses. The impact of the offerings depicted by the fictitious company profiles / adverts, showed that there was a clear preference for companies that offered a range of social, salary and developmental benefits. The structuring of packages for employees has a huge influence in retaining and attracting talent in any company with Bryant and Allan (2021) finding that employees may value non-financial aspects more than just pay raises and bonuses. This can lead to a healthier workforce with health benefits included as Azeez *et al. (*2021) stated. Tiwari (2021) posited that employees have different needs and interests that will change depending on the stage of their career.

Offerings that explicitly mentioned the emphasis on the work environment, culture and support systems from the perspective of the applicant were seen as more attractive. Participants indicated that an offering that did not explicitly state the importance of a pleasant and motivating work environment was regarded as a less attractive proposition.

Salary: It was found that there was an even split across all participants when asked if salary was the most important aspect of an employment package with the importance of salary tracking downwards with the more mature employed graduates. When asked if they would take a lower salary for more social benefits the undergraduate group presenting a neutral answer while 40% of graduates and 33% of the experienced participants said No. In terms of what they consider to be more important between ‘learning outcomes’ or ‘higher salary’ for a graduate when joining a company, 70% of participants said 'learning outcomes'. An interesting finding was that having a state-funded graduate internship for a lower initial salary but a guaranteed job in the future was stated as being unattractive by 63% of participants. Yet the company that indicated in its profile that it worked primarily with public contracts and offered security, was considered highly attractive.

Learning and Development: The explicit mention of a good learning environment for graduates, knowledge sharing, and development opportunities were also seen as attractive for participants when looking at the company profiles. Participants also favoured offerings that presented a company that focused on employers' feedback for future improvement, with over 90% indicating that the provision of on-the-job learning was important for a first job post-graduation. When participants were asked what they valued more, learning outcomes or a higher salary, 70% of participants said learning outcomes. It is important for incoming graduates to value learning outcomes within the early stages of their careers as significant knowledge is learned and implemented which would have an impact on their careers. Chiang and Birtch (2011) and Zafar *et al. (*2020) suggested that employees are also more inclined to respond to higher performance demands if their employer invests in their needs such as training and development - this was borne out in the findings were the inclusion of development opportunities through explicit mention of training and feedback systems in the offering were seen as highly attractive and that a positive benefit can be received by an employer if training is positively implemented. Findings show that a company that does not have a good learning environment for graduates is regarded as a less attractive employer. This aligns with Bigelow *et al. (*2019) that wages and benefits were the most important factor for workers to remain in the construction industry, followed by learning new skills. Continuing this theme, Kaewnaknaew, (2022) found that factors such as training development and recruitment had positively affected the performance of a company. Experienced participants were seen to value learning and other benefits more than fresh graduates who are more attracted to monetary benefits i.e., salary. This point agrees with this study's findings that companies should promote the recruitment of graduates and actively train graduates with 'on the Job Learning' to increase the performance of their company, a win-win situation. Performance and motivation can also be increased by employees when they are challenged by and satisfied with their jobs. Kadir *et al. (*2019) found that leadership, organisational culture, commitment, and compensation impacted work satisfaction and thus improved work performance aligning with Pananrangi *et al.,* (2020) finding that when employees are more motivated and satisfied with their jobs, their performance increases, thereby benefitting the employer aswell. Companies presenting offerings that did not promote a commitment to enhancing personal fulfilment or value to career were seen as less attractive - a pleasant work environment was seen as a benefit by the participants.

Work-life Balance and Social Aspects: From the company perspective when company representatives were asked what they thought makes their company attractive to employees, the main response was a good work-life balance and social nights out, aligning with Dassler *et al.,* (2022) work indicating that that work-life balance was the third most important dimension of benefits to an employee. Companies emphasising social aspects, can improve overall work performance as employee's moods and attitudes toward work performance will improve. Graduates were seen to always add value to an organisation and 60% of companies agreed that to take on a state-funded graduate program would maximise the number of jobs for construction graduates.

This would benefit the organisation due to subsidised work funded by the government, as well as the employee benefiting from the learning aspect of employment and receiving a basic wage, however only 60% of undergraduates were interested in graduate programs. The general recognition that that graduates add value to the future of the company agreed with Cappelli and Keller (2014), in that all employees should be seen as a strength when creating value for an organisation and should be actively sought by the company. Therefore, all efforts should be made to ensure that the right people are attracted into the company and retained within it.

Survey participants were asked if having social benefits within a company made it an excellent employer, 68% agreed with this statement. Participants were also asked if they thought a company having compensation benefits such as health benefits made them an excellent employer, 85% agreed. In many cases, the attractiveness factor increased when 'non-package' issues such as the work environment, employee supports, and company culture were specifically mentioned in the offering. Amundso (2007) argued that an employee’s perception of benefits varies across different interests and needs such as relationships, flexibility and learning etc. If an employer was to tailor social benefits around employees individually rather than whole, employees may then be more inclined to take social benefits as they could have a higher value (personally) than monetary benefit. However, when asked if they would do more overtime for social benefits, 62% of participants said no, and were not inclined to favour the receipt of social benefits for working overtime but would rather receive monetary compensation. When asked in the interviews if they would take a smaller salary to receive more social benefits, overall, 60% of interviewees said no. But analysis of responses from undergraduate to experienced participants showed that the groups had different interests as they matured. The undergraduate groups were neutral while graduates already in employment favoured receipt of more social benefits, a common response from this more mature group was to have more social events through work.

Access to Technology: Participants also mentioned that they wanted access to the best available technology to work with. This would not traditionally be viewed as part of the compensation package as such. Schlechter *et al.,* (2021) stated that complete exclusion of non-financial rewards will be detrimental to job attractiveness, it is important to find a balance between financial and non-financial rewards.

Additional Benefits: When asked what additional benefits they would like to receive from their employer, 50% said a paid gym membership and 55% said a car or petrol allowance. Adverts that depicted an offering that included benefits such as health insurance, gym membership and the availability of an Employee Assistance Program were seen to be more attractive. Offerings that specifically mentioned a work environment where employee wellness was valued, and supported, scored highly compared with those that did not. In all, 60% of participants agreed that flexible work hours were important in relation to the attractiveness of an employer.

Sustainability: Regarding the impact of mentioning a commitment to environment and sustainability practices with a focus on being eco-friendly, only one third of the participants indicated that this would be a factor they would consider when determining the attractiveness of an offering from an employer.

Social Media Presence: While all participants agreed that a growing economy benefits graduates in terms of finding employment, only 50% of interviewees agreed that there were enough attractive offerings within the current market for both full role opportunities and graduate programs, even though 60% of the undergraduate participants said they would not join a graduate program. In terms of the impact a good social media presence has when choosing a company, 80% of graduates felt that a good social media presence is important when choosing a company. Reis De Neves (2019) found that using more than one form of social media is crucial to build a company's brand in the IT sector, also stating 'it is crucial for building brands through social media platforms as 79% of job seekers are likely to use social media in the hunt for their next job and 84% of employees consider leaving their current jobs if another company has a better reputation'. Therefore, the use of social media as a component of a company's recruitment activity is essential, using social media, e.g., LinkedIn, to promote and advertise jobs as socila media sites are essential intermediaries internally and externally (Cappelli and Keller, 2014).

It should be noted that companies in the Irish construction sector are not only competing but with the international opportunities available to graduates willing to emigrate for work and therefore should take notice of the findings presented here to maximise their attractiveness to the best talent in the marketplace.

CONCLUSION

In conclusion, the key elements from this study highlight the importance of certain factors that make a company more attractive when applying for a role. There are many studies focused on the attributes employers look for when hiring graduates but there was a gap in the knowledge regarding how graduates rated the attractiveness of Irish-based employers based on the composition of their offerings. These attractors include a pleasant work environment, learning development opportunities, and work-life balance. The results suggest that employers who indicate in their offering that they invest in their employees through training and development and promote work-life balance, can attract graduates, and also benefit from increased performance, motivation and retention of their staff. However, the study also found a divide between participants regarding the importance of salary as a factor in employment packages, with less mature participants valuing monetary benefits more than learning and development outcomes. These findings have been supported by various studies discussed in the literature review, making the conclusions drawn in this study reliable and valid.

It is important to note the limitations of this pilot study, such as the small sample size for experienced or mature participants and the potential for bias in the participant selection process. Therefore, further research in the form of a wider sample pool in this area is needed to verify and extend the findings of this study.

Overall, the implications of this study suggest that companies in the Irish construction sector when advertising roles, especially to graduates, need to develop offerings that prioritise promoting a positive work environment with access to appropriate technology, investment in employee training for learning and development while delivering work-life balance to attract and retain talented graduates. This pilot study's results are relevant to the Irish Construction Sector and could help employers attract today's graduates through effective use of social media platforms and present attractive recruitment packages, giving employers an advantage in what is a competitive hiring environment and ensure their ability to successfully contribute to the future of construction in Ireland.

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DEVELOPMENT OF CONCEPTUAL MOTIVATION FRAMEWORK TO ENHANCE CONSTRUCTION LABOUR PRODUCTIVITY IN THE UK

John Kojo Tawiah Hayford[1], Timothy Eccles and Daniel Fong

Centre of Integrated Delivery of the Built Environment, School of Built Environment and Architecture, London South Bank University, UK

Motivation is essential because labour performance depends on motivation. The study presents vital motivation factors influencing labour productivity and the relationship between social compliance, motivation, and productivity for decision-making. The construction industry in the U.K. is to become the largest construction market by 2030. However, construction productivity in the U.K. is low relative to other industries, resulting in a skilled labour shortage and low productivity growth. Hence, the opportunities for research to improve productivity in constructing for the future through motivation by social compliance. The study conducts a critical literature review of 32 significant motivation and productivity articles from construction and other industries in an online database to identify 31 factors. The findings indicate that motivation mediates social compliance and productivity. The study developed a conceptual motivation framework that indicates a positive relationship with motivation, social compliance, and productivity. The next stage is empirically testing the framework on sites.

Keywords: factors; motivation framework; productivity; social compliance

INTRODUCTION

The bond between motivation and labour productivity is widely accepted. Enhancing labour motivation is vital to maximising productivity (Khan *et al.,* 2013). Social compliance enhances motivation (Razzaue and Eusuf 2007; Alam and Alias 2018). For effective management in constructing the future to improve productivity, it is imperative to understand factors with an edge to motivate labour. The construction industry essentially contributes about 6-10% of the GDP to many countries' economies (Naoum 2016; Alaghbari *et al.,* 2019). In 2018 the industry contributed about 6% of the U.K. total economic output (Rhodes 2019). For management in constructing for the future to achieve the U.K. becoming the largest construction market by 2030 (Hairstans and Smith 2018), the government has called to cut the cost of construction by 33% and deliver 50% faster projects by 2025 (Rhodes 2019; Noruwa 2020). However, construction productivity in the U.K. is low relative to other industries affecting skilled labour shortage and productivity growth (Jarkas and Radosavljevic 2013), which presents an opportunity to study to improve productivity.

[1] hayforj2@lsbu.ac.uk

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The importance of productivity to the economy has led to this area being researched. For instance, Olomolaiye (1990) in AlAbbadi (2020), identified supervision and management as the most influential factors. Maloney (1983) cited in AlAbbadi (2020), rewards systems and job security were identified to increase productivity. Sweis *et al. (*2008) investigated factors affecting baseline productivity in the U.K., and the U.S.A. compared with Jordan, and Jarkas (2015) identified design errors, change orders and supervision as the most impactful factors. Alaghbari *et al.,* (2019) in Yemen presented work experience, materials shortage, and site management as impactful factors. El-Gohary and Aziz (2014) ranked the management category the highest in Egypt.

Johari and Jha (2020) India presented accomplishment and respect as the highest. Additionally, (Thomas and Yiakoumis 1987; Sonmez and Rowings 1998 cited in AlAbbadi 2020), and Kisi *et al. (*2017) discussed proposing a framework to identify productivity factors. Jalal and Shoar's (2019) framework to model factors affecting productivity the framework was not purely motivation. The DEMETEL used for factor reduction by (Ohueri *et al.,* 2018; Jalal and Shoar 2019) is complicated (Lin and Tzeng 2009). Eze *et al. (*2020) motivation framework considered only tradespeople's views, whiles, Alabbadi's (2020) motivation framework, the 'Rotated Component Matrix' used to design the framework has 19 variables. However, 20 variables reported in the framework need clarifying.

Though previous studies identified many factors influencing productivity, however, the effect of social compliance on productivity through motivation is limited compared with other industries (Alam and Alias 2018). Lack of motivation negatively influences productivity (Jalal and Shoar 2019). Several studies on productivity are classified as information technology (El-Mashaleh *et al.,* 2007), project delays (Sweis *et al.,* 2008) and health and safety (El-Mashaleh *et al.,* 2010). The productivity studies mostly focused on external factors like health and safety, weather, materials, and technology (Sweis *et al.,* 2013).

These frameworks presented could be clearer hence the need for a simple and accurate framework to fill this knowledge gap through social compliance (Alam and Alias 2018). The study aims to identify the motivation factors that influence labour productivity to develop a conceptual motivation framework to improve construction labour productivity in the U.K. These factors are worth researching because they may lead to a deeper understanding of productivity. Automating construction tasks that could improve productivity seems unlikely except for prefabrication and tools due to a lack of capital investments (Kazaz *et al.,* 2008). The study grouped the motivation factors into four classifications and established the relationships between motivation, social compliance, and productivity for the development of the framework.

METHOD

The study employed a critical literature review to identify the motivation factors influencing productivity. The review process was governed by search and selection criteria adopted by Sadiq *et al. (*2021) that helped arrive at the most pertinent papers to conduct the review and establish the gap. The study searched construction and other industry journals publishing productivity books, articles, conferences and dissertations from Google Scholar, EBSCOhost, Springer, Scopus, Elsevier, and Emerald. The title, abstracts, findings, and conclusions relevant to the keywords were selected. The 32 pertinent papers were reviewed to identify 31 factors mapped into four groups adopted from Kazaz *et al. (*2008), the most cited groups derived by

Vroom (1964); organisation, economic, physical, and physiological factors, worked as (social compliance variables), productivity as (dependent variables) and motivation as (mediation variables). The study established a relationship between social compliance and motivation as a hypothesis (H1), a relationship between social compliance and productivity as (H2) and a relationship between motivation and productivity as (H3) for the framework.

Motivation Factors

Organisation factors
The organisation refers to how work is organised, company culture, and leadership (Hoel and Salin 2003). Productivity improvement has a link with the quality of management. What dictates a site to be productive is that the management understands productivity and how it can positively influence it (Alabbadi 2020). The review identified nine organisation factors detailed in Table 1. Compliance with these factors could drive motivation. Together with economic, physical, and physiological factors could drive motivation and higher productivity.

Table 1: Organisation Motivation Factors

Item	Organisation motivation factors	Articles
1	Working in a safe workplace	(Aiyetan and Olotuah 2006; Alaghbari *et al.*, 2019; Eze *et al.*, 2020; Ohueri *et al.*, 2018; Borcherding and Garner 1981; Cherian and Jacob 2013; Njambi 2014; Andrew-Martin 2005; Lindner 1998; Chandrasekar 2011)
2	The style of the supervision	(Kazaz *et al.*, 2008; Jarkas and Radosavljevic 2013; AlAbbadi 2020; Eze *et al.*, 2020; Ailabouni *et al.*, 2007; Jarkas *et al.*, 2015; Mahamid *et al.*, 2013; Rakib *et al.*, 2020; Abukhait and Pillai 2017; Alaghbari *et al.*, 2019; Noah and Steve 2012; Nasr *et al.*, 2020; Andrew-Martin 2005; Chandrasekar 2011)
3	Provision of training facilities	(Kazaz *et al.*, 2008; Khan *et al.*, 2013; AlAbbadi and Agyekum-Mensah 2019; Eze *et al.*, 2020; Ohueri *et al.*, 2018; Cherian and Jacob 2013; Abukhait and Pillai 2017; Chandrasekar 2011)
4	Timely delivery of materials	(Kazaz *et al.*, 2008; Jarkas and Radosavljevic 2013; Alaghbari *et al.*, 2019; AlAbbadi 2020; Jarkas *et al.*, 2014; Eze *et al.*, 2020; Borcherding and Garner 1981; Ugulu *et al.*, 2019; Chandrasekar 2011; Rakib *et al.*, 2020)
5	Timely response to requests for information	(Hiyassat *et al.*, 2016; AlAbbadi 2020; Jarkas *et al.*, 2014; Jalal and Shoar 2019; Mahamid *et al.*, 2013; Jarkas *et al.*, 2015; Rakib *et al.*, 2020; Lorincová *et al.*, 2019)
6	Clear communication	(Hiyassat *et al.*, 2016; Naoum 2016; Mahamid *et al.*, 2013; Noah and Steve 2012; Lorincová *et al.*, 2019)
7	Provision of welfare facilities	(Ugulu *et al.*, 2019; Chandrasekar 2011)
8	The image of the company	(Aiyetan and Olotuah 2006; Lorincová *et al.*, 2019)
9	Availability of logistics supports	(Alaghbari *et al.*, 2019; Eze *et al.*, 2020; Hossain and Roy 2016; Borcherding and Garner 198; Chandrasekar 2011; Rakib *et al.*, 2020)

Economic factors
The construction industry is essential and affects every country's GDP. The industry contributes about 6-10% to many countries' economies, promotes employment growth, and links other industries (Dixit *et al.,* 2017). In 2018 the industry contributed 6% of the total economic output of the U.K. economy (Rhodes 2019). The critical literature review identified four major economic factors detailed in Table 2. Compliance with these factors could drive motivation. Together with the organisation, physical, and socio-psychological factors could increase motivation and give higher productivity.

Table 2: Economic Motivation Factors

Item	Economic Motivation Factors	Articles
1	Financial package (Incentive payments, pay on time, commission, sharing profit, bonus)	(Aiyetan and Olotuah, 2006; Kazaz *et al.,* 2008; Jarkas and Radosavljevic 2013; Khan *et al.,* 2013; Zakeri *et al.,* 1997; Hiyassat *et al.,* 2016; AlAbbadi and Agyekum-Mensah 2019; AlAbbadi 2020; Jarkas *et al.,* 2014; Eze *et al.,* 2020; Gichunge and Musungu 2010; Widanagamachchi 2015; Ohueri *et al.,* 2018; Ailabouni *et al.,* 2007; Jarkas *et al.,* 2015; Mahamid *et al.,* 2013; Noah and Steve 2012; Samuel and Chipunza 2009; Abukhait and Pillai 2017; Njambi 2014; Hossain and Roy 2016; Lindner 1998; Lorincová *et al.,* 2019; Chandrasekar 2011)
2	Fringe benefits - provision of transport, telephone services, social Insurance, free medical facilities	(Aiyetan and Olotuah 2006; Gichunge and Musungu 2010; Njambi 2014; Hossain and Roy 2016; Lorincová *et al.,* 2019)
3	Having a safely secured job	(Eze *et al.,* 2020; Gichunge and Musungu 2010; Samuel and Chipunza, 2009; Lindner 1998; Hossain and Roy 2016; Lorincová *et al.,* 2019)
4	Opportunity for promotions	(Aiyetan and Olotuah 2006; Zakeri et al1997; Eze *et al.,* 2020; Ugulu *et al.,* 2019; Lindner 1998)
5	Provision of retirement benefits	(Widanagamachchi 2015; Samuel and Chipunza 2009)

Physical factors

Physical factors refer to the work itself, a decent job, interest in work and many others detailed in Table 3. The literature review identified four major physical factors. Compliance with these factors could drive motivation. Together with organisation, economic, and physiological factors could drive motivation and higher productivity.

Table 3: Physical Motivation Factors

Item	Physical Motivation Factors	Articles
1	Nature of the work itself	(Aiyetan and Olotuah 2006; Zakeri *et al.,* 1997; AlAbbadi and Agyekum-Mensah 2019; Lorincová *et al.,* 2019; Njambi 2014; Widanagamachchi 2015; Kazaz *et al.,* 2008)
2	Flexible working hours conditions	(Chandrasekar 2011; Samuel and Chipunza 2009; Abukhait and Pillai 2017)
3	Moving labour between different tasks	(Kazaz *et al.,* 2008; Khan *et al.,* 2013; Andrew-Martin 2005; Alam and Alias 2018; Hossain and Roy 2016)
4	Performance feedback information	(Chandrasekar 2011; Lorincová *et al. (*2019)

Physiological / Socio-psychological factors

The physiological needs include the basic needs required for any person's survival (Maslow 1943 cited in AlAbbadi 2020). In this framework, the physiological factors refer to the relationship between workmates, management, participation in decision-making, and many others, detailed in Table 4. The study identified 13 physiological factors from previous articles. Compliance with these factors could enhance motivation. Combining these factors organisational, economic, and physical factors could drive motivation to higher productivity.

Social Compliance - Motivation - Productivity

Social compliance implies conformity to standards. The standards comprise the relevant regulations of the respective country, ILO conventions regarding labour standards and rights, fair labour practices, working conditions, building standards, health and safety, and code of conduct (Alam and Alias 2018). Social compliance improves motivation and productivity (Razzaue and Eusuf 2007; Moazzem and Sehrin 2016; Rahman and Hossain 2010). Social compliance that could improve motivation and productivity has yet to become reality on-site.

Table 4: Socio-Psychological Motivation Factors

Item	Socio-psychological Motivation Factors	Articles
1	Relationships among workmates and management	(Aiyetan and Olotuah 2006; Zakeri *et al.,* 1997; AlAbbadi and Agyekum-Mensah 2019; Jarkas *et al.,* 2015; Mahamid *et al.,* 2013; Samuel and Chipunza 2009)
2	Work appreciation or recognition	Aiyetan and Olotuah 2006; Zakeri *et al.,* 1997; Eze *et al.,* 2020; Widanagamachchi 2015; Samuel and Chipunza 2009; Njambi 2014; Hossain and Roy 2016; AlAbbadi and Agyekum-Mensah 2019; Lindner1998; Chandrasekar 2011; Lorincová *et al.,* 2019)
3	Provision of health and safety facilities	(Aiyetan and Olotuah 2006; Eze *et al.,* 2020; Kazaz and Acıkara 2015; Ugulu *et al.,* 2019; 2011; Samuel and Chipunza 2009;)
4	Ability to take part in decision making	(AlAbbadi and Agyekum-Mensah 2019; Jarkas *et al.,* 2014; Samuel and Chipunza 2009; Lorincová *et al.,* 2019)
5	Multiple skills for different tasks	(Alaghbari *et al.,* 2019; Eze *et al.,* 2020; Naoum 2016; Ailabouni *et al.,* 2007; Mahamid *et al.,* 2013; Rakib *et al.,* 2020)
6	Feelings of work accomplishment	(Aiyetan and Olotuah 2006; AlAbbadi 2020; Ohueri *et al.,* 2018; Johari and Jha 2020; Nasr *et al.,* 2020; Njambi 2014)
7	Equal opportunities and fair treatment	(Hossain and Roy 2016; Lorincová *et al.,* 2019)
8	Support from team members	(Hiyassat *et al.,* 2016; Eze *et al.,* 2020; Cherian and Jacob 2013; Lorincová *et al.,* 2019)
9	Value and respect for one another	(Lorincová *et al.,* 2019; Johari and Jha 2020)
10	Freedom of choosing how to achieve tasks	(Samuel and Chipunza 2009)
11	Able to come out with innovative ideas	(Samuel and Chipunza 2009; Chandrasekar 2011; Lorincová *et al.,* 2019)
12	Free time or vacation	(Lorincová *et al.,* 2019)
13	Attendance at social functions	(Sunyani *et al.,* 2020)

Management may need the knowledge to implement desired compliance standards (Ullah *et al.,* 2013). This study addresses how compliance with motivation factors establishes positive relationships with motivation and productivity to influence management decision-making to improve productivity in the construction industry. The organisation, economic, physical, and socio-psychological factors (social compliance) worked as (independent variables), and whether social compliance has a positive relationship with productivity through motivation (mediating variables) and a positive relation with productivity (dependent variables).

Motivation factors

Motivation is a process which activates productivity (Griffin and Moorhead 2011 cited in AlAbbadi 2020). Motivation factors differ; therefore, labour is motivated by different motivators (Lunsford, 2009). Labour is motivated by intrinsic and extrinsic. Intrinsic motivation is a desire that performs tasks that lead to satisfaction without external incentive (Herzberg 1966 cited in AlAbbadi 2020). Incentives achieve extrinsic motivation (Herzberg 1966). Extrinsic motivators consist of financial rewards, bonuses, and benefits. Identifying factors for compliance could be challenging. What motivates one labour will not necessarily motivate another (AlAbbadi 2020). The study focused on motivation factors that influence productivity to establish the relationship between motivation, compliance, and productivity.

Labour Productivity factors

Productivity is the input and output, where output implies the product produced and input implies resources such as labour, capital, technology, and materials (Saha and Mazumder 2015). Productivity is defined as a ratio volume measure of outputs to a ratio volume measure of inputs (Hiyassat *et al.,* 2016). The industry depends on both inputs and outputs to complete projects. Combining these inputs drives companies to generate outputs (Saha and Mazumder 2015). The primary input to improved productivity in construction is labour (Swies *et al.,* 2013; Kisi *et al.,* 2017). Labour is essential despite advancement of technology due to a lack of capital investment (Jarkas *et al.,* 2014). Labour accounts for about 30% to 60% of the total project costs (Fayek 2011). Labour remains an essential productive resource. The study establishes the relationship between motivation, compliance, and productivity.

Assessing the Relationship Between Motivation and Social Compliance

Motivation factors that could drive motivation differ. Individuals are motivated by different motivators (Lunsford 2009; Vroom 1964 cited in Alabbadi 2020). Compliance motivates labour (Razzaue and Eusuf 2007). Labour is motivated by social compliance, such as financial and welfare facilities (Baral 2010). Motivation depends on compliance implementation and hypothesizes that: H1: has a positive relationship between social compliance and motivation.

Relationship between Social Compliance and Labour Productivity

Labour is likely to feel associated when supported. Labour involves themselves with their company when associated with welfare facilities (Glavas and Godwin 2013). Companies engaged in social compliance attract competent labour and improve productivity (Umeokafor *et al.,* 2014). There is a positive relationship between social compliance and productivity (Siegel 2009). Social compliance reinforces relationships with labour. It is hypothesized that H2: there is a positive relationship between productivity and social compliance.

Assessing the Relationship Between Motivation and Labour Productivity

The relationship between motivation and productivity has been established. The earlier studies could not confirm direct links. Motivation is the cause of performance (Olusadum and Anulika 2018). Satisfaction occurs when motivators exist that increase motivation (Herzberg 1959). Lack of motivation negatively affects productivity (Jalal and Shoar 2019). Productivity depends on motivation (Dina and Olowosoke 2018; Hiyassat *et al.,* 2016). Positive job characteristics are essential in forming the relationship between motivation and productivity (Hackman and Oldham 1976). Motivation is linked with productivity (Johari and Jha 2020), hypothesising that: H3 has a positive relationship between motivation and productivity.

Relationship Between Motivation, Social Compliance and Labour Productivity

Social compliance enhances motivation and drives productivity (Alam and Alias 2018). A link between a positive work environment and productivity has been established (Battisti and Iona 2007). Labour becomes motivated by knowing their rights are protected. Compliance ensures labour rights and practices (Fukunishi and Yamagata 2013). Social compliance, motivation, and productivity are related. Productivity depends on social compliance, whiles motivation mediates social compliance and productivity (Alam and Alias 2018).

FINDINGS

The finding indicates that social compliance drives motivation and improves productivity (Razzaue *et al.,* 2007; Van-Woerkom and Meyers 2015; Alam and Alias 2018). Motivation improves productivity (Kazzaz *et al.,* 2008). The framework Figure 1 suggests a positive relationship between motivation, social compliance, and productivity and that motivation mediates between social compliance and productivity.

Research Contribution

The contribution to this study is the framework, and it is all about social compliance. This framework is a conceptual motivation framework to improve construction productivity; the previous studies needed to have established that compliance with motivation factors drives motivation and productivity. The study examined 31 factors influencing productivity into four groups (Kazzez *et al.,* 2008). The organisation, economic, physical, and socio-psychological factors (social compliance) in Table 1 - 4 and Figure 1 work as an (independent variable), productivity (dependent variable) and motivation (mediating variable). Compliance in this study is an aspect of management system concerned with the extent a company operates by the terms and conditions of motivation policy and practices. The degree to which employers can monitor compliance is written as the parties' right to adhere to mandatory obligations (Alam and Alias 2018). Assessment involves verifying that labour meets the qualification standards. Employers create an organised framework for contractors to report activities. Third-party Consultants may look for potential compliance gaps and ensure compliance (Baral 2010). Noncompliance refers to failure to comply with motivation policies by the authority having jurisdiction, the standards by industry-recognised quality management, or rules presented by a company that controls workplace motivation (Baral 2010). Recognition of motivation compliance is required before a company is allowed to work. Certifications and recognition may be revoked if one becomes non-compliant. Individuals or companies that have become non-compliant will incur penalties. For labour, this likely means disciplinary action. For companies, this can be enforceable stop-work order. Failure to comply could be motivation lawsuits from labour against their employer. Compliance requires the implementation of codes of practice and policies that ensure the regulations daily.

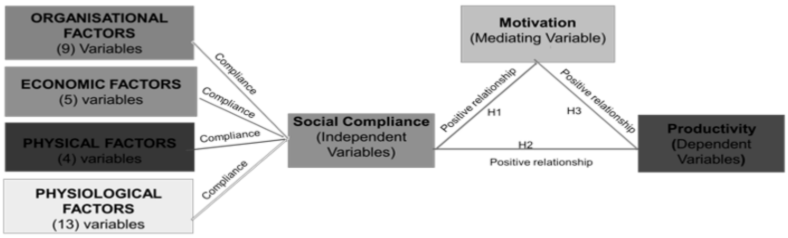

Figure 1: Conceptual Motivation and Productivity Framework

CONCLUSIONS

The review revealed that social compliance drives motivation and improves productivity (Alam and Alias 2018). And motivation drives productivity (Kazzaz *et al.,* 2008). Compliance motivates labour (Razzaue *et al.,* 2007; Van-Woerkom and Meyers 2015). The critical literature review identified 31 factors influencing labour productivity to develop a conceptual motivation framework that indicates a positive relationship between motivation, social compliance, and productivity. The review revealed that motivation mediates social compliance and productivity. The framework could enhance management decision-making to improve low productivity growth. The next stage empirically tests the framework and establishes which motivation factor group improve motivation and productivity in the U.K.

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INFRASTRUCTURE DEVELOPMENT

MANAGING CHANGE IN MEGAPROJECTS

Norfahana Abdul Ghani[1] and Apollo Tutesigensi

School of Civil Engineering, University of Leeds, Woodhouse Lane, Leeds, UK, LS2 9JT

Management of change is an important aspect of managing any construction project. Much of the literature on management of change in projects concerns changes managed as variations to construction contracts. These changes may be construed as first-order changes. On occasion, project changes are so radical that they cannot be managed as variations to the construction contract. Such radical changes are sometimes referred to as second-order changes. There is limited research undertaken about second-order changes in megaprojects. We argue that second-order changes in megaprojects can be analysed and explained using mainstream literature about managing organisational change. Hence, we adopted a systematic literature review methodology to determine a conceptual framework for managing radical changes in megaprojects. Specifically, an in-depth review of 25 organisational change management (CM) models was conducted. This resulted in the identification of the Association of Change Management Professionals' Standard for Change Management (ACMP-SCM) as an appropriate model with which management of change in megaprojects can be analysed. We argue that with the ACMP-SCM, we can critique how changes have been managed in past megaprojects as well as design and implement changes better in future megaprojects.

Keywords: change management; megaprojects; project change; second-order change

INTRODUCTION

Changes are inevitable in projects. Change can be required in any phase of the project lifecycle and can have a significant impact on overall project's success and success criteria. Drawing on Levy and Merry (1986), changes in projects can be categorised as first order or second order changes. First order changes are minor improvements and adjustments that do not change the system's core and occur as the system naturally grows and develops Levy and Merry (1986). In construction projects first order changes are usually managed as variations to the construction contract. Second order changes are multi-dimensional, multi-level, qualitative, discontinuous, radical organisational changes involving a paradigmatic shift (Levy and Merry, 1986; Gareis, 2010). Second order changes lead to a new identity. In construction projects, second order changes cannot be managed as variations to the construction contract - they often lead to cancellation of the old construction contract and/or creation of a new and different construction contract.

This paper focuses on management of second order changes in construction megaprojects. By their very nature megaprojects are large and complex organisations, albeit temporary - however, even though they are temporary organisations, they tend

[1] cnnag@leeds.ac.uk

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to have a relatively long project duration. From this, we conclude that we can use main-stream management and organisational literature and theory to analyse second order changes in megaprojects.

The management and organisational literature demonstrate that effective management of change (MoC) significantly influences organisational success (Gilley *et al.,* 2008; Turner and Muller, 2005; Hornstein, 2013). Despite the importance of effective MoC, previous studies (Musa *et al.,* 2017; Hwang and Low, 2012; Musa *et al.,* 2021) demonstrate paucity of studies focusing on implementing MoC models, particularly in megaprojects. With this paper, we seek to contribute to debate and understanding of MoC in megaprojects. We achieve this by identifying 25 models of MoC in organisations, assessing them for appropriateness for megaprojects and recommending the Association of Change Management Professionals (ACMP) model as the most appropriate MC model that can be used to analyse MoC in megaprojects.

MoC is one of the most important aspects of managing megaprojects. The efficacy of overall MoC practice in different types of projects can vary widely depending on project nature, industrial type, project complexity, project size, contract methods and the level of experience of project participants (Zou and Lee, 2008; Motawa *et al.,* 2007; Hwang and Low, 2011). According to Beer and Nohria (2000a), the whole area or evaluating MoC has been plagued by a lack of empirical evidence. Organisational change initiatives are often triggered as a response to both internal and external drivers (Allen *et al.,* 2007); Avila and Graces, 2017) such as; new management strategies (Wissema, 2000), changing customer demands (Augustsson *et al.,* 2017), economic repercussion (Price and Van Dick, 2012), market shifts, changes in demographics (Rock, 2012), new business models (de Biassi, 2018), introduction of new technologies (Allen *et al.,* 2007), political and regulatory changes (Paul, 2015). Since megaprojects are like organisations in many respects, these internal and external drivers can and do manifest in megaprojects. With this theoretical connection between organisations and megaprojects, the publications on MoC and MoC models and frameworks that exist in organisational literature may be utilisedto gain better understanding of MoC in megaprojects (Errida *et al.,* 2018).

Megaprojects have long been understood as large temporary networks of public and private actors, connected through a complex web of relationships, who jointly work to deliver a capital asset such as a high-speed train, mega-event, or an airport (Gil *et al.,* 2017). Megaprojects clearly bring together, under various contractual arrangements, differing and competing partners, interest, values, and modes of rationality (Van Marrewijk *et al.,* 2008). Previous research has focused on endemic debates of megaprojects, problems of cost, and schedule overruns, inadequate up-front strategising (Morris, 1994), stakeholder management failures (Lessard, 2008), lack of investment in design flexibility (Gil and Tether, 2011), strategic misinterpretation, optimism bias, and technical incompetence (Flyvbjerg, 2014;2017). Typically, megaprojects involve interaction between several organisations and require coordination of the works of several disciplines and involves a wide range of project management methods aligned with the complexity defined by APM (2008).

Second order changes to a megaproject will involve changing these interactions. Despites the extensive research on megaprojects, there are limited published resources about such phenomena. However, Migliaccio *et al. (*2008) reports on a second order change in the $1.3b SH 130 tolled expressway project in Texas, US. From this megaproject, it is argued that adoption of a new approach to procurement of services needed in the delivery of construction projects requires comprehensive change, including significant modification to both the work processes and the existing organisational structure (ibid) - this would be tantamount to a paradigm shift. Effective implementation of such paradigm shift requires owners to correctly identify the dimensions of change in the delivery cycle to establish new work relationships with their stakeholders (FHWA, 2004). Migliaccio *et al.,* (2008) emphasized that changing project delivery strategy is not easy and the information about how this change should be implemented is limited, especially at the organisation-side level. Yet such change has far-reaching consequences for all concerned and deserves to be understood thoroughly and implemented effectively. This is why research of the kind reported in this paper, which is aimed at identifying a conceptual framework for MoC in megaprojects, is important. It is important because it provides a theoretical basis from which empirical work can be undertaken to increase knowledge about, and improve practice of, MoC in megaprojects.

METHOD

The method used for this paper is the Systematic Literature Review. SLR is an exact and reproducible method for identification, evaluation, and interpretation of predefined fields of study. The approach is particularly suitable when the analysed subject is fragmented across fields of study (Denyer, 2008; 2009). The literature review process is performed according to predefined steps and search strategy, which increases transparency, reproducibility, and quality of results. This paper adapts and combines the guidelines suggested by Tranfield *et al. (*2003) and Mok *et al. (*2015) to conduct a SLR and employed the PRISMA systematic method to minimise bias and errors by providing 'high-quality' evidence (Moher *et al.,* 2009). Criteria for inclusion and exclusion of studies were established using Davies and Crombie's (1998) model. In the first step, the search criteria were established and applied. The search was limited to peer-reviewed papers in English that were published in recognised journals in the "Scopus" database. Search strings were developed from the identified keywords with the help of the Boolean operator *AND*/*OR* to search and access the relevant literature. Search strings employed in this review were: "Change management" AND "Conceptual" OR "Model" OR "Framework" AND "Organisation" OR "Project".

The databases provide complementary bibliographic information. No further criteria were defined to limit the impact of classification errors in the databases, which increased effort in the following steps, but at the same time, it increased the quality of results. The screening process was based on the PRISMA method (Moher *et al.,* 2009), a two-stage filtering process previously applied by Yang *et al. (*2011b), and more recently Mok *et al. (*2015). In stage 1, the authors focused on the relevance of papers. For stage 2, the authors focused on fields of study covered in the papers. Both stages of screening were performed using spreadsheets and data imported from databases in CSV files. A total of 226 articles were retrieved after the first selection stage. After the exclusion of conferences, non-English and books the first stage screened out publications which did not contain the above-mentioned and led to exclusion of 87 records. In the next step, papers were read, and screening was performed based on the full text of papers. Full-texts copies were downloaded from databases authors were eligible to (EBSCO, Science Direct, Emerald, JSTOR, Wiley, and Academia, Research Gate, Google Scholar). A total of 28 papers were included in this review.

The final stage was focused on the evaluation of the CM models. Multi Attribute Utility Theory (MAUT) was utilised to evaluate the MoC models. Four criteria namely effectiveness, inclusive practice, comprehensiveness, and holistic management were utilised. Multicriteria evaluation of the models was undertaken using the lexicographic method of sequential elimination as the final step. Rogers (2012) explains this method thus: the options are examined initially on the most important criterion; if an option has a better score on the chosen criterion than all other options, it is chosen and the process ends; if, however, a number of options are tied on the most important criterion, this subset of tied option is then compared on the next most important criterion; and the process continues in a sequential manner until a single option is identified or all criteria have been gone through and complete separation is found to be impossible. If complete separation is found to be impossible, either another method is used or more criteria are identified. Hence, assessing each model would provide insights into CM studies to help future research use suitable models that fit the change situations. As such, the results help us define which models are most suitable for our research project in managing second-order change in megaprojects. Table 2 describe the evaluation criteria.

FINDINGS

CM models and frameworks found in the organisational CM literature are presented and discussed. Firstly, the authors discussed CM models and framework. Thereafter, we identify a conceptual CM model proposed and explained. The conceptual model is expected to be employed in our research project, as a frame of reference for the author research project. The findings of this study may provide useful insights for decisions needed for the successful implementation of change management models and frameworks in the study of organisational change. 25 models were identified and reviewed. This review yielded the list of models of organisational change management shown in Table 1 in identifying the conceptual model from the existing study of organisational change that can be used in future research to analyse how change has been managed.

Change management models

Parry *et al. (*2013) distinguishes between two categories of change management models which are processual and descriptive models. A processual model determines the steps for conducting and managing change for example Lewin's 3-stage model of change, Kotter's 8-step model, Kanter's change wheel, IMA'S 10 steps, and Luecke's 7-step model. Whereas a descriptive model specifies the main variables and factors that affect organisational performance and organisational performance and organisational change success: for example, Parry et al.'s (2013) change tracking model, Cummings and Worley's change management model, Burke and Litwin's model of organisational change, and Nadler and Tushman's congruence model (Eridda and Lotfi, 2021).

Burnes (2000) have attached the "emergent" label to studies that examine change "as -it-happens", which is, perhaps, not surprising given that an important argument of this approach has been that radical large-scale change does not simply occur overnight (it is not an event) but takes time. As such, change is viewed as continuous process and consequently, attempts to impose a linear sequence of planned actions on what are untidy process "which unfold in an iterative fashion with much backtracking and omission" (Buchanan and Storey, 1997; Dawson, 1994; 2005). According to Dawson (2015) the processual approach is not making a statement against the importance of planning for change, rather, it is pointing out that change is unpredictable and therefore that there will be a need to accommodate and adapt to the unexpected, the unforeseen twists and turns, the omissions and revisions that are all part of managing the process of change over time.

Lewin's 3-stage model is considered the theoretical foundation of planned change management. Lewin's (1951) model is continuing to underpin many contemporary change methodologies in organisations (Burnes, 2004a). The key contributions Lewin's 3-step model is that a successful change project involves three steps: unfreezing, moving, and refreezing (Lewin, 1947; 1951; Burnes, 2004a; Hossan, 2015; Eridda and Lotfi, 2021). Lewin (1947) suggest that to manage processes, an organisation must 'unfreeze' its current state into a neutral position so that old behaviour can be unlearned, and new behaviour can be successfully adopted. Then change should be implemented by utilising driving forces and minimising resisting forces. Lewin's (1947) that to understand individual, group and organisation behaviour and to manage change, it is important to identify, plot and establish the forces that influence change. The second notable change management processual model is proposed by Kotter (1995; 1996). Kotter methods consisting of eight steps, which more holistic, noting that organisations could use this method to avoid failures in implementing change and increase their chances of success (Al-Haddad and Kotnour, 2015). The eight steps to ensure a successful change process: (1) establish a sense of urgency about the need to achieve change, (2) create a guiding coalition, (3) develop a vision and strategy, (4) communicate the change vision, (5) empower broad-based action, (6) generate short-term wins, (7) consolidate gains and produce more change, and (8) anchor new approaches in the corporate culture (Errida and Lotfi, 2021).

Pollack and Pollack (2015) applied the model for the case study research which describes a change manager's action research enquiring into the use of the process to manage a major organisational change. However, the change model was found to not represent the complexity of required action, which its required managing the change team to facilitate multiple concurrent instances of Kotter's model throughout the organisations. Cole *et al. (*2006) found the actual execution of change to be one of the key factors in determining success or failure. Moreover, scholars have critically commented on how Kotter's eight stage process creating a major change has been used to manage an organisational change (Springer *et al.,* 2012; Lintukangas *et al.,* 2009; Day and Atkinson 2004; Ansari and Bell 2009; Joffe and Glynn 2002). Mento *et al. (*2002), developed a 12-phase approach to implement and manage change efforts successfully: (1) determine the idea and its context, (2) define the change initiative, (3) evaluate the climate for change, (4) develop a change plan, (5) identify a sponsor, (6) prepare the recipients of change, (7) create cultural fit, (8) develop and choose a change leader team, (9) create small wins for motivation, (10) constantly and strategically communicate the change, (11) measures progress of the change effort, and (12) integrate lesson learned. More detailed models have been established such as ACMP. The ACMP model determines 33 processes and organised into five main process groups.

According to Errida *et al. (*2018), descriptive models are oftentimes overarching and takes a broader array of key organisational factors into consideration (Errida and Lotfi, 2021). Burke and Litwin (1992) distinguish between transformational and transactional factors and include the following in their model: mission and strategy, organisational culture, leadership, management practices, structure, systems (policies and procedures), task and individual skills, individual needs and values, motivation, and work unit climate.

Table 1: Lists of change management models

	Processual models		Descriptive models
1	Lewin's three step change model (Lewin, 1947)	12	Cummings and Worley's CM model (Cummings and Worler, 2013)
2	Kotter's 8-step change mode (Kotter, 1995)	13	Burke and Litwin's model (Burke and Litwin, 1992)
3	Luecke's seven steps (Luecke, 2003)	14	Pressi's change management methodology (Pressi, 2017)
4	ADKAR, Pressi (2003)	15	McKinsey'$ 7-S (Peters and Waterman, 1982)
5	ACMP's Standard for Change Management (ACMP, 2014)	16	Change tracking model (Parry *et al.,* 2013)
6	Bridges model of transition (Bridge, 2003)	17	Best practice model for change management (Clarke and Garside, 1997)
7	Kanter 's change model (Kanter, 2011)	18	Change formula (Beckard and Harris, 1987)
8	Mento *et al.,* change model (Mento *et al.,* 2002)	19	Change management body of knowledge (Smith *et al.,* 2014)
9	Jick's 10 steps model (Jick, 1993)	20	Change first model (Changefirst, 2010)
10	The change leader's roadmap (Anderson and Anderson, 2010)	21	GB's change model (Garvin, 2000)
11	Judson's five-phase model (Judson, 1991)	22	CMI's change management maturity (Perkins, 2012)
		23	Congruence model (Nadler and Tuskaas, 1980)
		24	Kaostet's change model (Inester, 2000)
		25	Armenakis *et al.,* (Armenakis *et al.,* 2007)

The Burke and Lewin model has been based on the authors experience with organisational change projects and a selection of empirical studies to support their reasoning regarding causal relationships but has not been empirically tested and validated (Parry *et al.,* 2013). Appelbaum and Wohl (2000) employed Burke and Litwin's model and added: change process [unfreeze/change/refreeze; organisational behaviour process (behaviour modification)], organisational goals, organisational design (encompassing systems and structure), technology and learning.

Our findings identify multiple change management models that are applied to bring about change in organisational change management. The change management approach or method would only be suitable for some situations as the change method should depend on the organisational context (Kotter and Schlesinger, 2008). Four main criteria were identified to assess the 25 CM models: comprehensiveness, holistic management, effectiveness, and inclusive practice. The criteria were identified based on the critical success criteria that must be linked with the specific situation related to change and should be defined appropriately, hence focus is very important. Comprehensiveness refers to the CM model's ability to facilitate a comprehensive understanding of the situation. Holistic management refers to the model's potential to incorporate every change aspect (McKinsey, 2008). The CM models should promote the effectiveness of the model in managing the changes. For effectively managing change, it is necessary to develop a sense of urgency since this factor emphasizes the employees going outside their comfort zones (Appelbaum *et al.,* 2012). inclusive practice, where the CM model should facilitate the involvement of people to implement the changes.

Each model explains the basic concept of CM, which starts from identifying the current conditions, then realising the need for change, entering the transition phase, implementing the change, and then reaching the desired condition. Analysing these models can be observed that each model has their own particularities and focus in the change management study. In the next step, we access each 25 models on a scale of 1 to 10 for each of the criteria: comprehensiveness, holistic management, effectiveness, and inclusive practice. The performance matrix for the 25 models is given in the Table 2.

Table 2: Performance matrix of CM models

Change Model (CM)	Attribute/Criteria			
	Comprehensiveness	Holistic Management	Effectiveness	Inclusive Practice
CM1	5	3	5	8
CM2	5	8	8	5
CM3	3	3	3	3
CM4	5	5	5	8
CM5	8	5	8	8
CM6	3	5	3	5
CM7	5	3	5	5
CM8	5	3	3	3
CM9	5	3	5	8
CM10	5	3	5	5
CM11	5	3	5	5
CM12	5	3	5	5
CM13	5	3	5	5
CM14	8	3	5	5
CM15	5	5	8	8
CM16	3	3	3	3
CM17	3	3	3	3
CM18	3	3	3	3
CM19	3	3	3	3
CM20	3	5	3	5
CM21	5	8	8	5
CM22	3	3	3	3
CM23	8	5	5	5
CM24	5	5	5	5
CM25	3	3	3	3

To apply the lexicographic method of sequential elimination, we placed the criteria in the following order of importance: effectiveness (R1), inclusive practice (R2), comprehensiveness (R3), and holistic management (R4). The method of lexicographic sequential elimination exercise as per Table 3. On the most important criterion, R1, four CM models are tied for the first position, which are CM2, CM5, CM15, and CM21. Therefore, the process should move to the second most important criterion, R2 with the four tied models. On the second criterion, which is the inclusive practice of CM models, two models: CM5 and CM15 are still tied. We then consider CM5 and CM15 on the third most important criterion, R3, the comprehensiveness of the model and find that CM5 prevails over CM15 - and is therefore the overall winner.

Conducting in depth study of change management models leads us to the understanding that CM demand clear methods and strategies. The model might be selected differently, depending on the occasion. In theory we have some models says that one can be comprehensive way of change management. We argue that the CM model could be one best way to manage the changes, particularly in managing the changes in megaprojects. The CM model can be superimposed and should be tested to improve the change management practice and bridge with the existing theory. But in so doing, we identified the ACMP processual model as the most suitable model for assessing the managing changes in megaprojects. The Standard for Change Management (ACMP) represents debate and perspective from around the world.

ACMP's standard for CM describes the areas of knowledge, established norms, processes, tasks, and skills necessary for CM practitioners to be effective in managing change in the industries and organisations, which it designed to benefit both individuals and organisations (ACMP, 2014; 2019). The ACMP model provides a more detailed process list, which determines 33 processes, and is organised into five (5) main process groups: (1) evaluate change impact and organisational readiness: designed to assess, evaluate, and anticipate an organisation and its stakeholders' readiness, ability, and capacity to transition from the current state to a future state, (2) formulate the change management strategy: designed to develop a high-level approach to change management.

Table 3: Lexicographic elimination evaluation

Change Model (CM)	Attribute			
	R1	R2	R3	R4
CM1_Lewin's three step change model (Lewin, 1947)	5	8	5	3
CM2_ Kotter's 8-step change mode (Kotter, 1995)	8	5	5	8
CM3_ Luecke's seven steps (Luecke, 2003)	3	3	3	3
CM4_ ADKAR, Prosci (2003)	5	8	5	5
CM5_ ACMP's Standard for Change Management (ACMP, 2014)	8	8	8	5
CM6_ Bridges model of transition (Bridge, 2003)	3	5	3	5
CM7_ Kanter 's change model (Kanter, 2011)	5	5	5	3
CM8_ Mento et al. change model (Mento et al., 2002)	3	3	5	3
CM9_ Jick's 10 steps model (Jick, 1993)	5	8	5	3
CM10_ The change leader's roadmap (Anderson and Anderson, 2010)	5	5	5	3
CM11_ Judson's five-phase model (Judson, 1991)	5	5	5	3
CM12_ Cummings and Worley's CM model (Cummings and Worler, 2013)	5	5	5	3
CM13_ Burke and Litwin's model (Burke and Litwin, 1992)	5	5	5	3
CM14_ Prosci's change management methodology (Prosci, 2017)	5	5	8	3
CM15_ McKinsey's 7-S (Peters and Waterman, 1982)	8	8	5	5
CM16_ Change tracking model (Parry et al., 2013)	3	3	3	3
CM17_ Best practice model for change management (Clarke and Garside, 1997)	3	3	3	3
CM18_ Change formula (Beckard and Harris, 1987)	3	3	3	3
CM19_ Change management body of knowledge (Smith et al., 2014)	3	3	3	3
CM20_ Change first model (Changefirst, 2010)	3	5	3	3
CM21_ GE's change model (Garvin, 2000)	8	5	5	8
CM22_ CMI's change management maturity (Perkins, 2012)	3	3	3	3
CM23_ Congruence model (Nadler and Tushman, 1980)	5	5	8	5
CM24_ Knoster's change model (Knoster, 2000)	5	5	5	5
CM25_Armenakis et al. (Armenakis et al., 2007)	3	3	3	3

This change strategy will incorporate, integrate, and align change management plans, activities, tasks, and milestones into other activities and the organisation's operations, (3) develop the change management plan: employ specific change management methodologies and tools to develop detailed plans for implementing the change management strategy, (4) execute the change management plan, and (5) close the change management effort: determine the effectiveness of the work, monitor progress, and transition. Moreover, breaking the process into doable parts makes it more manageable and provides a framework and clear vision for managing the changes (Smith, 2021). Furthermore, it is designed to benefit both individuals and organisations to be effective in managing the changes. The ACMP framework encompasses five distinct areas of focus. It highlights a list of work streams which includes sponsor accountabilities, leadership alignment, stakeholder engagement, communication, culture and behaviour, impact assessment and management, readiness planning, learning and development, performance management, risk management, and benefits realisation. Our observation of the model shows that the model might be relevant to managing radical changes, particularly in megaprojects.

CONCLUSIONS

In the current literature field, there exist many theories and CM models, most of them share likenesses in some respects. However, there is a paucity of research and information on what is involved in the large-scale change or transformation process, distinct from the surrounding methodology and generalised critical success factors such as project performance. Hence, what are the new directions or models to be employed in the research and practice of radical change in projects? Additionally, research efforts in this area will improve understanding beyond the impasse of radical change management. In addition to theory building, as in this paper, there should be a systematic programme of theory testing in the area of the radical change of the project. Thus, identifying change management models is suggested to advance research into radical change to the project, such as investigating the case study that has experienced radical change to the project hence accessing the managing changes could be a theory that contributes to the study of change management. The SLR in identifying the model or framework for managing change for megaprojects provide an understanding of the change management study; as above, a framework helps the researcher to determine the right approach to apply in each situation. A structured change management model is also important for the organisation to deal with change. We argue that ACMP focuses on a comprehensive definition of change management, as well as the standard elements involved in its execution, hence as an appropriate model with which management of change in megaprojects can be analysed.

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LEADERSHIP FOR THE FUTURE: TOWARDS THE CHALLENGE OF UNDERSTANDING LEADERSHIP IN THE AEC SECTOR

Roisin Murphy, Rory Concannon[1] and Oluwasegun Seriki

School of Surveying and Construction Management, Bolton Street, Dublin, D01 K822, Ireland

The Irish Architecture, Engineering, and Construction (AEC) sector faces ongoing challenges relating to low productivity, digital adoption, sustainability, and innovation. Effective leadership is required to transform the sector to address these challenges and meet the future needs of society. However, there remains a lack of empirical evidence relating to leadership requirements, assessment, and development, in the context of the Irish AEC sector. As part of an ongoing study with the aim of developing resources to support leadership development, this research, conducted through a review of literature, examines how leadership is being assessed and explored in the AEC sector. The findings highlight the importance of leadership in addressing critical issues facing the sector including innovation, modernisation, sustainability, and safety. Furthermore, the findings underscore methodological challenges faced in exploring leadership in practice from a solely positivist quantitative approach. This research makes important contributions by highlighting current trends in AEC leadership research, and illuminating the contextual complexity surrounding what is effective leadership in the AEC sector.

Keywords: leadership; leadership assessment; AEC sector; construction sector

INTRODUCTION

The AEC sector in Ireland contributes significantly to economic growth, employment, and the provision of the built environment within which we work, live, socialise, and learn (Murphy and Seriki, 2021). The sector must address significant challenges to meet future societal demands (DPER, 2019) including sustainability, labour shortages, supply chain volatility, and a reluctance to innovate (KPMG *et al.,* 2020). It is acknowledged that these challenges are not unique to Ireland (similar challenges have been highlighted in the 2016 Farmer report on the UK sector) however, the leadership required to address these challenges may be significantly different in an Irish context as national culture can affect prototypical understanding of leadership and how effective leadership is defined and interpreted (Antonakis *et al.,* 2003). Leadership is an essential factor required for the sectors transformation towards innovation, modernisation, and sustainability (Farmer, 2016; Murtagh *et al.,* 2020) . Consequently, understanding and developing leadership is imperative.

Industry stakeholders have expressed the need for effective leadership (Construction Industry Federation, 2019), however, there remain significant misconceptions surrounding the nature of leadership in practice (Northouse, 2021). Leadership is a complex but well researched phenomenon (Löwstedt *et al.,* 2021), which in practice,

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[1] D21127527@mytudublin.ie

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is an interactive, social, and dynamic human behaviour informed by motivation, values, and context (Potter *et al.,* 2018; Yukl *et al.,* 2002; Zhang *et al.,* 2018). Leadership can be viewed as a process, and as such, can be learned, developed, and taught (McCauley and Palus, 2021). However, despite the maturity of leadership research in other sectors, leadership research in the AEC sector is still in its infancy (Löwstedt *et al.,* 2021).

A route to enhancing leadership, and more effective leaders, is through leadership development and training (Day *et al.,* 2021), and for leadership development initiatives to be meaningful and effective, they must be derived from a clear understanding of the leadership requirements of the sector (Simmons *et al.,* 2020). However, a fundamental knowledge gap exists in relation to empirical evidence surrounding effective leadership in the Irish AEC sector. As part of an ongoing study, taking a systematic approach, this research examines how leadership in the AEC is being explored. Following an outline of the theoretical background and the methods employed, the results highlight both the import of leadership and the methodological challenges faced in assessing leadership in AEC settings. By understanding leadership in practice, that knowledge can inform leadership development initiatives of practical benefit to the sector (Simmons *et al.,* 2020).

Theoretical Background

For over 70 years, researchers have examined which leader behaviours, traits, and competencies are effective in different situations (Northouse, 2021; Yukl *et al.,* 2002). Studies in a broad range of sectors including, hospitality, banking, manufacturing, and healthcare have demonstrated the effects of leadership on critical issues such as performance, innovation, productivity, and sustainability (Parry *et al.,* 2014; Pham *et al.,* 2021; Yukl *et al.,* 2002). Leadership has been examined using diverse methods including observational studies, ethnography, interviews, surveys, and experiments (Grill *et al.,* 2019; Löwstedt *et al.,* 2021; Parry *et al.,* 2014; Yukl *et al.,* 2002). The contingent nature of leadership has been demonstrated, in that, leaders will behave differently depending on factors including cultural setting, project objective, team configuration, resources, and urgency (Northouse, 2021; Wipulanusat *et al.,* 2017; Zhang *et al.,* 2018). Furthermore, research finds leadership to be a complex social phenomenon that requires context derived from interactions between leader and follower (Bryman, 2004; McCauley and Palus, 2021).

Leadership in practice can be enhanced by development initiatives but need to be contextualised to the area of deployment (Day *et al.,* 2021; McCauley and Palus, 2021). Leadership development studies have shown that the context should be derived through empirical evidence and understanding of leadership within the area of investigation (Day *et al.,* 2021; Simmons *et al.,* 2020). Of critical importance, Day *et al.,* (2021) contend that leadership development initiatives are built on scientifically sound frameworks.

Leaders' values, motivations, and behaviours have been studied and developed into identifiable frameworks of how leadership is enacted and examined (Grill *et al.,* 2019). Prior research supports two meta categories of leadership behaviour, Task-oriented and Relations-orientated (Banks *et al.,* 2018) Task-orientated behaviour is concerned with behaviours that are focused on defining subordinate roles and tasks, directing efforts, and deploying discipline (Lingard *et al.,* 2019). Relations-oriented behaviour is the degree to which a leader demonstrates concern for team members, demonstrates support, and recognises efforts (Grill *et al.,* 2019).

Avolio and Bass, (1995) further categorised leader behaviours into groupings that represent three leadership styles referred to as The Full Range Leadership Theory (FRLT). A leadership style is a distinct set of behaviours and values used to describe a leaders influence on, and interaction with, followers, organisation, and objectives (Potter *et al.,* 2018). Leadership styles are defined, observable, and comparable, and as such, have proven to be a valuable tool in assessing leadership in practice (Banks *et al.,* 2018). Table 1 provides a summary description of the FRLT leadership styles; Transactional, Transformational and Laisse-Faire.

Table 1: Summary descriptions of FRLT leadership styles

Leadership Style	Summary Description and Behaviours
Transactional (Avolio and Bass, 1995)	Team obey leaders for rewards. The reward may be praise, recognition, or avoiding disciplinary action.(Lingard *et al.,* 2019)
Transformational (Avolio and Bass, 1995)	Raises followers needs towards self-actualisation. Idealised Influence, Intellectual Stimulation, Inspirational Motivation, and Individualised Consideration. (Zavari and Afshar, 2021)
Laissez-Faire (Avolio and Bass, 1995)	Gives team freedom, avoids giving direction. Requires a large degree of self-motivation from team.(Olasunkanmi *et al.,* 2023)

Transactional, Transformational, and Laisse-faire leadership are supported by a vast number of studies (Banks *et al.,* 2018) and have been described as established leadership styles (Dinh *et al.,* 2014; Siangchokyoo *et al.,* 2020). There are a great many more leadership styles and constructs in the literature (Hussain and Hassan, 2016) however, many have not benefited from the same degree of large scale, multi sector, empirical validation (Banks *et al.,* 2018)

METHODS

As part of an ongoing study, a systematic approach was chosen for this review of literature. In line with Gough *et al.,* (2012) and Booth *et al.,* (2018) a relativist-idealist position was taken, in that the study is not seeking a single correct answer but examines, through the lens of a review of literature, the variation and complexity of research surrounding leadership in the AEC sector. A predefined framework, Figure 1., was developed to allow combining of data from different study types with the aim of delivering a coherent narrative synthesis of the data (Brunton *et al.,* 2020).

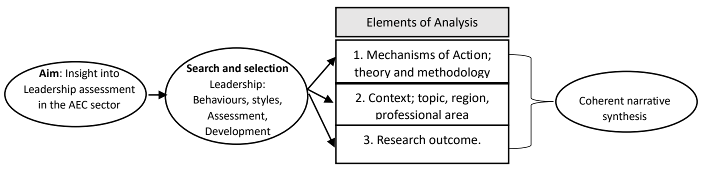

Figure 1: Review framework for search and analysis elements

The review is not comprehensive as it is limited to specific dates. Furthermore, guidelines for a systematic review indicate that a team of at least three researchers are involved in the selection of studies but, in this case, one researcher was involved in the selection (Page *et al.,* 2021). As the method was otherwise strictly followed, it can be described as systematic in approach.

Inclusion and exclusion criteria

The review is concerned with peer reviewed research published in indexed academic journals. It is limited to research focused on leadership assessment, evaluation, and development in the AEC sector. In order to deliver contemporary results, and to limit the examination to a manageable number of studies, the search was limited to a period from 2016 - 2023. Given the quantity of leadership styles mentioned in the literature, papers that examined leadership style were only included if the leadership style construct has benefited from meta-analytical, longitudinal, and multi-source validation studies.

Data Collection

Scopus and Web of Science were used as sources for the data collected. The Scopus database was chosen as it has been described as the world's largest abstract database of indexed, peer reviewed, scientific literature (Schotten *et al.,* 2017). Web of science was chosen as it has been described as having the most in depth scientific papers (Schotten *et al.,* 2017). Four separate searches using modified search parameters, including leadership style, leadership assessment, leadership development and leadership behaviours, were performed focusing on Architecture, Engineering, Construction, and AEC.

Data analysis

Taking an inductive approach, the data was examined in line with Schick-Makaroff *et al.,* (2016) using defined elements of analysis. The elements of analysis chosen to facilitate a coherent narrative synthesis were 1. Mechanisms of action (Data collection and theoretical underpinning) 2. Context (Region, topic, and professional area), and 3. Research outcome. Table 2 below summarises the search and selection as performed. Full text of 347 papers were examined resulting in 15 being deemed to meet all of the inclusion criteria.

Table 2: Summary of search and selection performed

Identification		Screening		Included
Records identified from databases (n = 3,712) less duplicates (n=1802)	Records screened by title. (n = 1802)	Abstract screening of reports (n = 737)	Full text of studies assessed for eligibility. (n = 347	Studies included in review. (n = 15)

FINDINGS

The search results delivered 15 research papers conducted in 18 countries. Table 3 presents a summary of the research papers included in this study. The dominant method of data collection was quantitative surveys, 13 were mono method studies with just two deploying mixed methods.

Table 3: Summary of studies included

Author	Topic	Region	Method
Grill *et al.,* (2019)	Safety	Sweden, Denmark	Mixed
Lingard *et al.,* (2018)	Safety	Australia	Quantitative
Löwstedt *et al.,* (2021)	Leadership attitudes	Sweden	Qualitative
Ntseke (2022)	Employee retention	South Africa	Quantitative
Olasunkanmi (2023)	Efficiency	Nigeria	Quantitative
Owusu-Manu (2021)	Leadership style	Ghana	Quantitative
Pham (2021)	Green innovation	Vietnam	Quantitative
Potter *et al.,* (2018)	Leadership style	UK and NZ	Quantitative
Shafique (2022)	Team performance	USA	Quantitative
Simmons *et al.,* (2020)	Behaviours	USA	Qualitative
Tabassi *et al.,* (2016)	Project success	Malaysia	Quantitative
Wipulanusat, (2017)	Innovation	Australia	Mixed
Wu *et al.,* (2022)	Safety	China	Quantitative
Zavari &Ashfor (2021)	Project success	Iran	Quantitative
Zhang *et al.,* (2018)	Innovation	China	Quantitative

The studies broadly fall into two categories (a) Studies examining the effects of leadership on specific challenges in the AEC sector and (b) studies that look to explore leadership in practice within the sector.

Exploring leadership styles in the AEC sector

This category of papers focused on leadership styles effectiveness in particular settings, what sets of behaviours and competencies may be useful to leaders, and what are the attitudes and understanding of leadership held by leaders in the AEC sector.

Olasunkanmi *et al.,* (2023) investigates perceived effectiveness of leadership styles in the Nigerian AEC sector and finds, through a large qualitative study involving 975 participants, that transactional leadership was considered the most effective style. Conversely, Tabassi's (2016) quantitative study on leadership sustainable building projects in Malaysia suggest that transformational leadership, combined with specific competencies, was a strong predictor of project success in sustainable construction (Tabassi *et al.,* 2016). The competencies found to be factors in successful leadership were strategic perspective, critical analysis, communication, empowerment, vision, and resource management. The differing results between the two studies highlights the possible effect cultural differences can have on leadership in practice.

Potter *et al.,* 2019 examines leaderships style in project managers in the UK and New Zealand construction sectors. Their results indicate that transformational leadership was the most prevalent style being deployed by the participants. The results diverge somewhat from Owusu-Manu *et al.,* (2021) who find democratic leadership to be the most common style of leadership being used by project managers in the Ghanaian construction sector. (Owusu-Manu *et al.,* 2021). The results are useful, in that understanding what leadership styles are being deployed in a professional context can assist in the identification, selection, and development of potentially high performing leaders in the role of project manager. Although enlightening, Potter *et al.,* (2018) and Owusu-Manu *et al.,* (2021) and Tabassi *et al.,* (2016) focused on the leader's perspective, paying little attention to the social dynamic involving team members, thereby providing a possibly less complete picture of the phenomenon.

Löwstedt *et al.,* (2021) take a different path to many researchers in the AEC sector industry in that they explore, through a qualitative study, attitudes and understanding of leadership in practice within the construction industry in Sweden. The inductive qualitative approach using in-depth interviews found that although leadership was viewed as somewhat important for the participants, it was seen as an 'add-on' to the more important skills of construction (Löwstedt *et al.,* 2021). This may have implications for leaders' willingness to partake in leadership development. This finding is important, as for leadership to be truly effective, it should be embedded across all levels of an organisation (Olasunkanmi *et al.,* 2023) and perceptions that it is an addendum indicates that it is not integrated.

Towards addressing the need for leadership development in the construction sector, Simmons, *et al.,* (2020) attempt to define what leadership competencies are required by engineering professionals. Employing the Delphi method, 24 leadership competencies were deemed important by the participants. The list of competencies is broad and perhaps vague with titles such as 'legal knowledge' and 'business skills'. Of the 24 competencies outlined, nine appear to relate to leadership behaviours (Yukl, 2012). While competencies are an important factor in leadership, omitting leadership behaviours and leadership values narrows the existing and broader established understanding of leadership that has developed over the past 100 years (Northouse, 2021; Yukl, 2012).

Leadership effects on specific challenges

As the search did not specifically look for particular challenges, these results give insight into some of the issues related to leadership that researchers find of interest. Innovation, environmental challenges, employee concerns, and site safety are the focus of these studies.

Leadership, according to Wipulanusat *et al.,* (2017), plays a fundamental role in organising and motivating teams through structures and processes to achieve a climate of innovation. Wipulanusat *et al.,* (2017) through a large-scale quantitative study involving over 3,000 engineers in Australia (both leaders and team members) found that when transformational leadership was deployed it encouraged innovation, and innovative behaviours, in employees. The results align with Zhang *et al.,* (2018) who also found that transformational leaders at an executive level develop a climate of innovation within the construction sector setting in China. Pham *et al.,* (2021) find that transformational leadership can promote both green learning and green innovation in supply chains in Vietnam. However, at the site manager level in Iran, Zavari and Afshar, (2021) in divergence with Zhang *et al.,* (2018), could not find a relationship between innovation in team members and transformational leadership.

These studies highlight that leadership is impacted by the context of role in addition to the context of cultural setting. These studies employed a positivist approach, in that they sought to confirm a relationship with a style of leadership and innovation which limits the ability to view leadership in a broader flexible way. However, Wipulanusat, *et al.,* (2017) in using a mixed method approach involving both leader and team members offers a more complete in depth insight. Furthermore, these findings indicate that incorporating transformational leadership into leadership development initiatives at the procurement, engineering, and executive level could help develop and foster a climate of innovation, which may have an impact on firms' propensity to modernise and engage with novel sustainable practices.

Shafique and Mollaoglu, (2022) find transformational leadership to be positively associated with team performance in green AEC projects. Leadership effects on team members is also examined by Ntseke *et al.,* (2022), who find through a quantitative study of engineers in South Africa that transformational leadership behaviours are associated with both employee retention and employee engagement. Although the results are in line with studies from other sectors, Ntseke *et al.,* (2022) do not take into consideration other factors effecting employee retention such as job security or salary which may be significant overriding factors in employee intentions. Failing to consider external factors of significance to participants may affect the robustness of the findings. While quantitative mono-method studies like Ntseke *et al.,* (2022) and Shafique and Mollaoglu, (2022) do provide insight, as leadership is a social interactive phenomenon, they can fail to capture a deeper understanding of the dynamic between leader and team member that qualitative methods allow. Furthermore, research relating to performance and team member retention is an important avenue which can inform leadership development requirements.

Site safety has been cited as an ongoing critical concern for the AEC sector and as such, unsurprisingly, safety has been the focus of a number of studies relating to leadership in this review. Lingard *et al.,* (2019) explore the effects of leadership style and communication on Health and Safety (H&S) practices of construction workers in Australia. The results indicate that transformational leadership is positively associated with H&S behaviours, but transactional leadership was the strongest predictor of H&S

compliance. This would indicate that a more ridged style of leadership is appropriate for improved safety. The results are largely in line with Wu *et al.,* (2022) who surveyed construction workers in China and found transactional leadership to be positively associated with safety compliance. Both of these studies collected data from team members as opposed to leaders which may be insightful as the investigations concern the participants own actions as opposed to desired actions from the leadership perspective. However, the studies only deal with one side of the leadership dynamic which, as with leader only studies, can present a less than complete picture (Parry *et al.,* 2014).

Conversely in Scandinavia, Grill *et al.,* (2019), using mixed methods involving onsite observations of interactions between leader and team member, found that transformational leadership was more positively associated with site safety measures. The study, through its design, pays attention to the interactive nature of leadership. However observational studies are challenging as the presence of a researcher can influence the behaviour of participants which in turn affects the data. While grill et al.'s study appears more comprehensive, in that it explored leadership from both leader and team member, the diverging results with Lingard *et al.,* (2019) and Wu *et al.,* (2022) may be as a result of the contingent nature of leadership highlighted by the different cultural settings. Findings like these have a practical benefit to industry in that they can help inform what specific leadership behaviours could be developed in order to enhance site safety.

DISCUSSION

Examining the research in concert does provide clear indications as to the positive effects of types of leadership on specific issues. While the work of Grill *et al.,* (2019); Lingard, *et al.,* (2019) and Wu, *et al.,* (2022) deliver valuable insights on effective leadership as it relates to site safety, it also highlights the contextual nature of leadership, in that, what is effective in China may not be effective in Scandinavia. However, because of the singular issues of these studies, their impact on developing an overall picture of leadership across the multiple arenas in the AEC sector is limited. The research exposes a further contextual challenge in the different leadership roles explored (project manager, site manager, executive), and how leadership can be different in each role. This has significant implications for leadership development initiatives as they need to be customised to the individual context (Day *et al.,* 2021; McCauley and Palus, 2021).

It is also worth noting the limited number of empirical studies (15) that met the inclusion criteria which reenforces the view that leadership research in the AEC sector is underserved. This highlights the need for explorations surrounding leadership in the Irish and broader AEC sectors. Furthermore, in line with other studies (Banks *et al.,* 2018; Parry *et al.,* 2014), this research shows a reliance on the positivist paradigm. Although informative, future research would benefit from explorations into other philosophical standpoints where broader and more flexible views are considered (Löwstedt *et al.,* 2021). However, this will create further challenges in terms of methods and resources.

A trend highlighted by Bryman *et al.,* (1988) of the near homogeneous use of solely quantitative methods which struggle to illuminate the intricacies of construction industry leadership appears to continue. This may be due to the technical nature of the sector not being conducive to examining social phenomenon (Bryman *et al.,* 1988; Löwstedt *et al.,* 2021). While the mono method quantitative approach can provide (limited) insight, diverse mixed method approaches as used by Grill *et al.,* (2019) and (Wipulanusat *et al.,* 2017) can provide greater insight (Bryman *et al.,* 1988; Northouse, 2021; Parry *et al.,* 2014). Furthermore, 11 out of 15 of the studies collected data from only leaders, or only team members, which provides a restricted view of interactive relationships (Zhang *et al.,* 2018). Mixed methods studies involving both leaders and team members have potential to provide considerably more in-depth and fuller picture of the leadership in practice (Grill *et al.,* 2019). This interconnected view of leadership should be considered when formulating a research strategy to explore the phenomenon in the Irish sector, which in turn can better inform what is needed and is appropriate for leadership development initiatives.

CONCLUSIONS

This research makes important contributions by illuminating the significant contextual and methodological challenges to exploring leadership in practice within the AEC sector. This study finds a reluctance on the part of AEC researchers to engage with the social interactive nature of leadership involving both leader and team follower. By doing so, researchers are examining a less than holistic view of leadership which will ultimately under inform the leadership development that is called for.

Particular leadership styles have been found to be effective in particular contexts, however, that context is of critical importance. Insights into effective AEC leadership vary in different jurisdictions and in different roles. So, in effect, there is no single answer to "what is leadership in the AEC sector", but a collection of leaderships, each of which must be investigated in order to build a picture of a what effective leadership looks like within the sector.

For leadership development initiatives in the Irish AEC sector to be significant, they must be based on empirical evidence derived from an Irish context. In order to make meaningful advances in this area, future studies should consider multi-level, leader and team investigations using diverse methods to build up a picture of effective leadership in the Irish AEC sector. It is only with this knowledge that we can scientifically inform the leadership development that is required to support the sector in meeting its future societal demands.

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POTENTIAL BENEFITS OF CLOSE PROXIMITY OF TAXI RANKS TO RETAIL DEVELOPMENTS

Josephine Llale[1] and Onkabetse Chaane-Moiloa[2]

[1] *School of Construction Economics, University of the Witwatersrand, Braamfontein, Johannesburg, Gauteng, 2000, South Africa*

[2] *Department of Construction Economics, University of Pretoria, Lynnwood Road, Hatfield, Pretoria, 0001, South Africa*

Taxi ranks within retail developments (RD) in South Africa are usually situated far from RD. Owners of RD regard taxi ranks as a nuisance. This is because the noise and traffic congestions associated with taxi ranks. The aim of this paper to investigate the potential benefits of bringing taxi ranks in closer proximity to RD. Interviews with built-environment consultants were conducted and a thematic data analysis was conducted to analyse the data. The findings reveal that the benefit of bringing taxi ranks closer to RD include increased in-store footprints in RD, potential increased employment, and social responsibility for the local community. There are, however, hindrances that prevent the development of taxi-ranks closer to RD. They include municipal by-laws and lack of users' involvement in the planning phase of RD. Integration of sustainability and regenerative design principles have the potential to eliminate some of the nuisances from by taxi ranks. Unless taxi ranks are brought closer to RD, businesses within those developments will continue to lose out on the benefits that closer proximity of taxi ranks to RD could bring to businesses within those developments.

Keywords: benefits, hindrances, infrastructure, retail developments, taxi ranks

INTRODUCTION

Minibus taxis are one of the most common modes of transport in South Africa. The mini-bus taxi transportation system is a system where 10-20 passengers traveling in the same general proximity travel together in a mini-bus for (Mckay *et al.,* 2017). Most Black people use minibus taxis to travel to their areas of work (Simpson *et al.,* 2014).

In South African, the built environment is still defined by the spatial developments of the apartheid era, where communities were separated according to race (Hindson, 1996; Moffat *et al.,* 2021). The migration of Blacks to urban areas was controlled through legislation (Hindson, 1996). Blacks were allocated townships on the periphery of cities (Hindson, 1996). These underdeveloped urban areas were located far away from the city's central business district (CBD) and suburban areas, where Whites lived. With insufficient public transportation in South Africa, minibus taxis soon became one of the most used forms of transportation for Blacks in townships (Schalkwyk, 2008).

[1] josephine.llale@wits.ac.za

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According to a study by Stats SA (2021), 80.2% of the South African population depend on minibus taxis to travel from work to home. This is why mini-bus taxi ranks in RD need to be carefully planned for as most people depend on taxis as a mode of transport. Currently, taxi ranks are not sufficiently integrated within the RD.

This paper aims to answer the question what are potential benefits of bringing taxi ranks in closer proximity to RD? A narrative literature study and interviews with built-environment consultants were conducted to answer this question. Thematic data analysis was conducted to analyze the data. This paper is divided into a literature review, methodology, findings, and conclusion.

LITERATURE REVIEW

This literature review is not a state-of-the-art review but rather a short overview of the current challenges of taxi rank's location in relation to RD and potential benefits of their closer proximity to RD. Google Scholar and the University of Pretoria's library were the main search engines used to source relevant articles. Main keywords used in the search included sustainability, transport infrastructure, public transport, public transport policies, retail developments and green buildings. Only articles relevant to the study were included in this paper.

Literature points out to several challenges facing the current location of taxi ranks in RD. Congestion is one of the challenges. Congestion is defined as the intense overload of the road network capacity due to regular or irregular service quality reductions that are further intensified by travel times or a variation thereof (Chakwizira, 2007). Figures 1 shows a typical taxi rank in Sandton, Johannesburg Gauteng, South Africa.

Gauteng Province is regarded as the economic hub of South Africa. Stats SA (2018a), reports that the province contributes a third to the country's gross domestic product (GDP). With an area of 18,176 km2, Gauteng is the smallest province in South Africa (Stats SA, 2020). With a 14. 7 million population, the Gauteng is also the province with the biggest population (Stats SA, 2018b). Gauteng's population relative to its size is arguably one of the reasons for traffic congestion. This traffic congestion can be a nuisance around RDs. This is because taxi ranks are often not included in the design of the RD.

Most shopping centres do not make adequate provision for minibus taxis (Pillay, 2001) This inadequacy often results in informal taxi ranks mushrooming outside of RD, thereby causing congestion in adjacent roads, and blocking pedestrian walkways. There is also inadequate provision of waste bins and ablution facilities which results in unhygienic conditions (Mathikhi and Ramukumba, 2020; Schenck *et al.,* 2022).

Congestion is closely linked with greenhouse gas emissions (GHG). The transport sector in South Africa is responsible for 10.8% of greenhouse gas emissions (GHG) in the country (DoT, 2019). 91.2% of GHG emissions are from road transportation (DoT, 2019). Taxis being the most widely used form of transportation in South Africa are arguably one of the main contributors to these emissions. There is, however, no evidence in literature to support that this is the reason taxis in RD are not situated near RD.

Coupled with GHG emissions is the noise pollution emanating from high traffic volume (Moroe and Mabaso, 2022) and the taxi drivers' behaviour (Sinclair and Imaniranzi, 2015). Taxis are an informal business in South Africa (Moroe and Mabaso, 2022). Although taxi routes are allocated to taxi drivers, there are no formal timetables for taxi rides. As a result, taxis often hoot to get the attention of possible commuters even though this hooting is sometimes regarded as unnecessary (Sinclair and Imaniranzi, 2015). This noise pollution is possibly one of the reasons why RD developers exclude taxis in the RD plans.

Despite these challenges, this paper argues that there are several benefits that can be derived from taxi ranks closer proximity to RD. For instance, by implementing some principles of sustainability and regenerative design within the life cycle of RD, some of these challenges may be addressed.

Figure 1: An informal taxi rank in Sandton, Johannesburg (Not Dated)

Sustainability in construction is defined as "…the ways in which built assets are procured and erected, used and operated, maintained, and repaired, modernised, and rehabilitated and reused or demolished and recycled constitutes the complete life cycle of sustainable construction activities' (Cartlidge, 2009: 29). Most people perceive sustainability as environmentalism, but sustainability includes also social equity and economic development (University of Alberta, 2013).

Understanding the needs of taxis and taxi commuters will ensure that RD are planned, designed, and constructed with the needs of the stakeholders in mind. For instance, RD developers should provide proper well maintained ablution facilities for taxi ranks. Enough waste bins that are services regularly should also be provided (Schenck *et al.,* 2022). Some of the waste from these taxi ranks may be recycled thereby providing some economic benefit and contributing positively towards the sustainability agenda (Schenck *et al.,* 2022)

Roads within the taxi ranks could be planned, designed, and constructed in such way that there is a proper flow of traffic. This will ensure that congestion within RD premises is minimized. Developers and relevant taxi stakeholders can also make rules that prohibits noise pollution such as hooting to get potential taxi commuters within proximity of RD. All stakeholders will benefit from the reduced traffic congestion and noise pollution. It is thus possible to bring taxi ranks within closer proximity to RD.

Another strategy that may be implemented and that might have potential benefits for RD is regenerative design. The aim of regenerative design is to "regenerate and/or restore the environment by improving the mutual relationships of the building, nature and human development processes within the context of place" (Mang and Reed, 2012b; Girardet, 2017; Trombetta, 2018; Axinte *et al.,* 2019 in Mbadugha *et al.,* 2019). RD and taxi rank's broken relationship can, thus, be potentially mended by applying some of the regenerative strategies.

The literature lists several regenerative strategies that may be implemented in a project lifecycle (Mbadugha *et al.,* 2019). In this paper only three strategies are discussed. Firstly, stakeholder and community participation and integration (Zari, 2010; Haggard, 2002; Litman, 2009; Gabel, 2009; Orr, 2018; Mang and Reed 2012a). In most infrastructure projects community engagement is missing, or it is superficial thus resulting in developments don't fully integrate the needs of the community into project.

In the South African taxi industry this lack of integration has resulted in the mushrooming of a number of informal taxi ranks next to RD. This lack of integration has made taxi ranks to be a nuisance in RD because there are no adequate amenities in RD to cater for their needs. Taxis and commuters, thus, find other means to cater for their own needs. These means may be unhygienic and detrimental to the environment. By engaging with all stakeholders and commuters, this oversight can be avoided in future RD.

The second strategy is conservation, restoration, and recycling (Thayer,1994; Zari, 2010). Regenerative design's main premise on biophilia. Biophilia refers to humans' innate love of nature (Planteria Group, Not Dated). RD developers can capitalize on this by incorporating the principles of conservation, restoration, and recycling in developing taxi ranks within their RD. In addition to providing waste bins and ablution blocks, by planting and maintaining plants that reflects the cultural identity of the community (Thayer, 1994; Zari, 2010; Litman ,2009; Hes *et al.,* 2017) may enhance the relationship between taxi ranks and RD.

Thirdly, the third regenerative strategy is awareness, education, and transparency (Gabel, 2009; Hes *et al.,* 2017; Lyle, 1994). Sustainability in Africa is yet to gain as much traction as in other developed countries. Taxis can potentially assist in driving the sustainability agenda in Africa. Given the high number of commuters that use taxis, by partnering with taxis through awareness, education and transparency, the sustainability agenda in Africa might gain the needed traction.

This literature review identified potential benefits that the incorporation of principles and strategies of sustainability and regenerative design can bring in RD. To answer the main question of this paper, that is, what are the potential benefits of bringing taxi ranks in closer proximity to RD, interviews with built-environments consultants were conducted. The next section discusses the research methods for this paper.

METHOD

Semi-structured interviews with five built-environment consultants were conducted to determine their perceptions on the potential benefits of the proximity of taxi-ranks to RD. By using semi-structured interviews, a predetermined questions can be explored fully through further probing (Saunders *et al.,* 2016). This in unlike in a structured interview where a phenomenon can only be explored according to the limits set by the interview schedule (Blumberg *et al.,* 2008) or an unstructured interview where a researcher may ask any question that may arise during the interview as there are no predetermined questions (Kumar, 2014). A semi-structured interview has both the rigidity of the structured interview and the flexibility of the unstructured interview; hence they were chosen (Saunders *et al.,* 2016).

Participants in this study were selected through purposive sampling. Purposive sampling allows participants to be selected strategically (Bryman and Bell, 2014). Thus, in this paper, participants were chosen based on their previous participation in RD or similar developments. Given the time-consuming nature of interviews, this led to sample bias where only a few potential participants participated (Saunders *et al.,* 2016). Only five participants participated in this paper. Another constraint was that this study is part of a Masters' degree research with tight time limitations hence the number of participants was deemed sufficient for the purpose of this study.

Participant 1 (P1) is an urban planner with about 40 years' experience. Participants 3 (P3) is a quantity surveyor and participants 2 (P2) is an architect both with over 10 years' experience. Participant 4 (P4) is an electrical engineer with 14 years' experience in private practice. Participant 5 (P5) is a sustainability consultant in RD with 11 years' experience.

Upon receiving ethical clearance, all potential participants were contacted through email or telephone. Only participants residing in Gauteng Province of South Africa were contacted. Gauteng Province is used as a case study for other provinces in South Africa. Participants who could not participate in face-to-face interviews were sent the interview guide through email. Their responses were also through email and were recorded and included in the findings' discussion. Face to face discussions were recorded and transcribed.

Thematic data analysis was used to analyse the data. Using thematic data analysis "…factors underpinning human attitudes and actions" (Saunders *et al.,* 2016:579). In this paper, the actions and thoughts guiding consultants working on RD was important to determine as this could be the reasons for the current dysfunctional relationship between taxis and RD. The next section discusses the findings of the semi-structured interviews.

FINDINGS

This section provides a summary of the findings from interviews semi-structured interviews with built-environment consultants. To answer the main question that this paper seeks to answer, "what are the potential benefits of bringing taxi ranks in closer proximity to RD?" it was important determine the consultants' perceptions about the influence of sustainability on transport infrastructure. Transport infrastructure in this paper refers to taxi ranks. Secondly, it was important to also determine what are the current practices of consultants in relation to transport infrastructure in RD. Lastly, participants were asked to identify potential benefits that sustainable transport infrastructure might bring to RD. The discussion in this section is thus divided into these three themes.

The Influence of Sustainability on Transport Infrastructure

All participants agreed that sustainability could have an influence on transport infrastructure hence there is a need to incorporate sustainability and regenerative design in RD. According to P5 "…regenerative thinking needs to be implemented in transport infrastructure." If there is a consensus of the influence of sustainability on transport infrastructure, then why is it not currently implemented in RD? The answer seems to stem from a misguided perception that incorporating sustainability design principles in RD is expensive (Coetzer and Brent, 2015). This misguided view was echoed by P3, "…substantial capital cost may be required to setup the infrastructure.…"

The perception that sustainability or green buildings are expensive does not seem to be held by the younger BE consultants. According to P2, "younger professionals seem to be incorporating sustainability in retail designs." This means that there is hope for wider application of sustainability in RD in future. Currently, however, there are various ways that capital cost in sustainable RD can be reduced. P3 recommends the use of local community sub-contractors in non-specialised works. This strategy will not only reduce costs, but it will also provide economic benefits to the community.

Current Practices in RD in Relation to Sustainable Transport Infrastructure

Current practices of RD do not adequately make provision for sustainable transport infrastructure. "Retail developers should stop designing from a place of privilege and provide public transport infrastructure… The public transport operators are forced to park on the sideways therefore it should be the responsibility of the retail" (P4). This inadequate lack of provision for taxi is baffling given that most South African use taxis as their means of transportation (Simpson *et al.,* 2014). This fact was echoed by P1 and P4. "Many people who visit malls arrive by public transport." (P1). P4 stated that "majority of South Africans who support RD use public transport therefore public transport infrastructure needs to be incorporated in retail developments."

There are many strategies that RD can implement to integrate taxi ranks within their developments. One the strategies that was emphasized by participants was the need to include taxi operators in the planning phases of RD (Zari, 2010; Haggard, 2002; Litman, 2009; Gabel, 2009; Orr, 2018; Mang and Reed 2012a). P3 concurred by saying" business partnering of retail developers and taxi association so that they can both be involved in the planning phases to avoid future problems such as congestion, noise etc".

Inadequate involvement of taxi stakeholders in the initial phases of the project might lead to the creation of White elephants. P3 provided an example of such an instance, "an example would be at the X Mall when the developer in conjunction with the municipality developed a taxi rank without proper consultation with the taxi association and for a long time the infrastructure was just a white elephant."

There were other strategies that participants said could possibly remedy the current practices such as to "… lessen the amount of parking bays for individual cars" (P2). P4 suggested the use of basement parking for taxis, "…mall basements are completely underutilised and should be compartmentalised to taxi/bus stations."

Another strategy was changing municipal by-laws that will include public transport infrastructure in RD (P4). The "Greening" of RD is another strategy supported by P1 and P4 (University of Alberta, 2013). "The Green Building Council of South Africa (GBCSA) should include a continuous inspection of sustainability practices of RDs as points are awarded to the transport category" (P4).

By incorporating sustainability and regenerative design strategies P4 perceives that there will be a proper RD that "… will ensure that a mixed class of people have access to the development and thus offering services from the low to high income earners" (P4). Participants envisage that by implementing these strategies some of the supposed nuisance brought about by taxis would be lessened and perhaps change perceptions about taxis.

Potential Benefits That Sustainable Transport Infrastructure Might Create for Gauteng RD

Participants listed several potential benefits that RD could derive from taxi rank closer proximity to RD. Some of the benefits include, "…increase footprints to the retail centres" (P2), "employment and business opportunities for local community," (P3), "an opportunity for retail developments as it increases the development's social responsibility" (P4) and" attract more customers / shoppers due to an attractive development that is easily accessible whether by public or private transport means" (P3).

P5 said that a Green Star certification by the Green Building Council of South Africa (GBCSA) might increase the profitability of RD as more people will visit the RD because of its accessibility and location efficiency. According to P5 if the specific areas within RD dedicated to public transport, it would be beneficial to commuters as this will be convenient than being dropped off far from the RD. In one RD mentioned by P5 the developers intentionally did not provide for more parking bays to encourage the use of public transport. The RD made provision for electric parking bays where in future, charging stations could be provided.

From the number of potential benefits mentioned by participants it is evident that closer proximity of taxi ranks to RD can be a viable option. By involving taxi stakeholders in the RD and incorporating several strategies such sustainability and regenerative design, it is possible to minimise some of the nuisance caused by taxi ranks in RDs.

CONCLUSION.

The aim of this paper was to investigate the potential benefits of bringing taxi ranks closer to RD. Findings from literature and interviews indicate that there are several potential benefits that can be derived from bringing taxi ranks closer to RD. Potential benefits to developers include increased footprint, increased employment and business opportunities, opportunity for increased social responsibility and profitability. For communities, potential benefits include convenience, increased opportunity for employment and business.

To derive these potential benefits, however, the perceived nuisance caused by taxi ranks such as congestion and noise pollution will need to be addressed through the implementation of many strategies such as changing municipal by-laws, involvement of stakeholders in the taxi industry and the incorporation of sustainable and regenerative design strategies in RD. Gauteng Province was used as a case study for other RD in South Africa. In this paper, only BE consultants were interviewed, the study recommends a similar study to be conducted where all stakeholders will participate in the study to gain a different perspective on this issue.

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ACCEPTANCE AND ADOPTION OF CONSTRUCTION 4.0 RELATED TECHNOLOGY: A REVIEW

C S R Perera[1], Valerie Francis and Gao Shang

Melbourne School of Design, University of Melbourne, Masson Road, Parkville VIC 3010, Australia

Construction 4.0 has attracted much attention but faces numerous implementation challenges. Despite extensive existing literature on the constraints, only a few consider the social aspects. To systematically assess technology acceptance and adoption of Construction 4.0-related technology (Cons 4.0-tech), this research investigated 150 published journal articles (in English) within the Scopus database to determine current research gaps and areas for future work. The analysis revealed a positive trend in this area, with three fundamental research gaps: (1) Previous technology acceptance and adoption research has paid little attention to organisational dynamics and relationships. (2) 64% of previous studies adopted a survey approach focusing on statistical relationships, while only a few examined their underlying causes and motivations. (3) Building information modelling (BIM) was the focus of much of the previous research, despite Construction 4.0 concentrating more broadly on technologies and their integration. As part of a PhD, this research established a research gap with a need to provide a comprehensive framework for technology acceptance and adoption of Cons 4.0-tech within an organisational context.

Keywords: construction 4.0; systematic review; technology adoption

INTRODUCTION

Construction 4.0 has emerged as a concept that enables digitisation, automation and integration of the process (Oesterreich and Teuteberg 2016). It predominantly focuses on creating a digital construction site assisted by technologies at each stage of the construction project. As stated by IBM's CEO Inni Rometty, it is a step towards the 'cognitive era' with technology that can understand and enhance responsiveness over time (Loosemore 2015). Many studies emphasise the benefits of Construction 4.0 and its use in the industry. These benefits are plentiful and encompass many technologies. For instance, simulation and modelling technologies have been demonstrated to significantly improve the early design of a construction project (Oesterreich and Teuteberg 2016). The technologies have also been shown to facilitate a risk-free virtual environment and real-time communication improving collaboration among parties (Wang *et al.,* 2013). Cloud-based platforms enable all participants to access information providing a 'single source of truth', thus enhancing decision-making and onsite and off-site communication.

With improved transparency and accountability, these technologies exhibit cost and time savings (Schwab 2017). For example, while labour costs can be reduced with

[1] savindi.perera@student.unimelb.edu.au

Perera, C S R, Francis, V and Shang, G (2023) Acceptance and Adoption of Construction 4.0 Related Technology: A Review *In:* Tutesigensi, A and Neilson, C J (Eds) *Proceedings of the 39th Annual ARCOM Conference,* 4-6 September 2023, University of Leeds, Leeds, UK, Association of Researchers in Construction Management, 426-435.

robotics and automation (Kovacs 2018), significant time and cost reductions can be achieved through 3D digital models (Bonfanti *et al.,* 2018). Tracking devices or sensors offer solutions for inventory management, theft minimisation, safety improvements, and access control can be facilitated (Sardroud 2012). Accordingly, these technological advancements enhance quality and safety while making the work easier and more efficient (Fernández and Pérez 2015). In this context, Greenwood *et al.,* (2002) predicted that this pioneering technology had a promising ability to improve the Construction Industry (CI), with Chen *et al.,* (2022) demonstrating the efficacy of these technologies in the following 20 years.

Despite such benefits, Construction 4.0 is coupled with many challenges. Research claims even if Construction 4.0 has gained media attention, research efforts and best practices are not pervasive (reference). Studies reveal that the challenges, barriers, and risks associated with restructuring organisations are still less investigated (Oesterreich and Teuteberg 2016, Forcael *et al.,* 2020). While research has recognised these challenges to be political, economic, social, technological, environmental, and legal (PESTEL), it is claimed that most studies on Construction 4.0 tend to focus on technical aspects and technologies (Sherratt *et al.,* 2020).

'People' are at the centre of change as the technological shift since they experience a complex change in their daily routines and are required to adapt to a dynamic working environment (El Hamdi *et al.,* 2019). Despite the substantial implications for its implementation, how Construction 4.0 affects work systems or what work people do is a problem that has received relatively little attention in discussions (Davies *et al.,* 2017). Technology acceptance is prominent among the social challenges (Oesterreich and Teuteberg 2016, Müller *et al.,* 2018). Research demonstrates that new technology failures in adoption in the market are very high, ranging between 40% and 60% (Gourville 2005). Since the success rate of technology is directly associated with user acceptance, it is of utmost importance to consider technological acceptance and adoption within a socio-technical context (Sepasgozar *et al.,* 2018). Therefore, this research aims to systematically analyse previous studies to provide a comprehensive overview of the current research on technology acceptance and adoption of Construction 4.0 to provide recommendations for further research.

METHOD

The systematic literature review (SLR) was conducted according to 'Preferred reporting items for systematic reviews and meta-analyses (PRISMA)' guidelines, including publications until 2022. PRISMA method allows the researchers to (1) identify large databases with scientific and academic literature through keyword and search strategies, (2) screen inclusion and exclusion criteria, and (3) conduct an eligibility process in appraising the relevant literature to analyse the data from the studies (Shahruddin and Zairul 2020). Figure 1 demonstrates the main steps adopted in this research.

For the SLR, using more than one database is recommended to improve the coverage of the included studies (Wuni *et al.,* 2019). Nevertheless, many have been conducted only on the Scopus database since it is recognised as the most extensive database for peer-reviewed abstract studies (Oliveira *et al.,* 2018, Wuni *et al.,* 2019, Wuni and Shen 2020).

Thus, only the Scopus database was used in this research because it is found to have a broader range, accuracy and ease of retrieving articles compared to similar literature databases such as Web of Science and Google Scholar (Wuni *et al.,* 2019, Wuni and Shen 2020). The subsequent sections present the scientometric analysis of the included studies and is supported by the content analysed findings.

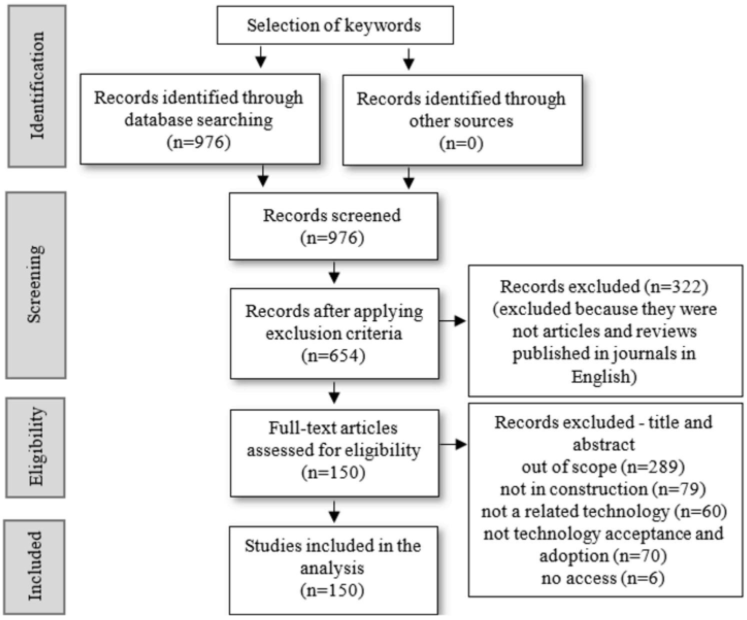

Figure 1: Research process for the systematic literature review (SLR)

FINDINGS

Analysis of the Publications by Year

The journal articles on technology acceptance and adoption in the CI range from 1995, as illustrated in Figure 2. Fewer articles were published before 2010, especially before 2000. As seen in Figure 2, although there is a slight spike in technology acceptance and adoption publications in the CI, a robust upward trend can be seen from 2013.

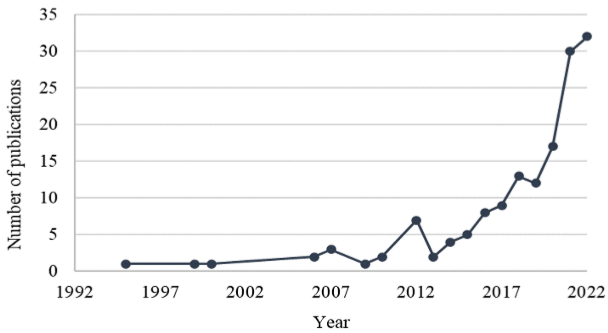

Figure 2: Number of journal articles published over time

It is worth noting that until 2000, studies focused on adopting new information technology (IT), and attention to smart construction technologies was given thereafter. For instance, close to 2014, the keywords were around ‘information technology’, ‘information systems’ and ‘computer-aided design’. Between 2014 to 2018, research was focused on ‘information management systems’ and ‘construction management’, while ‘building information modelling’ was the most prominent area of research around 2018. However, towards 2020, ‘innovative technology’, ‘emerging technology’, ‘construction automation’, ‘construction technology’, ‘digital technology', and 'digital construction' has gained attention. Therefore, it is expected that more research will be published on technology acceptance and adoption, indicating the research area as a prominent research domain in the field of construction, engineering, and management.

Analysis of the Publications by the Nature of Participants

The SRL indicate that the studies were from many perspectives, as shown in Figure 3.

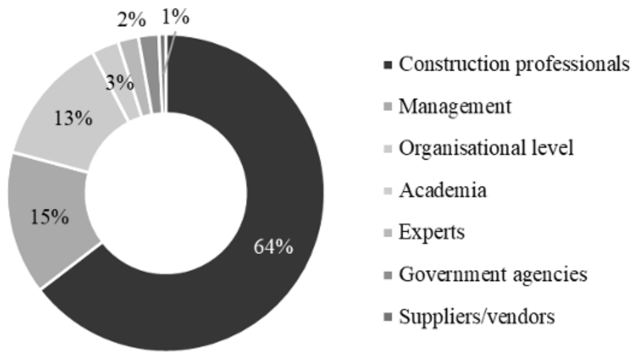

Figure 3: Analysis based on the nature of the participants

This demonstrates that most technology acceptance and adoption studies were conducted from the construction professionals' perspective. For instance, factors influencing technology acceptance (Zhao *et al.,* 2022), the relationship between job satisfaction and technology adoption (Singh and Holmström 2015), user perceptions of technology impact (Vigneshwar *et al.,* 2022), awareness (Govender *et al.,* 2018), user resistance (Ishak and Newton 2018), challenges and barriers (Al-Hammadi and Tian 2020), change management practices for technology adoption (Jaaron *et al.,* 2022) were some areas addressed from the construction professional's perspectives.

Twenty-one studies focus explicitly on the management's perspective. For example, Okoro *et al.,* (2022) evaluated the management's perspective in accepting immersive technology. Wang *et al.,* (2020a) surveyed top managers of SMEs in China to understand the behavioural logic of technology adoption. Similarly, Jaafar *et al.,* (2007) assessed the readiness of construction firm managers for technology adoption, while Mitropoulos and Tatum (1999) conducted a case study to examine how managers make technology adoption decisions. Accordingly, many researchers considered the predictors and the drivers of technology adoption from the management's perspective (Zakaria *et al.,* 2017, Nnaji *et al.,* 2019).

The SLR revealed that 13% of the studies focused on technology acceptance and adoption from the organisational perspective. Among these, Lin and Xu (2022) investigated the context of a design firm. While Adeniyi *et al.,* (2022) focused on contracting and consulting firms as a unit, Aghimien *et al.,* (2022) distinguished the organisational intention between main contractors and sub-contractors. Collecting data from top UK construction firms in the public sector, Fernandes *et al.,* (2006) observed that VR technology adoption is influenced by organisational, environmental and project factors. Although the study included user perspectives under organisational and project dimensions, the authors offer little explanation for the contribution of each dimension.

Enegbuma *et al.,* (2014) considered the organisation a collection of people, processes and technology and proposed to examine their relationship with strategic IT in construction and collaborative processes for BIM adoption. Similarly, Mom *et al.,*

(2014) assessed influencing factors under organisation, applications, tools, project teams, processes, and business models. These studies collected survey data from various participants, including owners, managers, and users, but have not focussed on distinguishing each party's influence. Although Lee *et al.,* (2015) evaluated the influence on individual and organisational intentions, only a few constructs were considered derived from established technology acceptance models. In addition, the study had limited explanations of the relationship between the constructs and did not explain the distinction between the roles of management and individual users.

On the other hand, in their research, Rankin and Luther (2006) examined an individual firm as a case study and focused on a single innovation to develop an innovation analysis framework. The framework incorporated macro and micro perspectives and considered the innovation process, including its production (research, development, and deployment) and incorporation (adoption, implementation, and acceptance) within a firm. Nevertheless, a single case study limits the findings, and thus, it would have been more interesting if a wider range of firms were evaluated. Consequently, the SLR substantiates a research gap since research on technology acceptance and adoption within an organisation has provided little knowledge of the dynamics of management decisions and user acceptance. Thus, evaluating the complex relationship between management and users is critical since, given the nature of Construction 4.0-related technology (Cons 4.0-tech), it is highly likely that the management will take the adoption decisions, which will then be followed at the individual level.

Research Gap 1: Research on technology acceptance and adoption has provided little knowledge of the dynamics within an organisation where management makes adoption decisions for users to follow.

Analysis of the Publications by the Research Process

Figure 4 provides an overview of research methods adopted in the studies identified in the literature focusing on technology acceptance and adoption in the CI.

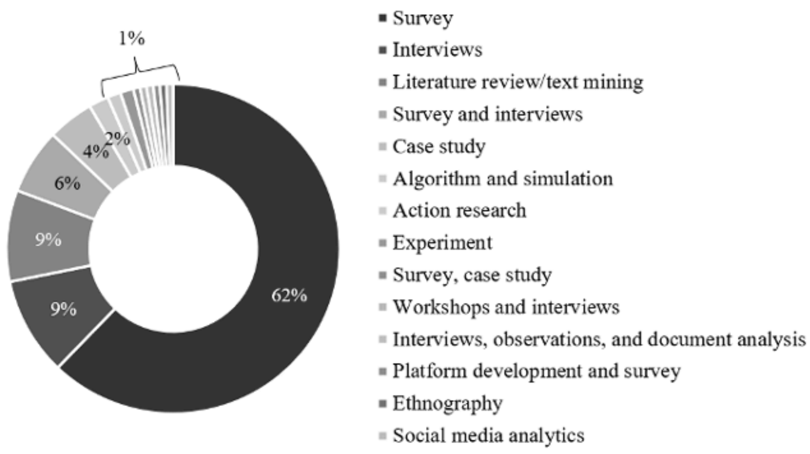

Figure 4: Analysis based on the research methodology

The questionnaire survey was the most widely held instrument for data collection, with a share of 62%. Among these, for most studies, data was collected to quantify the theories developed through the literature review (Al-Hammadi and Tian 2020, Wang *et al.,* 2020a, Ao *et al.,* 2022). Comparatively, the figure shows that just 9% of the studies employed interviews to collect data, while 6% combined interviews with surveys (Lee *et al.,* 2015, Singh and Holmström 2015).

As demonstrated in Figure 4, only 9% of the studies conducted literature reviews on areas such as smart building technology adoption (Ghansah *et al.,* 2021), big data adoption (Ram *et al.,* 2019), BIM adoption (Enegbuma *et al.,* 2014), and information and equipment technology adoption (Sepasgozar *et al.,* 2016)

Figure 4 demonstrates that current studies predominantly used quantitative methods such as surveys to statistically identify the relationships amongst variables. However, such studies do not provide an in-depth understanding of the underlying causes and motivations contributing to technology acceptance and adoption (Man *et al.,* 2017).

This is because people's interpretation of a piece of the world is determined by their opinions, attitudes, experiences, processes, or behaviours that can only be induced through qualitative studies (Rowley 2012). Therefore, the findings support the need to utilise more qualitative primary data to assess technology acceptance and adoption in the CI.

Research Gap 2: Qualitative primary data is required to provide an in-depth understanding of the underlying causes and motivations contributing to technology acceptance and adoption.

Analysis of the Publications by Technology

Figure 5 shows the findings in terms of the technology studied, both cumulative (right) and over the years (due to space restrictions, only from 2017 is shown on the left of the figure). Since 2017, at least one research in this area was found. Research on the acceptance and the adoption of BIM dominates and constitutes 37% of all studies, followed by IT/ ICT with 11%. The studies focusing on IT/ICT range from 1995 to date. Although the technology-focused is not explicitly stated, it is insinuated that the focus has changed to advanced technology with time, as described.

2022	2021	2020	2019	2018	2017		
14	7	6	9	6	4	**46**	Building information modelling
	3	2			2	7	IT/ICT
5	4	6	1	1		**17**	Emerging information technology
6	6	1				**13**	Immersive technology
2	1			2	1	**6**	Cloud computing
2	1		1	2		**6**	Off-site construction
2	3				1	**6**	Sensor
	2		1	1		**4**	Smart equipment technology
		1	1		1	**3**	Mobile computing/technology
	2	1	1			**4**	Big data
2	2					**4**	Artificial intelligence (AI)
1	1	1				**3**	Internet of Things (IoT)
	2					**2**	3D printing
	2					**2**	Robot
	2					**2**	Radio frequency identification
1						**1**	Blockchain
					1	**1**	Industrialised building systems
1						**1**	Drones
	1					**1**	Digital twin

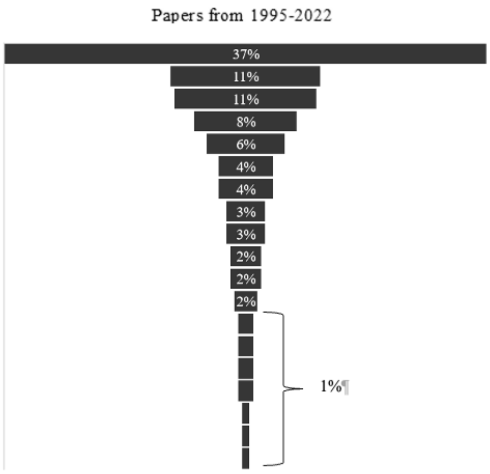

Figure 5: Analysis based on the technology

The number of publications on emerging information technology and cloud computing was significant at 11%. It is worth pointing out that the studies on emerging technology have investigated more than one smart construction technology. For instance, in their research, Nnaji and Karakhan (2020) assessed technologies for construction safety, including mixed reality, virtual reality, and wearable safety devices. Igwe *et al.,* (2022) focused on technologies such as mobile computing, virtual reality, BIM, IoT, drones, robots, and AI when the acceptance of contemporary technologies for cost management was studied.

Despite their focus on many technologies, it was interesting to note that these studies have provided little attention to differentiate between influential factors of different types of technology. Hence, very little is currently known to develop a comprehensive technology acceptance framework for adopting Cons 4.0-tech, considering differences in the influential factors.

Moreover, Figure 5 indicates that despite the uptake of technologies such as big data, artificial intelligence, IoT, 3D printing, robots, blockchain, and digital twins have received much less attention when technology acceptance and adoption are considered. Consequently, it was established that a research gap exists in providing a technology acceptance and adoption framework for Cons 4.0-tech within an organisational context, presenting an in-depth understanding of the underlying causes and motivations.

Research Gap 3: Previous research has not focused on developing a comprehensive technology acceptance framework for adopting Cons 4.0-tech, considering differences in the influential factors.

CONCLUSIONS

The implications of Construction 4.0 involve integrating different platforms of technology and assembly of data using advanced applications. Despite much research on Construction 4.0, most tend to focus on the technical aspects and social factors are often overlooked. Given that technology adoption's success highly depends on the acceptance of the technology, this research aimed to systematically analyse previous studies to provide a comprehensive overview of the current research on technology acceptance and adoption of Construction 4.0. This study observed technology acceptance and adoption to have gained significant attention in recent years. The paper then presents three research gaps in prior research and therefore provides recommendations for future research.

Firstly, while most publications focused on the user's perspective, this research established that the studies on organisations had understudied the dynamics of management decisions and user acceptance, especially given the Cons 4.0-tech's nature. Secondly, only a few studies provide insights into people's interpretations. Thirdly, the analysis found no attempts to differentiate between influential factors of different types of technology. Therefore, the study recognised several questions remained to be answered and provided an understanding of potential future research areas. The findings of this study form an integral part of a PhD research, which aims to bridge the research gaps identified.

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TWO PATHS COLLIDING AT ONE ROAD: INTEGRATING SPLIT MUNICIPAL CLIMATE ACTION AGENDAS

Rob Danie Raijmakers[1], Sean Vrielink[2], Remko Cremers[3] and André Dorée[4]

[1,2&4] Department for Construction Management and Engineering, University of Twente, Drienerlolaan 5, PO Box 217, Enschede 7500 AE, the Netherlands

[3] Municipality of Hengelo, Burgemeester van der Dussenplein 1, PO Box 18, Hengelo 7550 AA, the Netherlands

Local governments are key players in the implementation of local climate action agendas. However, elements of these agendas such as the energy transition (ET) and climate adaptation (CA) are deployed along separate and potentially suboptimal trajectories. Yet, it is unclear what local governments need to do to integrate these trajectories. Therefore, this paper aims to understand; from an interpretivist perspective; how municipalities can integrate the et and CA trajectories. The population of interest in this study is neighbourhoods where Dutch municipalities integrate elements of the et and CA. Following that; 19 interviews with civil servants from a variety of backgrounds were conducted across three cases. The data was then coded into facilitating and hindering factors; as well as methods for coupling different issues. This study complements existing knowledge by showing that increased coordination between policy; design and asset management phases is also necessary for the integration of the et and CA. Additionally, this paper proposes two interventions to exemplify how municipalities can improve the coordination between implementation phases; proving that increasing coordination between implementation phases helps local governments in implementing their climate action agendas.

Keywords: policy integration; local government; sustainability; design management

INTRODUCTION

As the consequences of climate change become more visible; the urgency to combat them increases. Climate change must be combated in two ways: by reducing greenhouse gas emissions and by adapting to the consequences of climate change that have already unfolded. The first strategy is called climate mitigation and includes trajectories such as the energy transition (ET) to end dependence on fossil fuels. The second strategy is called climate adaptation (CA) and includes measures to combat problems such as floods; droughts; and heat stress.

Since climate change is a global problem; every country should address it. In this context, the Dutch government signed the Paris Agreement in 2016 and translated its goals into two strategies: the Delta Programme for Spatial Adaptation (DPRA) (Deltacommissaris 2017) and the Climate Agreement ("Klimaatakkoord") (Ministry of

[1] r.d.raijmakers@gmail.com

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Economic Affairs and Climate Policy 2019). The DPRA is the CA strategy that aims to become climate resilient by 2050. The Climate Agreement is the climate mitigation strategy that aims to reduce greenhouse gas emissions by 95% from 1990 levels by 2050. Although different ministries oversee the implementation of these two strategies; Dutch municipalities are seen as the main acting agents for both et and CA efforts in the built environment. Ideally, this role provides municipalities the opportunity to deploy both agendas simultaneously; saving time; costs; space; and building nuisance. Although this is a commonly stated policy; in practise the two measures are mainly implemented separately. Figure 1 illustrates how the Dutch government implement the et and CA trajectories separately despite the proximity of measures in the public space. As a result, it may be possible for a road to be rebuilt for CA measures today and rebuilt again for et measures some years from now.

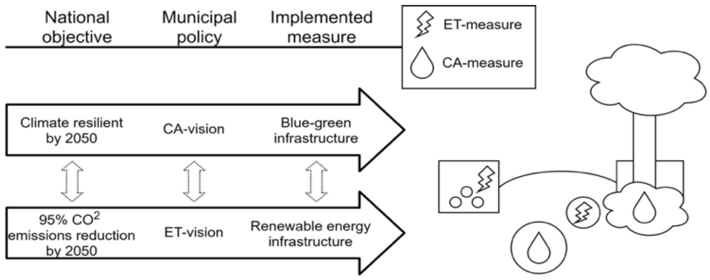

Figure 1: Two siloed transitions competing for resources in the public space

Integration is a topic that has been studied in various fields; but one of the most extensive fields of research concerns policy integration. One of the earliest studies of policy integration is by Underdal (1980); who argues that improving policy outcomes requires considering the effects of related issues. In this way, an improvement in one area limits its negative consequences in other areas. Lafferty and Hovden (2003) build on Underdal (1980) by explaining the role of sectoral policy making and suggesting two methods for integrating environmental interests into sectoral policy. While the authors in this research area tend to agree that more coordination is needed to improve integral policy making; many studies and scholars exclude the deployment and implementation of these integral policies from their scope.

Fragmentation in construction industry is also field of research where integration is an issue. Although many causes of fragmentation have been identified; Riazi *et al.,* (2020) discovered that the most often mentioned causes in the literature are:

- "Isolation of project professionals"
- "The sequential nature of construction process execution"
- "The confrontational culture between project parties"

Similarly, Alashwal and Fong (2015) discovered that construction projects become more fragmented when professionals do not form strong relationships; share information; and understand one another. According to Egan (1998); the separation of planning; design; and construction processes reflects the industry's fragmented structure and results in inefficiency in project delivery. Despite the prevalence of fragmentation, there are many potential solutions for both individual projects and the industry. According to Demirkesen and Ozorhon (2017); using integration management techniques such as task organisation and clearly defining the project manager's role reduces fragmentation improves project management performance. Whereas previous authors approached integration rationally; Çıdık and Boyd (2019) argue that the construction industry should encourage interdisciplinary collaboration at all levels to improve organisational sensemaking capability. Another way to improve integration is to look outwards rather than inwards. Van Buuren *et al.,* (2010); for example, describe programme management as a mechanism for achieving synergy and coherence among various projects; organisations; and processes. Although there is a lot of knowledge about integral implementation in the fields of fragmentation and project coordination; formulating integral goals and policies receives less attention.

While previous research provides valuable insights; neither the field of policy integration nor the fields of fragmentation and project management fully explain the (lack of) integration in municipalities and what municipalities need to do to improve the status quo. Therefore, this study seeks to fill this knowledge gap by examining how Dutch municipalities collaborate internally on interrelated issues such as the et and CA.

METHOD

This study used a case study with an interpretivist perspective to understand the dynamics of working more integrally. One of the advantages of conducting a case study is that it can examine a phenomenon that cannot be clearly separated from its context (Yin 2018). The case study approach is well suited because it is important to understand how and why the participants made their decisions to work integrally.

The three cases are set in neighbourhoods where Dutch municipalities organise a combined CA and et trajectory (see Table 1). These three cases differ from conventional municipal approaches because both trajectories are usually implemented as separate projects. The advantage of selecting these cases is that they show the possibilities and obstacles of a more integral way of working, which are not found in other municipal projects.

Table 1: Location and progress of the study cases

Case	Municipality	CA phase	ET phase
De Nijverheid	Hengelo	Yet to be included	Definitive design
Het Twekkelerveld	Enschede	Delivery	Programme of requirements
Hart van Zuid	Hengelo	Asset management	Asset management

Data collection relied on two methods: document analysis and interviews. Document analysis involved examining newspaper articles, and policy and project documents on the progress and decisions of the cases. In this way, the available written sources provide context to the cases and allow triangulation with other sources (Yin 2018). Data collection also relied on 19 semi-structured interviews with different purposes: 4 exploratory; 11 case-based; and 4 validation interviews. Snowball sampling was used to find interviewees from various backgrounds, such as policy advisors; project managers; and engineers.

The collected data was processed into facilitating and hindering factors, couplings between trajectories and potential interventions. The factors are coded as positive or negative influences on cooperation; categorised under the "exogenous variables" and "action arena" components of Ostrom's (2009) Institutional Analysis and Development (IAD) framework. Couplings between trajectories are characterised by participants from different backgrounds collaborating more intensively than conventions dictate. This means that regular project meetings between participants with similar backgrounds are not considered to be a coupling; but structural coordination between participants who would not otherwise interact is categorised as a coupling.

The results of the factors and couplings were summarised; and these results were used to design different interventions. The summary of results and the designed interventions were presented in the four validation interviews. In these interviews, new interviewees gave their opinion on the validity and usefulness of the results and interventions. This feedback was then used to redesign and finalise the interventions.

FINDINGS

What does it mean to integrate the et and CA trajectories?

There is a body of literature about integrating policy areas and managing projects with interrelated disciplines. However, this knowledge is not directly applicable to municipalities: while other organisations focus on specific activities; municipalities develop policies; design and implement measures and manage their assets and public space. Therefore, municipal-level integration of et and CA trajectories must include these activities to understand intra-organisational dynamics. Hence the conceptual framework must include the role of implementation phases and feature couplings (see Figure 2).

Implementation phases
Municipalities have a variety of tasks related to public space. Due to the variety of tasks; there are few civil servants with backgrounds in different fields. The typical municipal workflow often separates staff and task per phases of policy making and implementation. For example, policy advisors develop policy; project managers and engineers are usually involved in the preparation and design of public works; and asset managers maintain these structures. Although they might have similar disciplinary backgrounds and depend on one another; these professionals work at different levels of abstraction and rarely interact. It is therefore important the framework acknowledges the different implementation phases of the trajectories.

Couplings
Municipalities may integrate CA and et trajectories at different implementation phases. This results in different types of couplings because the objectives and benefits of a shared policy vision are different from the simultaneous construction of e.g.; a sewer and a district heating pipeline. The definitions of Uyterlinde *et al.,* (2017) were used to describe the types of couplings (or 'coupling opportunities'):

- Coupling ("koppelkans"): A transdisciplinary approach to harmonising and combining sectoral problems and potential solutions to achieve a more coherent strategy.
- Co-coupling ("meekoppelkans"): The inclusion of measures from with added value one trajectory during design and implementation of another trajectory.
- Coordination ("afstemming"): The coordination of existing work processes without additional investment or additional measures.

These types of couplings materialise at different stages of implementation. First, the "coupling" focuses on combining objectives and therefore takes place at the policy level and in early phases of the preparation and design level. Secondly, the "co-coupling" takes place in the technical phases of the preparation and design level as these phases allow for combining measures in the final design. After the policy and design phases are over; the execution may still be optimised. Therefore; "coordination" takes place at the realisation and asset management level.

Framework

The integration of different trajectories would require considering civil servants participating in different implementation phases and contributing to different couplings (see Figure 2). The framework should help to map the current practice and present the options for integration. For that, the implementation process consists of three levels of abstraction and seven milestones. Although civil servants may work on the same issue; the differences between their tasks are often such that they rarely interact with each other. Throughout the implementation process, civil servants work toward milestones at which they complete a (partial) product, such as a programme of requirements. The advantage of considering levels of abstraction and milestones is that the level of detail and the point at which the couplings are made are specified. In addition, specifying the types of couplings in the implementation process makes it easier to identify couplings and visually shows interviewees the different couplings.

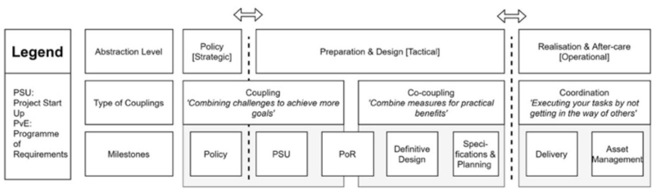

Figure 2: The implementation phases and couplings at the municipal level (based on Raijmakers (2022))

Why is the Integration of the et and CA Currently Hardly Happening?

When a municipality or utility company excavates a road; it is usually done to replace ageing infrastructure or to change the function of a road; for example, by creating more public green space. Although these interventions are easy to explain to residents; an asset manager conceded that 'residents might have lost their minds when they received the fourth or fifth letter informing them that their street was going to be dug up'. This is (hopefully) a rare situation; but interviewees gave several reasons why they cannot combine different interventions. The three most cited reasons are discussed in the next sections.

The first reason why interventions cannot be combined: Institutional rules create barriers between issues or even favour some issues over others. The most common examples given in the cases are that water-related issues have relatively high budgets and strict requirements; while public; green-related issues tend to have low budgets and requirements. In practise, this means that municipal public space redesigns have little public green because few measures can be paid for out of the allocated budget. This becomes a problem when effective CA interventions require measures from both sectors. Similarly; the societal costs saved by combining or avoiding measures; such as not replacing gas pipes after building district heating; cannot be shared among stakeholders. Another reason is: Civil servants with different areas of expertise and civil servants involved in different implementation phases have (too) few regularly scheduled interactions.

As a result, possible combinations of et and CA measures are recognised too late or not at all. Both municipalities studied installing a team of et policy advisors and another team consisting mainly of engineers and project managers with experience in CA measures. Yet, when a CA-oriented engineer was questioned why it is not common procedure to include professionals with et experience in all projects; he responded: 'Besides my project manager; who is responsible for the et within the municipality? The energy transition is just not a chapter in our program of requirements.' This sentiment is shared by a few other interviewees, who admitted that their design guidelines did not include et requirements and that they did not know of an et expert within the organisation to assist them. The reason for this discrepancy is that project teams have a narrow scope and input of policy advisors is not considered necessary. The opposite is also true: policy advisors do not always see the benefit of technical advice from engineers; for example, on subsurface issues. The third most frequently cited reason why measures cannot be combined: The timelines for infrastructure construction or replacement are too far apart. In practise, this means that a project to replace for instance a sewer cannot be combined with a project to build a district heating pipeline, which would not be built until several years later. Part of the reason for this problem is the physical uncertainty that asset managers face about the condition of their assets. Furthermore, municipalities often lack an overview of internal and external plans for existing and future assets. According to an interviewed team manager, this is a concern since 'not only are we behind the times; but we do not have the capacity to be reliable partners to utility companies.' As a result, municipalities cannot make reliable agreements with utility companies and between different departments to combine infrastructure interventions.

What Aspects of Integration Are Already Visible and Why That is the Case?

Visible couplings
In all three cases studied; civil servants coupled different issues within and between implementation phases. However, not all identified potential couplings are realised yet because the working process in de Nijverheid and het Twekkelerveld is not fully crystalised. Four couplings have been found:

4. between the et and CA.
5. between the et and another theme.
6. between CA and another theme.
7. and general coordination methods.

By spanning disciplinary boundaries, these couplings also bridged the gap between the engineering-focussed 'physical' and the wellbeing-focussed 'social' domain. For de Nijverheid and het Twekkelerveld; this meant that health advisors were involved in the traditionally engineer-driven implementation of CA. The same trend also holds for the ET: both de Nijverheid and het Twekkelerveld combine poverty alleviation policies of the social domain with the insulation efforts of the physical domain.

While et and CA couplings are more straightforward in combining policies or measures; the more general coordination methods may link disciplines and implementation phases. Of the three cases, the project team in het Twekkelerveld has the most sophisticated approach to coordinating its efforts. First, the SIA ("Stedelijk Investeringsafweging"; Municipal Investment Consideration) gathers information from all policy areas to determine which neighbourhoods of the municipality have the most problems and potential synergies. This analysis takes place at an abstract policy level; but this can lead to a DIA ("Dynamische Investeringsagenda"; Dynamic Investment Agenda) if a neighbourhood presents many potential synergies. A DIA is a neighbourhood-based urban renewal programme that combines problems and resources from the municipality, social housing corporations and utility companies. This programme is a five-to-ten-year project that combines policy and technical expertise to implement integral physical and social interventions. The main advantage of the DIA is that neighbourhood- or street-level projects can be managed within an integral framework as they determine their scope. However, the main challenge of this approach is that these smaller projects can still become more insular or sectoral in the engineering and realisation phases. To address this; one of the interviewees suggested a joint implementation agenda as a platform for the DIA project team to structurally manage smaller projects during their more operational phases. With this potential method, the neighbourhood-oriented approach in het Twekkelerveld would bridge multiple disciplines and connect the levels of policy; preparation and design; and realisation and asset management.

Facilitating factors

Although the civil servants interviewed encountered several obstacles in integrating et and CA; they still managed to find new ways of coupling different issues. There are several factors that helped the civil servants; but the three most frequently mentioned factors are discussed in more detail in the next sections. The first and most frequently cited facilitating factor is that the involved civil servants find a way to work toward an overarching goal. Although civil servants want to offer residents useful services; practise shows that they are reluctant to lower expectations regarding 'their' discipline. That is; civil servants defend the spatial and budgetary demands of their respective discipline when conflicting goals arise in policy or project implementation. This sectoral reflex was reduced when participants accepted that achieving an overarching goal with synergies sometimes means scaling back their sectoral goals. Furthermore, when there are irreconcilable differences of opinion or even conflicting policies; these conflicts must be decided by higher-level managers or by local politicians.

The second factor that facilitates the integration of different trajectories is to mutually provide insight into ambitions and planned activities. To determine whether there are any possible couplings in their project or policy area; interviewees often check formal plans and tools that are already available. For example, the et project manager in de Nijverheid consulted the sewer plan to determine if the construction of a city heating pipes could be combined with the replacement of old sewer pipes. So, plans and tools that shed light on potential synergies and risks help civil servants work in a more integrated way. The third factor also improves information sharing across disciplines and implementation phases; but it does so through informal face-to-face interactions rather than formal plans. This means that civil servants from different disciplines and implementation phases must be involved within and outside the project team. Therefore, project leaders must not only be careful to assemble a project team with diverse backgrounds; but also, regularly engage with important civil servants outside their team. For example, an external CA policy advisor and a sewage asset manager can still provide valuable information to a project team for construction of additional water retention. Conversely, the policy advisor and asset manager also receive valuable information and feedback from the project team in this manner.

How Can Municipalities Internally Integrate the et and CA Trajectories?

So far; the cases show a certain degree of working integrally while at the same time a struggle with sectoral obstacles. These obstacles show up in the form of institutional barriers between issues; and couplings that are discovered too late or not at all to be included in the planning process. The interviewed civil servants overcome these barriers by using formal plans and personal connections to gather information and feedback from other sectors. Another recurring theme is that participants are more concerned with finding a common goal than with protecting their sectoral goals; and that they try to resolve any conflicts quickly. Consequently, the cases show many substantive and procedural couplings at all implementation phases. The coordination couplings between abstraction levels are particularly important as they allow integral policies to be implemented integrally while providing feedback to the previous levels. Since municipal et and CA efforts involve extensive planning; construction; and maintenance existing and new infrastructure; it is important to align the three abstraction levels. Although the interviewees suggested many ideas; and many more can be conceived; it should be emphasized that civil servants from all implementation phases can contribute to a more integrated way of working. To demonstrate this; this study proposes two interventions from different professions, such as policy advisors and asset managers; which improve coordination between implementation phases.

Comprehensive policy strategy
The consequence of developing ET- and CA-policies separately is that the implementation of both areas is planned differently. As a result, municipalities execute measures at different moments and places and cannot combine these interventions. Municipalities can mitigate this problem by developing a strategy which addresses the most important challenges for the coming decades; guiding principles and the methods to address them. The advantage of this strategy is that municipalities consider potential synergies and conflicts between issues from an early stage. However, because not all risks of combining issues are obvious at the policy level; developing such a plan necessitates coordination with subsequent implementation phases. For example, while it is usually beneficial to plant trees in streets where district heating is being constructed; a possible lack of underground space may be overlooked at the policy level. Furthermore, policy strategies of this magnitude must be updated on a regular basis and require input from all implementation phases to incorporate new insights. Thus, a comprehensive policy strategy aids municipalities in better aligning policy objectives; but it needs input from more than just policy advisors.

Municipal works plan
Aside from integrating new infrastructure development, municipalities must also efficiently maintain and adapt existing infrastructure to new developments. This means that replacing an ageing sewer should ideally be combined with other activities such as upgrading the electricity grid (and vice versa). However, this is not possible because municipalities do not have a multi-year overview of their assets and thus cannot effectively collaborate with utility companies and social housing corporations. This can be resolved if municipalities develop a municipal works plan that includes two components: long-term financial planning and a short-term implementation agenda. In the long run, municipalities can use this plan to integrate asset maintenance and replacement schedules. In the short term, this plan can be used to combine asset management activities with the construction of new infrastructure. The effectiveness of this strategy is determined by asset managers' ability to coordinate both short- and long-term developments with policy advisors and project managers.

DISCUSSION

More coordination is clearly needed, according to the interviewed civil servants and literature. Depending on the study; the questions of who needs to cooperate more and how to do so are answered differently. On the one hand; research such as Underdal (1980); Candel and Biesbroek (2016); and Domorenok *et al.,* (2021) state that fragmentation can be reduced by addressing sectoral perspectives; (sub)systems; and boundaries. On the other hand, research like that of Demirkesen and Ozorhon (2017) state that fragmentation on in the construction industry can be reduced by better coordinating specialists; processes; and materials.

Existing research shows that there is an abundance of information available to develop coherent policies and implementation strategies. To effectively transform entire neighbourhoods; though; more is needed than better policy or project coordination. After all, the full potential of integral policies is not reached when they are implemented in a sectoral manner (and vice versa). However, literature and practise frequently make the implicit assumption that an integral plan leads to an integral implementation (and vice versa). The main contribution of this study is to demonstrate how the various implementation phases must be connected to achieve a more holistic approach. More specifically, this study examines which factors lead to more (or less) integral approaches; what methods civil servants use to coordinate with one another; and how municipalities could make more integral decisions. As a result, this study contributes to literature by showing that increasing the level of integration requires coordinating fragmented decision-making across implementation phases.

This study investigated ways to improve the coordination of et and CA pathways to get better results. This is not to suggest that greater coordination necessarily leads to better performance. Future studies could investigate cases when increased coordination failed to produce better results. Another relevant research topic is to investigate the impact of informal interactions inside organisations on the degree of holistic working. For instance, networks of informal interactions appear to fill in some of the gaps left by formal coordination.

CONCLUSION

This study found that Dutch municipalities are currently unable to realise an integrated implementation of the et and CA trajectories because civil servants from different implementation phases rarely interact structurally. Participants in the three cases; on the other hand; devised substantive couplings and coordination methods to integrate aspects of the et and CA. They implemented these methods by: (1) working toward an overarching goal; (2) providing insight into their ambitions and planned activities; and (3) interacting informally with professionals from various disciplines and phases of implementation. As a result, the process can involve more sectors. Furthermore, each phase of implementation contributes to integral solutions in subsequent phases while also providing valuable feedback to previous phases. Municipalities can therefore integrate the et and CA trajectories with improved collaboration between implementation phases.

Although integrating the et and CA is important; these are just two out of the many issues that municipalities must address. Public space is more than just a place for cables; pipes; and water storage: it is also a space where various residents work; play; move and live. Understanding how municipalities can integrate issues into their work allows them to better meet the needs of their residents. Thus, by emphasising the importance of collaboration across sectors and phases of implementation; this study aids municipalities in their efforts to contribute to a more sustainable and climate resilient built environment.

ACKNOWLEDGEMENTS

RDR designed the methodology; collected; and processed the data; wrote the manuscript and was responsible for the visualisation and project administration. KV; AD and RC have been extensively involved in the reviewing and supervision of this research. All authors were involved in the conceptualisation of this study.

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LEGAL ISSUES FACING ADJUDICATION IN THE IRISH CONSTRUCTION INDUSTRY: A DISCUSSION

Cathal Ryan[1], John P Spillane and James G Bradley

Irish Construction Management Research Centre (ICMRC), School of Engineering, Faculty of Science and Engineering, University of Limerick, Limerick, V94 T9PX, Ireland

The Construction Contracts Act 2013 (hereafter referred to as "the Act") was enacted a decade ago. However, the resolution method is yet to be widely adopted within the Irish context. This research aims to discuss the legal problems that the Act has faced to date. The way these issues are handled by the Irish legal system influences how the Act may be utilised in future. Adjudication cases that progressed to litigation, post the introduction of the Act, are the primary source for the discussion. Seven legal problems make up the basis of this discussion. Misinterpretation of the legislation is a recurring cause of legal problems. However, the adoption of court rules is gradually resolving this issue. Five of the seven problems were resolved, however one resolution resulted in the emergence of another legal issue. This study's essential contribution is to discuss the legal developments that have occurred since the Act has been in practice, in hopes that this information will assist contract parties in protecting their rights to payment security.

Keywords: ADR; case law; contracts; court; payment; dispute

INTRODUCTION

The Irish construction industry has a culture of payment deferral, particularly towards subcontractors, which has been present even during the sector's most profitable years (Bunni 2017; Hussey 2016). The economic recession of 2008 caused the practice of delayed or non-payment to escalate. Resultantly subcontractors and other Small to Medium sized Enterprises (SMEs) struggled to obtain payment for completed work. In 2009, 46.5% of jobs lost were in the construction industry (Treacy *et al.,* 2016). Construction disputes increased as a result of the limited commercial prospects and severe restrictions in cash flow. Subcontractors campaigned for the introduction of legislation that would protect them from the poor payment practices (Hussey 2016). The Construction Contracts Act 2013 (hereafter referred to as the "the Act") is the legislation for statutory adjudication employed in the Republic of Ireland (hereafter referred to as "Ireland"). On the 25th of July 2016, the Act became operational, making adjudication a statutory right to all construction contracts, subject to a few exceptions, for example, residential dwellings (Hussey 2016). Adjudication is a form of alternative dispute resolution (ADR). An ADR is a method or procedure for resolving disputes without resorting to traditional litigation (Rosenbaum 2005). Adjudication procedures tend to differ from country to country or, in some cases, from

[1] Cathal.Ryan@ul.ie

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state to state (Hin 2011). Ireland's adjudication procedure comprises of an independent, neutral third party (the Adjudicator) deciding on behalf of two disputing parties within an initial period of 28 days; the decision is binding on the parties until the parties finally settle the payment dispute or a different conclusion is reached. If the Act is utilised more frequently, subcontractors and SMEs will be better equipped at enforcing their right to payment security; additionally, poor payment practices would begin to decline. According to Lesch and Millar (2022), recession is inevitable; the only way to minimise the negative effects of recession is to develop wiser policies. Thus, improving payment practices could help the Irish construction industry avoid high levels of unemployment in future. However, annual reports reveal that adjudication has yet to be used to the degree anticipated prior to the Act's implementation of 150 adjudicator referrals per annum (Hussey 2019). To date the highest volume of referrals recorded is 71, in the 2021-2022-year period, the sixth year of the Act (Gogarty 2022).

In contrast, 187 adjudicators were referred within the first year of the UK's statutory adjudication legislation, the Housing Grants, Construction and Regeneration Act 1996 (HGCRA) being established. This was followed by a 600% increase in its second year (Nazzini and Kalisz 2022). Alternatively, the Act did not experience an annual increase in referrals until its third year, with a percentage increase of 256%. Studying all the cases where adjudication procedures have proceeded to litigation, post the Act's commencement, would answer some interesting questions. Such questions include, what legal problems has the Act has encountered thus far? Does the Irish legal system support the Act? How have instructions within the Act been interpreted by Adjudicators, Practitioners and most importantly Judges? What do these judgements mean for the Act going forward? 11 cases make up the basis of the discussion. These judicial decisions tackle some questions that have been pondered since the Act's inception. Such as "To what extent is the Adjudicator's decision "binding" on the parties?". While not every question may have a clear solution, this study could provide a foundation for future research, on dispute resolution. As Spillane (*et al.* 2011) highlights "the construction industry notoriously excels at dispute creation". Thus, conflict management in the form of dispute resolution are an important part of construction management.

It is possible that adjudication in Ireland has not yet reached its full potential due to drawbacks generally associated with using adjudication as an ADR method. "General drawbacks" include an increased likelihood of straining business relationships (Dutton 2021) and a reliance on goodwill from both sides to compromise (Ashworth *et al.,* 2013). However, these issues are consistent with adjudication use worldwide and are not unique to Ireland's situation. Nevertheless, there are problems that adjudication faces solely in Ireland. For example, authors Keogh and Lawless (2020) have expressed concern over anomalies created through the wording of Ireland's legislation. In the last six years, ten payment disputes have proceeded from adjudication to litigation to enforce an Adjudicator's decision. The arguments raised in these cases show a misunderstanding of how certain laws within the Act are to be interpreted. As a potential solution to the emerging case law, on the 26th of April 2021, Practice Direction HC 105 came into effect. This High Court rule appointed Mr Justice Garrett Simons as the presiding Judge, in charge of all adjudication enforcement applications (Harnett 2022). 'Practice Direction HC 105' provides that all enforcement applications will be "made returnable before the High Court" and ensures that "applications will be heard and determined with all due expedition" (The Courts

Service of Ireland 2021). Resultantly the High Court of Ireland has had to give its stance on how directions within the Act are to be interpreted. Their judgements demonstrate how adjudicators should enforce the Act in future. However, this topic is yet to be discussed in an academic context. Hence, the research objective is to study the case law, detailing the most prominent legal problems the Act has faced to date, what problems have been resolved, and what problems still require clarity.

METHOD

Initially this paper was going to consist of a systematic literature review (SLR), detailing the development of the Act to date. The SLR format was chosen due to its structured approach, rigorous conclusions, and the ability to synthesize the data. However, an investigation into the literature yielded only 8 results. Additionally, some results appeared to have no significance to the study with a weak connection to Ireland's adjudication practice; for example, "Five years on: A review of statutory adjudication in Malaysia"(Munaaim 2019). Due to the limited resources, the study has pivoted to a discussion on case law. All case law material in this investigation was accessed through the Westlaw IE portal on the University of Limerick Glucksman Library website. Once the selection criteria are applied, 11 cases remain. The inclusion criteria required that cases proceeded to litigation, referenced the Act, and were conducted in the Republic of Ireland under Irish law. Cases that predate the 25th of July 2016 were excluded. Eleven cases were conducted between 2019 and 2022. An in-depth study was undertaken for each of the cases. All cases were compared to find common issues. Due to the limitations of this paper, only reoccurring problems which have appeared in two or more cases feature in the discussion, as they are deemed to be of greater importance. Thus, only seven cases are discussed below. Note sources such as annual reports, articles and books have also been used to analyse adjudication's development to date further.

DISCUSSION

Court cases often have lengthy titles; thus, the cases have been abbreviated and will be referred to as follows:

- K&J Townmore Construction Limited v Kildare and Wicklow Education and Training Board
  - K&J Ltd. -v- Kildare & Wicklow Training Board (2019)
- Kevin O'Donovan and The Cork County Committee of the GAA v Nael G. Bunni and James Bridgeman (Respondents) and OCS One Complete Solution Limited (Notice Party)
  - Cork GAA -v- OCS Ltd. (2020)
- Construgomes & Carlos Gomes SA v Dragados Ireland Limited, Bam Civil Engineering and Banco BPI SA
  - Construgomes -v-Dragados Ltd. (2021a)
- Principal Construction Limited v Beneavin Contractors Limited
  - Principal Ltd. -v- Beneavin Ltd. (2021)
- Aakon Construction Services Limited v Pure Fitout Associated Limited
  - Aakon Ltd. -v- Pure Fitout Ltd. (2021a)
- Aakon Construction Services Limited v Pure Fitout Associated Limited
  - Aakon Ltd. -v- Pure Fitout Ltd. (2021b)
- John Paul Construction Limited v Tipperary Co-Operative Creamery Limited
  - JPC Ltd. -v- Tipp Co-op Ltd. (2022)

From an analysis of these cases, seven prominent legal problems repeatably emerged. The extent to which the Adjudicator’s decision is “binding” on the parties, in this context the term "final" refers to a decision which the parties must oblige. The decision cannot be challenged. Alternatively, the term "binding" refers to decision that acts as final, unless or until it is superseded. Hence, McCann (2019) highlights the "temporary" nature of an Adjudicator's decision as a drawback commonly associated with statutory adjudication. Many parties have raised this issue within court proceedings. Concerning the Act, the terms “binding until” and “if binding” within sections 6.(10), 6.(11), and 6.(12) have raised questions regarding the enforceability of an Adjudicator’s decision. In the KandJ Ltd. -v- Kildare and Wicklow Training Board (2019) case, the defendant implies that because an adjudicator's decision under section 6 of the Act is "merely binding", it can be challenged or rejected by a party. Judge Barniville disagreed with this assertion, stating that section 6.(10) of the Act "expressly qualifies" the binding nature of an adjudicator's decision. Barniville emphasized the following section 6.(10) details: “The decision of the adjudicator shall BE BINDING UNTIL the payment dispute is FINALLY SETTLED by the parties or a different decision is reached either by arbitration or in court proceedings”.Similarly, in the Construgomes -v-Dragados Ltd. (2021a) case, Judge Butler interpreted that the "pay now, argue later" principle refers to the legally binding immediate "obligation to pay on foot of an adjudicator's decision" that must be complied with before parties seek to resolve the dispute through other mechanisms provided for in their contract, for example, arbitration. Not paying the total amount awarded is a form of non-compliance with the Adjudicator's decision. Thus, “the adjudicated award is to be enforced as it stands, and it is not subject to deductions of one sort or another”. The binding nature of an Adjudicator's decision was doubted again in the Principal Ltd. -v- Beneavin Ltd. (2021) case. Pursuant to section 6.(11), Principal Ltd. sought leave of the High Court to enforce the Adjudicator’s decision. Beneavin Ltd. responded by asserting that because the phrase "if binding" is absent from the corresponding provision in the UK’s HGCRA, it is easier to resist the enforcement of an adjudicator's decision in Ireland than it is in the UK. Judge Meenan stated that section 6.(11) must be read “subject to the provisions of section 6.(10)”. The UK authorities determine that an adjudicator’s decision may be unenforced “either on the grounds of jurisdiction or natural justice”. Thus, Meenan believes "if binding" should be interpreted in that narrow context. Aakon Ltd. -v- Pure Fitout Ltd. (2021a) is the most recent case to debate the term “if binding”.

Here, Judge Simons held that the term "if binding" used in section 6.(11) is “intended to address the contingency of the adjudicator’s decision having been superseded by a subsequent decision of an arbitrator or Court”. The term is not intended to suggest that the status of an Adjudicator’s decision is “uncertain”, nor is it “an invitation to parties to question the binding nature of the adjudicator’s decisions in enforcement proceedings”. In the JPC Ltd. -v- Tipp Co-op Ltd. (2022) case, Simons described an Adjudicator’s decision as “provisional only” and “not final and conclusive”, nevertheless it gives rise to an "immediate payment obligation" which is enforceable upon the parties. To summarise, an adjudicator's decision is to be treated as "final", unless or until it is superseded by an agreement which both parties are content with, or a decision reached by arbitration or litigation. However, parties must abide by an immediate payment obligation, before attempting to resolve the dispute through other channels. Finally in a litigation proceeding, an adjudicator's decision will only be unenforced if the Adjudicator lacks jurisdiction or breaches natural justice.

In Ireland adjudication is a statutory entitlement and therefore, is subject to judicial review (Pickavance 2015). However, the High Court of Ireland is yet to answer whether judicial review "lies to restrain an adjudicator from reaching a decision on a pending adjudication". When asked about the matter, Simon J replied that the answer could just as easily be "yes or no" (Harnett 2022). Judges have taken either side of this argument. For example, Judge Barr's ruling in the Cork GAA -v- OCS Ltd. (2020) case found that "the interests of justice would be best served" by granting a stay on the adjudication until the determination of the judicial review proceedings. Contrastingly, in the JPC Ltd. -v- Tipp Co-op Ltd. (2022) case, Judge Simons refused to perform a judicial review for the following reasons. Firstly, the fact that an Adjudicator's decision is "provisional only" lessens the need for "rigorous judicial intervention at the time of enforcement application". Furthermore, Simons believed that Tipp Co-op Ltd. (2022) had attempted to "judicially review the adjudicator's decision through the back door", as they attempted to have the Court review the "underlying merits of an adjudicator's decision (where the substance of the defence had previously been addressed) under the guise of identifying a breach of fair procedures" (Graydon 2022). In doing so, the Court re-confirmed the "pay now, argue later" approach to enforcing adjudication awards. Finally, Tipp Co-op Ltd. applied for review after the three-month time limit for judicial review under Order 84 "Judicial Review and Orders Affecting Personal Liberty" of the Rules of the Superior Courts (RSC) had expired (The Courts Service of Ireland n.d.). For these reasons the Court felt they did not have to answer whether judicial review could prevent an Adjudicator from deciding. While Simons maintains that the Act is "silent" on this matter and fails to address its relationship with Order 84. While no guidance has been given on this matter to date, Harnett (2022) gathers that current jurisprudence suggests judicial review is pursuable where an error of law is asserted. Nevertheless, judicial review is unattainable where the Respondent can pursue another effective alternative remedy. It is unclear if the ability to refer a dispute to arbitration constitutes an effective alternative remedy (Harnett 2022).

Davies and Heading (2022) criticised Irish adjudication practices stating there is uncertainty around the extent that crossclaims can be used to limit financial exposure. In 2021, two cases touched on this matter. Firstly, in the Construgomes -v-Dragados Ltd. (2021) case, Judge Butler explicated that there is "no express reference" within the Act regarding the Respondent's ability to make a crossclaim to a claim which has been referred to adjudication. However, while crossclaims are "not expressly part of the statutory adjudication process," making it difficult to see how a crossclaim obligation could arise, it is more difficult to justify a contracting party losing "all entitlement to claim in any forum for matters that could have been part of a crossclaim". Additionally, Construgomes claimed that Dragados Ltd. had acted fraudulently. This accusation was based on the British case Henderson -v- Henderson (1843). In this case, the English Court ruled that a party may not raise any claim in subsequent litigation which they should have rightfully addressed in a previous action (Geary 2017). Butler determined that the Henderson -v- Henderson (1843) case did not apply to the Irish adjudication process; thus, responding parties are not required to include all their potential crossclaims in an adjudication and retain the right to pursue them subsequently.

This matter was raised again in the Principal Ltd. -v- Beneavin Ltd. (2021) case. Beneavin Ltd. put forward a counterclaim, seeking payment of liquidated and ascertained damages, in response to Principal Ltd.'s referral. The Adjudicator stated they had no jurisdiction to consider a counterclaim "which in law is a separate action". Beneavin Ltd. believed the Adjudicator was breaching the rules of natural justice.

Under section 6.(9) of the Act, Adjudicators “may deal simultaneously with several payment disputes" once they all arise under the same construction contract. However, the Adjudicator explained that Adjudicators only have jurisdiction to determine payment disputes which have been referred to them. Thus, they can only adjudicate on a single dispute raised unless the parties “clearly and expressly consent otherwise” within their notice of intention to refer. TheAdjudicator acknowledged that defendants are entitled to raise counterclaims as part of their defence against the Applicant's claims for payment. However, they cannot raise a counterclaim to gain a "monetary award" in their favour, such as an adjudicated award (Harnett 2022). In conclusion, Judge Meenan deemed that the Adjudicator had acted within their jurisdiction, as it was evident that they considered the “substance of the counterclaim” within their decision. To summaries, crossclaims and counterclaims may be raised within an adjudication to limit financial exposure. It is not a breach of natural justice for an Adjudicator to refuse to allow a counterclaim if the substance upon said claim is built upon had been considered. However, it is a breach of natural justice for an Adjudicator to make a ruling without considering the substance upon which the attempted crossclaim is based.

The Act was likely inspired by the HGCRA, with the relevant provisions of both legislations sharing many similarities (O’Malley 2020). Regardless, British case law (along with any other region's case law) has limited relevance in Ireland, as highlighted in the Aakon Ltd. -v- Pure Fitout Ltd. (2021a) case. Here Judge Simons proclaimed it is not possible to "read across" case law decided by the HGCRA and apply it to the Construction Contracts Act 2013 due to the significant differences between the legislative approaches adopted in the two jurisdictions and the procedures governing the enforcement of an adjudicator's decision. Prior to the Aakon Ltd. -v- Pure Fitout Ltd. (2021a) case, there have been examples where Judges have chosen to utilise (Principal Ltd. -v- Beneavin Ltd. (2021)) or ignore (Construgomes -v- Dragados Ltd. (2021)) foreign case law. Within the same Aakon Ltd. -v- Pure Fitout Ltd. (2021a) case, Simons made another somewhat contractionary comment on this matter. Simons explained that comparing case laws is “of great assistance in addressing the question of principle as to whether and when a court should depart from the literal meaning of the legislation”. Nevertheless, the consensus regarding the utilisation of foreign case law is as follows; in line with Simons’ statements, Adjudicators and Judges cannot aimlessly apply case law decided by foreign legislations to adjudication cases under the Act, but it may be used to come to a decision, where the Adjudicator or Judge “considers the cases with caution” and deems that the foreign case law is relevant.

A “smash and grab” adjudication is one in which the Applicant claims payment of the total amount of an application for payment on the basis that the Respondent has failed to deliver a response within time to a payment claim notice under the Act (Harnett 2022). The Adjudicator is concerned with payment notice rules rather than the underlying works; thus, the payee's application is not evaluated (Simson 2021). "Smash and grab" adjudications only determine what needs to be paid now rather than what is ultimately owed. They leave room for future debate and argument over the true value of the costs (Waters 2021). Aakon Ltd. -v- Pure Fitout Ltd. (2021a) is an example of a “smash and grab” adjudication. In this case, Pure Fitout Ltd. accused the Adjudicator of breaching the rules of fair procedures by “failing” to consider their defence that the works' true value should be calculated. While Pure Fitout Ltd. was entitled to adjudicate the true value of the work, the Adjudicator explained that they could only proceed once they complied with the Adjudicator's decision and paid the awarded sum. This judgement is another example of the aforementioned "pay now, argue later" principle. The Court judged that there was no breach of fair procedures, as they believed the defence was inadmissible at the time, and the Adjudicator had not disregarded it. Unfortunately, case law is yet to decide if "smash and grab" adjudications are legitimate under the Act.

When questioned on this matter within the Aakon Ltd. -v- Pure Fitout Ltd. (2021a) case, the Court emphasized that they were not concerned whether this legal position was correct or not. Yet the Court did, somewhat ironically, acknowledge the following points made by Hussey (2016): Firstly, "there is no provision under the Irish legislation which stipulates what the consequences of failing to respond to a payment claim notice are to be" and secondly, it does not state, in the absence of a response, the amount claimed in the payment claim notice is payable by default. In conclusion, currently, it appears the High Court of Ireland will enforce a "smash and grab" adjudication award. Although it sounds unfair, Simons (2021) guarantees that the High Court will not enforce an Adjudicator's decisions when it is obvious that the decision was made without following fair procedures, even on a provisional basis. Additionally, the Respondent is not left without a remedy. As seen in Aakon Ltd. -v- Pure Fitout Ltd. (2021b), a second "true valuation" adjudication will be allowed.

In the Aakon Ltd. -v- Pure Fitout Ltd. (2021a) case, Judge Simons stated it is "at least arguable" that a subsequent referral can be used to further refine a previous claim. However, as seen in Aakon Ltd. -v- Pure Fitout Ltd. (2021b), a subsequent adjudication does not have the legal ability to undo the binding effect of an earlier decision. During the initial adjudication process, Pure Fitout Ltd. pursued its own separate referral to adjudication. The second Adjudicator valued the works in dispute at a figure less than specified in the payment claim notice. Pure Fitout Ltd. believed that the second Adjudicator's decision superseded the first, under section 6.(10) of the Act; thus, they should not have to pay the sum awarded in the first adjudication. Pure Fitout Ltd. was incorrect; under section 6.(10), an adjudicator's decision can only be superseded by a court proceeding, arbitral proceeding, or settlement between the parties. Hence, Simons (2022) warns that a successful party may wish to enforce the Adjudicator's decision but said decision "may be superseded by the subsequent court proceedings".

Judge Simons (2021) explained that the interrelationship between serial adjudication decisions is more complex. A subsequent adjudicator's decision is merely a factor that the Court might consider, depending on its suitability and relevance to a case. While Pure Fitout Ltd. had the right to seek the enforcement of the second Adjudicator's decision, the Court ruled that a subsequent claim cannot commence without first complying with the first Adjudicator's decision. Thus, the binding effect of a prior judgment cannot be legally reversed by a subsequent adjudication's outcome. However, Simons (2022) notes, where a party seeks to have second subsequent adjudication enforced by the court, and is successful, that party is "entitled to recover any overpayment" which they had paid to the opposing party in order to comply with the initial adjudication's outcome.

The High Court's ability to refuse to enforce an Adjudicator's decision
In the JPC Ltd. -v- Tipp Co-op Ltd. (2022) case, Judge Simons acknowledged that under the Act, the statutory adjudication process intends to be "far more expeditious than conventional arbitration or litigation". However, the swift nature of adjudication

could affect the accuracy of decisions. Dutton (2021) claims that Courts will frequently support an Adjudicator's decision, even if it is erroneous. Notably, within the British case, Carillion Construction Ltd v Devonport Royal Dockyard Ltd [2006], Lord Justice Chadwick proclaimed, “The need to have the right answer has been subordinated to the need to have the answer quickly”.

Furthermore, Davies and Heading (2022) assert that the Irish Courts will enforce Adjudicators’ decisions unless an Adjudicator lacks jurisdiction or breaches the rules of natural justice; this is consistent with the previously mentioned Principal Ltd. -v- Beneavin Ltd. (2021) judgement. In Simons’ judgement, he appears to agree with Davies and Heading's observation, stressing that the High Court have a "limited role" in the adjudication award enforcement process, and the Court's discretion to refuse to enforce an adjudicator's award is a "narrow one". Once the formal proofs for enforcement required by the Act and Order 56B: "Adjudication" of the RSC have been established “then leave to enforce will generally be allowed”. Thus, it seems that the Court will only refuse to enforce an Adjudicator’s decision where the Adjudicator lacks jurisdiction or breaches the rules of natural justice. Consequently, if an Adjudicator’s decision has gone against a party, they would require solid reasoning in order to resist enforcement. The onus of proof is on the party opposing the enforcement application to demonstrate that there has been an “obvious breach of fair procedures”.

CONCLUSION

This paper initially looked to review the entire adjudication case law that has emerged since the Act came into force on the 25th of July 2016. However, due to the volume of legal problems which arose within the case law, the research of this paper once again had to pivot. Resultantly, issues that feature in two or more cases are prioritised. Of the seven repeatably emerging legal difficulties which form the basis for this discussion, five have received some form of resolution. The problems which have been resolved are as follows:

1. The extent to which the Adjudicator’s decision is “binding” on the parties.
2. The parameters surrounding a party’s ability to make a counterclaim or crossclaim during an adjudication or subsequent proceedings.
3. The legitimacy of using case law decided under foreign adjudication legislations to reinforce judgements under the Act.
4. The effect, if any, that a second subsequent adjudication has on the original decision.
5. The High Court's ability to refuse to enforce an Adjudicator’s decision.

While most of the solutions seem to benefit the Act, the latter has led to another problem which seems more likely to hinder the Act's development. It is unfair that the unsuccessful party of an adjudication has little defence against the enforcement of the Adjudicator's decision. Moreover, while they are entitled to pursue a subsequent adjudication, this may not be financially practical for a party who is ordered to pay a wrongly disputed sum (O'Malley, 2020). Unfortunately, some problems have yet to be assigned a remedy. These problems include:

1. The extent to which a party can obtain a stay on adjudication pending the determination of the judicial review proceedings.
2. The legitimacy of "smash and grab" adjudications.

Furthermore, other unresolved problems feature in cases that are not discussed in this study; for example, the scope covered by the term “dispute relating to payment”.

While many issues are yet to be discussed, at least this discussion on adjudication case law provides a foundation for future research, for studies relating to the development of Ireland's adjudication practices. This research could be expanded in future, to discuss the solutions to problems that have yet to be resolved. Additionally, this paper could be compared to the judgements of new emerging case law, revealing the extent to which the Act, like many legislations, continues developed and change over time. In conclusion, it appears that the Irish legal system is supporting the Act, particularly considering the implementation of Practice Direction HC 105. This is especially evident in the presiding Judge, Garrett Simons, who goes to great lengths to explain how they interpret the law in each case they preside over.

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OFFSITE CONSTRUCTION

BUILDING TIME, COST AND QUALITY PERFORMANCE OF MODERN METHODS OF CONSTRUCTION IN A LIVE RESEARCH PROJECT

Vasil Atanasov[1&3], David John Greenwood[2], Tinashe Masvimbo Madebwe[3] and Rebecca Cox[4]

[1] *Law School, Robert Gordon University, Garthdee House, Garthdee, Aberdeen, AB10 7AQ, UK*

[2] *Department of Mechanical & Construction Engineering, Northumbria University, Newcastle upon Tyne, NE1 8ST, UK*

[3] *International Construction Claims Consulting Limited, 43 Frankland Road, Durham, UK*

The use of modern methods of construction (MMC) has been embraced by the construction sector of many countries, largely due to assertions that some MMC processes can be economically effective and efficient. MMC have been received as opportunities by governments to stimulate economies and support demands for new homes, and contractors to improve their profit margins. Although many studies have commented on the implications of using specific MMC, no evidence has been presented of the relative building time, cost, and quality performance of multiple MMC in one live house construction experiment. This paper presents an analysis of the value of turning to MMC including steel-based and timber-frame modular construction, light-gauge and panelised light-gauge steel frame construction and aerated concrete panelised construction methods. The findings presented here are likely to facilitate decision-making processes relating to these performance aspects of the MMC which were largely inferior to the traditional construction method discussed here and identify areas of improvement. Further advancements are required to improve the performance and desirability of these MMC.

Keywords: case studies; house building; live research; modern methods; performance

INTRODUCTION

The definition of modern methods of construction ('MMC') has been a subject to debate. It has been argued that, inter alia, (i) timber frames are not considered modern and thus do not fall within the definition of MMC and (ii) MMC make use of off-site manufacturing systems along with innovative materials, precision manufacturing techniques and digital technologies (Housing, Communities and Local Government Committee, 2019). The steel-based and timber-frame modular construction, light-gauge and panelised light-gauge steel frame construction and aerated concrete panelised construction methods discussed in this paper, fall within this definition.

[1] vasil.angelov.atanasov@mail.com

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The use of MMC has been embraced by the residential building sectors in many countries over the past decades (Zhang *et al.,* 2021; Saad *et al.,* 2023). This is largely due to assertions that some of the construction processes involved in MMC can be relatively more economically effective and efficient. For example, it has been argued that MMC are (i) likely to produce buildings of comparatively higher quality and (ii) relatively more time efficient (e.g., see Lawson *et al.,* 2012). Furthermore, MMC have been received as an opportunity by (i) construction contractors to improve their profitability and (ii) governments to stimulate economies and satisfy demands for new homes (Mesároš and Mandičák, 2015; HM Government, 2017; Spišáková and Kozlovská, 2019; Meacham, 2022). For instance, the UK requires at least 260,000 new homes each year to keep up with this demand. However, this target has proven difficult to achieve (Home Builders Federation, 2014). In the UK 98% of the local councils were unable to meet the regional housing demands (Oliveira *et al.,* 2019). This has been attributed to, inter alia, a lack of effective strategies to address (i) planning constraints; (ii) inadequate efficiencies of some construction processes involved in MMC; (iii) the insufficient number of large housebuilding companies and (iv) unsatisfactory economies of scale. Specifically, it has been argued that (i) is the main root cause which impacts (ii to iv) and the viability of MMC (Barker, 2004; Home Builders Federation, 2006; HM Government, 2017).

Although many studies have commented on the performance of specific MMC and/or the key principles characterising MMC, no evidence has been presented of the relative time, cost, and quality performance of multiple MMC in one live construction experiment (Tam *et al.,* 2007; Lawson and Ogden, 2008; Blismas and Wakefield, 2009; Modular Building Institute, 2010; Pan and Sidwell, 2011; Lawson *et al.,* 2012; Jellen and Memari, 2013; Rahman, 2014; Farmer, 2016; Generalova *et al.,* 2016; Lopez and Froese, 2016). This paper contributes to the fulfilment of this research gap.

LITERATURE REVIEW

Although the aim of this literature review is not to provide a comprehensive evaluation of all MMC, it offers an overview of key arguments (presented in the identified literature) related to the time, cost, and quality performance of (and some of the key principles characterising) the discussed in this paper MMC. Academics have argued that speed of construction is one of the main advantages of MMC over traditional construction methods (e.g., see Lawson and Ogden, 2008; Jellen and Memari, 2013; Sutrisna and Goulding, 2019). This advantage has been attributed to, inter alia, the ability to conduct simultaneous (i) off-site and on-site activities and (ii) construction and remediation efforts (Jellen and Memari, 2013). Lawson and Ogden (2008), Lawson *et al. (*2012) and Langston and Zhang (2021) argued that off-site manufacturing techniques can reduce the construction periods of modular buildings by up to 50%, but those efficiencies are greater in high-rise buildings as, inter alia, inadequate economies of scale and supply chains can cause time inefficiencies to low-rise buildings constructed with MMC. Modular construction methods offer another key advantage that is a simultaneous construction of building elements which should decrease on-site construction time (Modular Building Institute, 2010). Furthermore, construction periods can be reduced by applying (i) open panel and hybrid construction methods which can decrease construction time by around 25% and (ii) volumetric (or modular) construction methods which can reduce construction periods by approximately 60%. However, such construction time efficiencies are achievable only if the building designs are without flaws and finalised early in the construction project management process (National Audit Office, 2005; Ayinla *et al.,* 2022). In theory, this can be achieved by full integrations of the design, manufacturing, and construction teams (HM Government, 2013; Dowsett *et al.,* 2019). On the other hand, panelised, hybrid and volumetric construction methods typically require longer design periods (Oliveira *et al.,* 2019). To summarise the main arguments, although the application of MMC can contribute to construction time efficiencies; specifically, shorter on-site construction periods, it is unclear if meaningful overall time efficiencies have been achieved, or are likely to be achieved in the future, and how such efficiencies can be ensured in house building.

The identified literature centres on several aspects of the price and cost of MMC. Such costs typically include investments in production facilities, economies of scale, transport costs, minor repair costs and preliminaries (e.g., crane hire) The last two components are usually more cost efficient. This varies among the different building methods and contexts but impacts the desirability of all MMC (Sutrisna and Goulding, 2019). For example, modular construction methods can be more cost efficient than traditional construction approaches when used in high-rise buildings, poor soil conditions and restricted site workspace (National Audit Office, 2005; O'Connor *et al.,* 2014; Generalova *et al.,* 2016; Iuorio *et al.,* 2019). However, MMC incur significantly higher off-site manufacturing costs than traditional construction methods (Blismas and Wakefield, 2009; Pan and Sidwell, 2011; Lawson *et al.,* 2012). Furthermore, MMC can, at least in theory, reduce maintenance costs by improved precision of manufacturing of building components under factory conditions (Pan and Sidwell, 2011). However, studies suggest that further efficiencies are required to improve the affordability and viability of MMC; specifically, a 15% reduction in price which can be achieved by, inter alia, (i) increases in the volume of the construction works and a subsequent reduction in the start-up price (National Audit Office, 2005; Home Builders Federation, 2006; Rahman, 2014) and (ii) the use of off-site manufacturing techniques, but this mainly relates to high-rise buildings (Lawson and Ogden, 2008; Iuorio *et al.,* 2019). Lopez and Froese (2016) and Iuorio *et al.,* (2019) have provided cost analyses of some MMC, where the former concluded that the overall construction cost of modular high-rise buildings was 7% lower than the panel buildings. However, this study has significant limitations; specifically, the like for like comparison was impacted by many different building elements and construction site conditions and unavailability of detailed cost plans.

Construction quality includes three main components: durability, whole life costs and performance (National Audit Office, 2005). Leakage problems and perception issues relating to lightweight building elements, often used in MMC, are frequently perceived as indicators of low building quality which affects the desirability of such buildings (Tam *et al.,* 2007; Rahman, 2014). On the other hand, one of the main perceived advantages of off-site construction is achieving relatively higher construction quality by ensuring greater precision of manufacturing, quality control and management due to installations of building components under factory conditions by competent personnel (National Audit Office, 2005; Pan *et al.,* 2008; Blismas and Wakefield, 2009; Modular Building Institute, 2010; HM Government, 2013; Miles and Whitehouse, 2013). However, those advantages may prove difficult to realise due to, inter alia, inadequate competency of human resources (Yu *et al.,* 2019). Therefore, the primary argument is that the building quality of a particular MMC is influenced by the extent of off-site manufacturing used in that construction method and the competence of the human resources. For example, the degree of off-site manufacturing (and thus the quality management and building quality) is greater in volumetric construction systems than panelised construction methods (Lopez and Froese, 2016; Oliveira *et al.,* 2019). However, the identified literature does not provide comprehensive studies of the number and types of patent defects in homes built with the five MMC discussed here. This is one of the objectives of this study.

METHOD

Introduction to Case Studies

The data presented here was generated in a live research and construction project involving the building of over forty semidetached houses which were assembled on over twenty land plots (i.e., a "pair" of semidetached houses were assembled on each land plot) with six different construction methods. Each pair was assembled with one construction method. Therefore, each land plot corresponds to one construction method and one case study. All houses were similar, located on one construction site and were built at the same/similar time. Since a 'like for like' comparison is essential to accurately measure and evaluate the time, cost, and patent defect performance of those houses, the twelve most similar semidetached buildings were selected from that sample; specifically, the houses had identical/similar gross internal floor area, number of storeys, number of bedrooms and building fabric. Those twelve houses include two houses built with a traditional construction method (Case 1) and ten houses built with five MMC, namely the light-gauge concrete panelised construction (Case 2); the timber frame modular construction (Case 3); the light gauge steel frame modular construction (Case 4); the panelised light-gauge steel frame construction (Case 5) and the steel frame modular construction (Case 6) methods. Therefore, this study is based on an experimental approach where the data (a set of six case studies), provided by the organisations involved in the project, was filtered to ensure the most similar houses were compared. The names of the parties and some project features were anonymised to ensure their confidentiality. The project was completed before the start of the COVID-19 pandemic, Brexit and the war in Ukraine and thus was unaffected by high inflation and other external factors such as supply chain issues which might have impacted the research findings if the project was affected by those events.

The research approach includes three main stages, namely (i) reviews of the individual house designs to identify differences between building elements which could impact the research findings; (ii) interviews with site personnel; specifically, the main contractor's site manager and quantity surveyor, were conducted to identify further factors that impacted the performance of each MMC and (iii) analyses of the three sets of data required for the time, cost and patent defect comparisons were conducted.

Reviews of residential building designs
The main findings from those reviews include differences in (i) the number of bedrooms; (ii) the number of storeys; (iii) the size of the ground floor internal areas; (iv) the type of building fabrics; (v) the type of smart technologies and (vi) the type of heating and electrical systems used in those residential buildings. As noted above, those limitations were reduced by selective sampling of identical/similar houses.

Interviews of relevant construction personnel
The main findings from the interviews with the site manager and quantity surveyor were (i) the six factors noted above were likely to impact the time, cost and patent defect performance of those buildings; (ii) construction plant requirements and/or site logistics also impacted the performance of some MMC; specifically, delay was caused to the modular homes by deficient site logistics which impacted the use of cranes; (iii)

inadequate drainage designs and water board issues; (iv) problematic designs of modular buildings; specifically, the design and construction of two units were rectified after the units were delivered to site; (v) relatively small contractors constructed the modular buildings and (vi) the nature of some patent defects was unclear from the records, so the help of site personnel was required to categorise those defects.

Data requirements
The three sets of data required for the time, cost and patent defect comparison were (i) baseline programmes (which indicate the planned durations) and as built programmes and data (which indicate the actual design, manufacturing, and construction durations); (ii) cost value reports (CVR), final accounts and material costs which articulate the elemental cost of the buildings and (iii) reports specifying the patent defects conveyed by the residents.

Data collection

As noted above, construction time, cost and patent defect performance data were collected to fulfil the objectives of this study. The data collection is discussed next.

Construction time data
Since one of the objectives of this study is to measure and evaluate the planned and actual construction time performance of the five MMC discussed here and compare the findings to the relevant traditional construction method, the detailed baseline programmes (specifying the agreed by the specialist subcontractors, the main contractor, and the client planned activity durations) were used to measure the planned design, manufacturing, and construction durations. The programme updates and the as built records were used to measure the actual durations of the programme activities.

Construction cost data
As noted above, the cost data was recorded in a CVR and included two main components. Component **1(**Construction Costs) included the costs of supervision, plant, labour, materials, overheads and building elements. Component 2 was Preliminary Costs. Detailed elemental cost plans for the building substructures were provided. The main limitation of the elemental cost plans was that the modular plots were priced as lump sum costs which included most building superstructure elements. Therefore, those building elements were excluded from the detailed comparison.

Reported patent defects
The patent defects were reported by residents and recorded by the main contractor's customer care department for a twelve-month period after the construction completion date. This data was logged in a Microsoft Excel file and included address, the nature and location of the defect and the issue closure details. The data was filtered to ensure that only information relating to defects and design issues was identified. As noted above, some defects were categorised as miscellaneous. The site team's assistance was sought to establish the nature of those defects and categorise them. Only the building defects were included in this analysis (i.e., the defects in structures and areas such as gardens, fencing and sheds were excluded). As different electrical and heating systems were installed in the twelve houses, two sets of results were produced. The first data set shows the defects in those systems and the second one excludes them to improve the objectivity of the comparison. The defects in electrical and heating systems were likely to distort the research results because some heating and electrical systems generated significantly more patent defects than others.

Data analysis

The aim of this study is to identify, measure, analyse, synthesize, evaluate, and categorise the time, cost and patent defect performance of six construction methods used in a live research and residential construction project, including five MMC.

Construction time performance

Figure 1 illustrates a summary of the key findings from the relevant data analysis; specifically, it offers a comparison of the planned and actual construction durations.

Figure 1: Construction time performance

Time (per a pair of houses)						
Build Duration (Weeks)	Traditional	Modern Methods of Construction				
		Concrete Panel	Timber Frame Mod.	Light Gauge Steel	Steel Frame Mod. T1	Steel Frame Mod.T2
Planned duration	21	14.4	15.8	14.4	15.4	8.4
Percentage difference vs Traditional	0.00%	-31.43%	-24.76%	-31.43%	-26.67%	-60.00%
The actual duration	46.2	56.8	54.4	51	52.4	51.4
Percentage difference vs Traditional	0.00%	22.94%	17.75%	10.39%	13.42%	11.26%

The main research finding is that the planned time efficiencies did not materialise; specifically, (i) MMC should achieve, at least in theory, construction time efficiencies which are illustrated in Figure 1 by the shorter planned construction durations and (ii) the actual construction durations of all houses built with MMC were (between 10.39% and 22.94%) longer than the traditionally built dwellings.

Construction cost performance

Figure 2 shows a summary of the key findings from the data analysis; specifically, the cost of (i) substructures; (ii) superstructures; (iii) joinery; (iv) miscellaneous building elements (e.g., decoration, tiling, vinyl, and mastic sealant) and (v) preliminaries.

Figure 2: Construction cost performance

Cost (per pair of houses)	Traditional	Concrete Panel	Timber Frame Mod.	Light Gauge Steel	Steel Frame Mod. T1	Steel Frame Mod.T2
No. of buildings	2	2	2	2	2	2
No. of beds	2/3 bed	2/3 bed	2/2 bed	2/3 bed	2/2 bed	2/2 bed
Ground internal floor area (GIFA)	78/83	78/83	78/78	78/86	78/78	78/78
Substructures	£33,368.00	£33,473.00	£31,719.00	£34,724.00	£31,103.00	£34,646.00
Superstructures	£35,478.00	£69,409.00	£190,000.00	£71,940.00	£237,987.00	£187,685.66
Joinery	£14,846.00	£11,008.00	£0.00	£12,906.00	£0.00	£0.00
Miscellaneous	£45,059.11	£43,101.67	£0.00	£40,387.62	£0.00	£0.00
Prelims	£7,407.00	£14,415.50	£770.00	£12,060.00	£770.00	£770.00
Building TOTAL (per pair of houses)	**£136,158.11**	**£171,407.17**	**£222,489.00**	**£172,017.62**	**£269,860.00**	**£223,101.66**
Cost per m2	**£845.70**	**£1,064.64**	**£1,426.21**	**£1,048.89**	**£1,729.87**	**£1,430.14**
Percentage difference from Traditional	**0.00%**	**25.89%**	**68.64%**	**24.03%**	**104.55%**	**69.11%**
Adjust build cost (78m2)- Most Common G	**£65,964.80**	**£83,041.98**	**£111,244.50**	**£81,813.26**	**£134,930.00**	**£111,550.83**

The key finding from the cost comparison is that the cost of traditional construction was substantially lower than MMC; specifically, the cost per m2 of the traditionally built homes was from 25.89% to 104.55% lower than the properties built with MMC. The substructure cost of all six construction methods is comparable; however, the superstructure cost of the latter method was substantially higher than the former method. The use of modular construction methods generated insignificant preliminary cost efficiencies when compared to the higher construction costs of those methods.

Reported patent defects

Figure 3 illustrates a summary of the key findings from the data analysis; specifically, the number of reported issues with snagging items (or minor defects/outstanding work) per category, including (i) structural cracks; (ii) flooring; (iii) render cladding; (iv) brickwork; (v) decoration; (vi) plastering; (vii) damp; (viii) joinery; (ix) plumbing; (x) roof; (xi) screed; (xii) sealant and (xiii) windows and doors.

As noted above, various innovative smart technologies, electrical and heating systems were tested in the houses which were excluded from the comparison because this data distorted the overall findings. The main discovery was that overall, save for the houses constructed with the light steel gauge construction method, the average patent defect rate of houses built with MMC was higher than the traditionally built dwellings. Furthermore, the concrete panel systems averaged more defects than the three modular construction methods.

Figure 3: Reported patent defects

Average defects for all construction types (excluding heating and electrics)														
Type	**Structural cracks**	**Flooring**	**Render Cladding**	**Brickwork**	**Decoration**	**Plastering**	**Damp**	**Joinery**	**Plumbing**	**Roof**	**Screed**	**Sealant**	**Windows doors**	**TOTAL**
Traditional	0	0	0	0	0	0.17	0	0.83	0.83	0.33	0.17	0.17	1.67	4.5
Concrete panel	0	0	0	0	0	0.5	1	1	2	1.25	0	0	2.75	8.5
Timber Frame Modular	0	0	0	0	0	0	0	0	2.5	1	0	0	0.5	5
Light Gauge Steel	0.07	0.07	0.07	0	0	0	0.13	0.67	1.4	0.4	0	0.07	1.07	4.07
Steel Frame Modular Type 1	0.13	0.38	0.13	1	0.38	0.38	0	0.63	2.38	0.25	0	0	2.25	8.38
Steel Frame Modular Type 2	0	0	0.17	0.17	0	0	0	0.5	1.5	0.33	0	0.17	2	4.83
Average defects when all modern methods of construction are combined compared to traditional construction														
MMC	0.06	0.11	0.09	0.26	0.09	0.14	0.17	0.63	1.77	0.49	0	0.06	1.66	5.74
Traditional	0	0	0	0	0	0.17	0	0.83	0.83	0.33	0.17	0.17	1.67	4.5

The reported issues include dampness in the homes built with the light steel gauge and concrete panel building methods. Since the main construction difference between those two MMC and traditional construction is the inner leaf assembly, this could be the reason for the damp issues.

CONCLUSIONS

The discussion and conclusions centre on the relative time, cost, and patent defect performance of the five MMC examined here. The main finding is the relatively inferior time, cost, and quality performance of those MMC. This verifies previous arguments that some offsite approaches do not offer many real improvements compared with their onsite counterparts (Ayinla *et al.,* 2022). The areas of further advancement, include early detection of design and site issues, enhanced economies of scale, standardisation, and competence of human resources (e.g., see Yu *et al.,* 2019).

Construction Time Performance

The data presented here highlights some of the disadvantages of the modular construction methods; specifically, the impact of site and design issues on their construction time performance. For example, the inability to rectify design issues quickly on site means that the modules must be carried back to the manufacturing plant to be repaired and brought back again once the issues have been resolved which resulted in inadvertent delays. This suggests that, inter alia, the arguments made by (i) the National Audit Office (2005) claiming that modular construction methods are likely to produce time efficiencies of up to 400% when compared to traditional construction methods and (ii) Lawson and Ogden (2008) and Iuorio *et al.,* (2019) who suggested that some MMC can generate construction time efficiencies of 30-50% , are very optimistic theoretical estimates that can be significantly influenced by such time performance factors and may be difficult to achieve without further improvements. Therefore, the use of MMC does not guarantee actual construction time savings, unless such construction site and design issues are reduced. Furthermore, the specialist MMC contractors were relatively smaller which may have impacted the construction time performance of those MMC. Consequently, (i) the time efficiencies associated with, inter alia, simultaneous off-site and on-site activities (and contemporaneous construction and remediation efforts) can be offset by design and site issues and (ii) it may be unrealistic to use MMC to increase the number of homes built, which is a target of many governments, unless effective, efficient, and viable solutions to the issues presented here are applied.

Construction Cost Performance

The main finding is unrealised potential and/or unrealistic assessments of the potential cost advantages of using MMC in house building. For example, previous studies suggest that (i) off-site manufacturing could lead to cost savings of between 10 and

20% (Lawson and Ogden, 2008) and (ii) 15% cost reduction could ensure the viability of some MMC (National Audit Office, 2005). However, (i) one is unlikely to be achieved in low-rise home building, unless significant cost improvements are attained in the future and (ii) a cost reduction of around 25% (not 15%) may improve the viability of the concrete panel and light gauge steel construction methods as their costs were respectively 25.89% and 24.03% higher than the traditionally built houses. Therefore, a smaller (than 25%) cost reduction is likely to improve the viability of those two MMC if, among other things, the quality, desirability, and speed of construction provide advantages that offset the higher overall costs. For example, the planned construction durations indicate that, at least in theory, speed of construction is still a viable advantage of those two MMC. The two MMCs resulted in more reported patent defects. Consequently, the desirability of those two MMC is unlikely to increase based on their actual time, cost, and patent defect performance.

The data presented here corroborates the higher overall MMC costs than traditional building; specifically, the greater costs of the building superstructures which is attributable to, inter alia, greater manufacturing and set up costs (Lawson *et al.,* 2012). Therefore, the higher overall construction cost is indeed one of the main barriers to the use of MMC (Pan and Sidwell, 2011; Sutrisna and Goulding, 2019). Moreover, this study confirms that the MMC have lower anticipated (or theoretical) preliminary costs than traditional building (Lawson *et al.,* 2012). However, (i) the actual preliminary costs of the concrete panel and light steel gauge construction methods was higher and (ii) even if the planned preliminary costs materialised, this would not have made a significant impact on the overall cost performance as using MMC in home building was significantly more expensive than applying the traditional construction method because of the higher superstructure costs. This study also verifies that the costs advantages of using MMC in home building vary. For example, the concrete panel and light gauge steel houses were around 25% more expensive than their traditionally built counterparts whilst some other MMC (see Figure 2) were between 68% and 104% more costly than the traditionally built houses. Therefore, the construction sector has not moved further forward over the last two decades as MMC are still relatively economically inefficient which could have been impacted by, inter alia, the lack of (i) adequate planning and governmental support (Mesároš and Mandičák, 2015); (ii) a significant increase in MMC demand (Home Builders Federation, 2006; Rahman, 2014) and (iii) standardisation (Generalova *et al.,* 2016).

Reported Patent Defects

It has been claimed that the relatively higher quality and durability of MMC are one of the greatest advantages of off-site construction (Miles and Whitehouse, 2013; Yu *et al.,* 2019). Although the data presented here is limited to patent defects and design issues, the analysis of the findings suggests that, save for the light steel gauge construction method, the traditional construction method still outperforms the MMC discussed here. This data also verifies study findings suggesting that panelised systems generally result in more defects than full modular systems; specifically, defects associated with drylining, joinery, mechanical and electrical works (e.g., see Lopez and Froese, 2016). Furthermore, this study contradicts claims that the fixing methods used in buildings constructed with MMC cause leakage problems (Tam *et al.,* 2007). There were no reported damp issues in any of the modular buildings. This finding indicates that quality improvements in MMC are possible which is an important revelation as this can, in theory, improve the desirability of MMC. The limitations and mitigation measures of this study are discussed in the Methodology and Data Collection section. Future research should focus on improving the time, cost and patent defect performance of the five MMC discussed here by, inter alia, minimising the identified here issues and applying the offered solutions.

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A REVIEW OF THE ROLE OF PROJECT MANAGEMENT OFFICES IN ESTABLISHING OFFSITE CONSTRUCTION CAPABILITIES

Buddhini Ginigaddara Appuhamilage[1], Mahmoud Ershadi and Marcus Jefferies

School of Architecture and Built Environment, University of Newcastle, University Drive, Callaghan NSW 2308 Australia

Modern construction calls for lean principles which promote optimal use of resources and offsite construction (OSC). Project Management Offices (PMO) are important to establish project management (PM) methods. OSC is one of the domains in which PMO can facilitate communications and processes. Considering recent OSC technology developments and interrelations between off-site and onsite activities, the application of PMO can be advantageous in managing the interfaces and achieving on-time delivery. Research advocates many opportunities for OSC key players to harness the full potential of changing technological dynamics. However, the overlapping and diverse body of knowledge on OSC requires integrative studies to capture the contrasts and provide an exhaustive framework of such OSC capabilities. This research adopts a qualitative approach to review expert opinion on the role of PMO in inducing integrated OSC PM through central governance. The coherence of PMO capabilities in the OSC domain needs to be maintained since they are closely interrelated and complementary to each other. This study indicates the impact of central governance on bringing separated elements of OSC PM together and aligning offsite operations with strategies.

Keywords: offsite construction; project management; governance

INTRODUCTION

Constructing the future means prioritising sustainability objectives and adhering to environmental standards, which can be only achieved through achieving an industry-wide consensus on an overarching framework for sustainability. Modular construction is one of the cornerstones for a sustainable future that necessitates close collaboration of clients and contractors as parts of a construction supply chain. Integrative structures such as Project Management Offices (PMO) can benefit organizations in better implementation of initiatives for fully modular construction. PMO is an approach to integrated project management through central governance systematizing decision-making arrangements (Overgård, Jensen, and Thuesen, 2022). Previous research has argued that PMO incorporates characteristics to address project management matters concerning both the internal and external environment of an organization (Parchami Jalal and Matin Koosha, 2015). Regarding the

[1] Buddhini.GinigaddaraAppuhamilage@newcastle.edu.au

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interdisciplinary nature of construction projects, the internal environment deals with the interactions of several functional teams under the leadership of executives to achieve a specified target. Meeting the design and engineering specifications of deliverables also requires quality assurance throughout construction to enable project managers in identifying deviations and rectify errors in advance (Ershadi, Jefferies, Davis, and Mojtahedi, 2021).

The PMO phenomenon was first introduced to the literature in the late 1990s (Carden and Brace, 2022). This organizational concept has been theorized as a hub for the establishment of project management practice, as well as the centralized management of projects under its domain (Oliveira *et al.,* 2017). Three roles are generally assumed for PMOs: supportive, controlling, and directive. They are complementary to each other to provide full support for the project management practice in project-based organizations. The supportive role involves providing infrastructure such as processes, databases, knowledge repositories, etc. The controlling aspect refers to the operational oversight of operations in terms of complying with tools and methods; while the directive aspect extends the span of control to cover strategic matters of managing projects such as governance and portfolio-level decisions (Project Management Institute, 2017). These roles are interrelated since emphasizing just one aspect while neglecting others would not guarantee making a difference in the PM environment.

The functions and services that PMOs deliver to a construction organization justify their existence and their value to the construction business (Sergeeva and Ali, 2020). The PMO services for construction organizations aim to not only support projects but also to track business benefits. According to a survey conducted by Desta, Root, and Diederichs (2006) in the German AEC sector, the frequent tasks undertaken by PMOs in this sector include (1) Information dissemination (73.5%), (2) methodology development (67.6%), (3) monitoring and control (64.7%), (4) document lessons learned (52.9%), (5) resource allocation (50%).

The importance of OSC has been investigated in the literature. However, the approach to achieving integrated OSC project management is less explored. Regarding the potential of PMOs in this domain, there is still a need to explore how these entities induce such an integrated approach in construction projects. Therefore, the present study explains one of the important applications of the PMO concept in achieving this objective.

LITERATURE REVIEW

Offsite construction

According to the literature, OSC, refers to construction project delivery using modern methods of construction (MMC) where buildings are made in factories to be transported and erected onsite (Perera *et al.,* 2022). Furthermore, other words are used to refer to OSC and some of them are offsite manufacturing, offsite production, prefabrication, volumetric construction, panelised construction, and modular fabrication. OSC is a sustainable and an eco-friendly alternative that reduces the embodied carbon and end-of-life impacts (Tavares, Gregory, Kirchain, and Freire, 2021). Recent studies conducted on sustainability and OSC proves how OSC can be a better alternative to resolve negative environmental impacts of traditional construction (Langston and Zhang, 2021). Despite its existence for centuries, the uptake of OSC in construction projects has been accelerated due to Industry 4.0-driven technological advancements (Perera *et al.,* 2022). Factory-based production processes used in OSC promote those technologies such as advanced robotics, exoskeletons, cyber-physical integration, and similar technological adoptions.

PMO roles

Three roles are generally assumed for PMOs: supportive, controlling, and directive. They are complementary to each other to provide full support for the project management practice in project-based organizations. The supportive role involves providing infrastructure such as processes, databases, knowledge repositories, etc. The controlling aspect refers to the operational oversight of operations in terms of complying with tools and methods; while the directive aspect extends the span of control to cover strategic matters of managing projects such as governance and portfolio-level decisions (Project Management Institute, 2017). These roles are interrelated since emphasizing just one aspect while neglecting others would not guarantee making a difference in the PM environment.

An effective PMO is expected to support projects, control operations, and execute strategies (Paton and Andrew, 2019). In this regard, proper support mechanisms such as reporting systems and methodologies are required to allow for informed decisions at the portfolio level. A mere focus on supportive functions makes PMOs passive entities without the capability of enforcing methods and policies in projects. It is advised in previous research that without establishing a structure for project governance, the PMO may fail to deliver its expected value (Singh, Keil, and Kasi, 2009). A culture of governance should be established to intervene in project operations and decisions to minimise deviations from targets and maximise the productivity of all parties that contribute to the project delivery (Singh *et al.,* 2009).

Specifications governing PMO functioning in construction

Achieving full benefits from employing PMO principles in the construction industry requires an understanding of its specific characteristics in this context. It is needed to think outside of the boundaries of construction processes and incorporate factors from the surrounding environment to study construction-related PM outcomes concerning organizational structure, market, competitors, and business partners (Qi, Zhang, Wu, Chen, and Cai, 2014). A higher level of PM maturity is achieved only by benchmarking construction best practices and adapting the organization's PM practices to global standards so that maximum business values can be achieved through high-quality project delivery (Sandhu, Al Ameri, and Wikström, 2019).

Parchami Jalal and Matin Koosha (2015) theorized that conceptualizing this phenomenon in the construction sector requires an in-depth understanding of the internal and external environment of a construction enterprise. First and foremost, PMO specifications are driven by the role of an organization in the construction industry, ranging from employer/owner (in the public sector) to contractor, designer, and consultant (in the private sector). For instance, principal contracting organizations are responsible for coordinating involved parties and integrating their outcomes to ensure on-target delivery of projects. Thus, functions such as interface management are likely to take higher priority in such organizations. As a result of reviewing these studies, a conceptual framework of variables affecting the PMO characteristics in the construction industry was adapted from Parchami Jalal and Matin Koosha (2015) and Oliveira *et al.,* (2017). Considering this categorization, the internal and external factors that influence PMO contextualization in construction organizations can be enumerated as follows:

Nature of business: Contracting organizations need to take major decisions concerning outsourcing, partnership, tendering, and procurement. The complex nature of these decisions demands robust decision support systems to be in place. Effective environmental scanning should be applied by PMOs to help executives make informed decisions in such areas (Qi *et al.,* 2014). Contractors need to take their role, scale, and sector of business into account for designing suitable PMOs. A PMO which is running in large construction organizations may require more sophisticated tools and processes in comparison with that of small contracting firms.

Organizational drivers: The organization which hosts a PMO needs to consider both contextual and structural matters. The contextual aspect reflects the systems, maturity, culture, processes, and status of projects. They govern the arrangement of resources to be assigned to projects. Such elements can pave the way for standardizing PM practice or may hinder this process. Thus, close consideration helps practitioners to fit the structure of their PMO to the level of readiness in an organization that is characterized by such factors (Aubry, Hobbs, Müller, and Blomquist, 2010). The other type of organizational factors points to the structural attributes of a construction organization that encompasses delegation of authority, distribution of decision-making power, the framework of project governance, and level of complexity.

External drivers: This facet is related to the surrounding environment of an organization. PMO as a hub for PM activities needs to scan recent changes in regulations related to environmental standards, changes in the labour market, economic variables, and advanced tools and technologies (Daft, 2015). Best practices of the industry both on a national and global scale should be adopted towards enhancing procedures and methods that are being utilized in projects. One of the domains in which PMOs can contribute includes strategic planning of the enterprise by providing an overview of opportunities to liaise with strategic partners, entering a new area of business, and changes in portfolio-level rearrangements (Bredillet, Tywoniak, and Tootoonchy, 2017). An overview of the internal and external environment of construction organizations has been illustrated in Figure 1.

METHOD

The present study was conducted using a literature review and expert opinion on the role of PMO in inducing integrated OSC project management through central governance. The retrieval of the literature reflects different perspectives of researchers around concepts related to a certain topic. The role of PMO in central governance was assessed by reviewing relevant literature and eliciting research findings on the topic. The viewpoints of experts were obtained by interviewing them via an online platform. They were asked to provide their view on the key factors promoting integrated OSC project governance through PMO. The key steps of the research were (1) literature review, (2) expert interviews, and (3) thematic analysis.

A purposive method was used to select participants to provide their comments on the role of PMO in inducing integrated OSC project management through central governance. The criteria which were used for purposive sampling include (1) employees who work in collaboration with a PMO unit in main construction contracting companies based in New South Wales, Australia, and (2) more than 5 years of experience in project management. Initially, a list of 65 eligible participants was developed and an invitation email was sent to all the potential participants, out of which 20 participants agreed to attend interviews. The online interviews via

Microsoft Teams were conducted with participants to ask them the questions and record their answers to be thematically analysed after the session. The demographic analysis of 20 participants revealed that 40% had more than 15 years of PM experience, 40% with 11 to 15 years, and 20% with 5 to 10 years. The current paper reports part of broader research and the findings related to the role of PMO in establishing integrated OSC projects through central governance are discussed.

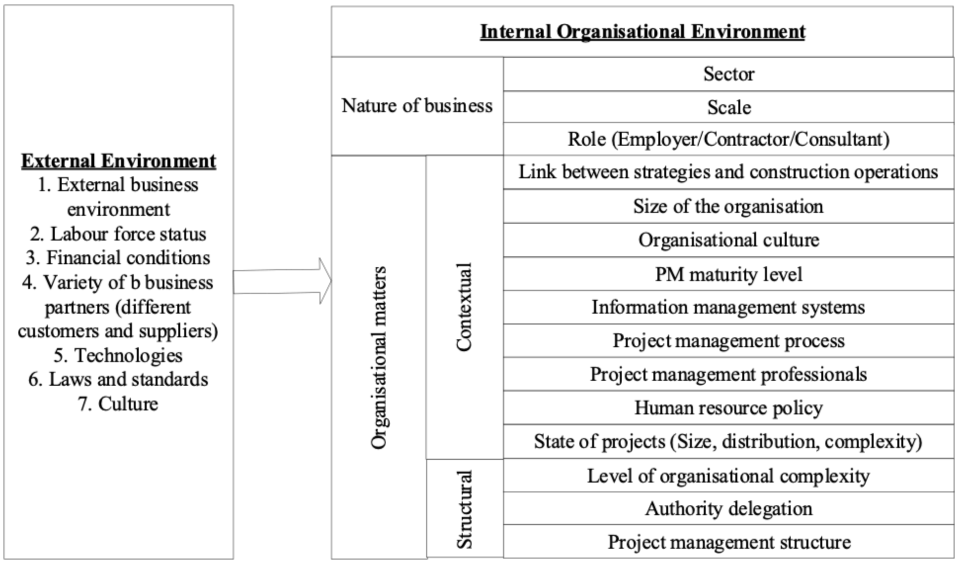

Figure 1: Domains of PMO influence in the construction industry

Each transcript which was developed as a result of an interview was reviewed and thematically analysed in terms of conceptual implications so that similar points can be consolidated to form an emergent open code. The interview transcripts were returned to participants for check and possible adjustment. The source of each factor was assessed in terms of their meaning and impact (Jaramillo, Sossa, and Mendoza, 2019). Then open codes were assigned to the relevant axial code deductively. Finally, 6 open codes and 3 axial codes (main factors) were identified to represent the factors for achieving integrated OSC project management through central governance mechanisms.

FINDINGS

As a result of conducting interviews and thematic analysis of the interview transcripts, three main factors were found concerning central governance. Table 1 summarizes the findings of the thematic analysis.

The summarized quotes were achieved as a result of reviewing the transcripts from 20 interviews. The frequency refers to the number of participants that mentioned the points. The first categorization refers to open coding and then the themes were identified in the axial coding (deductive) step. Three factors have been explained as follows and discussed considering the findings of previous studies on the topic.

Portfolio-level monitoring: Monitoring projects and their overall performance from the perspective of strategies is of crucial significance for any organization. The portfolio-level monitoring enables companies to ensure the alignment of operations with strategic goals. The significance of this level of monitoring was asserted by participants as the interconnection between projects and the organization's strategic plan. This finding can be discussed considering theoretical discussions in the literature. Deciding to bid on specific projects is one of the challenges faced by main construction contractors (El-Mashaleh, 2012). A PMO entity can significantly integrate different criteria to properly address this challenge by prioritizing such opportunities based on clear baselines such as the status of resources, competitors, and business strategies (Sandhu *et al.,* 2019). Integration of performance indicators at the portfolio level provides executives with information to make informed decisions about bidding tenders that affect the future development of core competencies.

Table 1: Deductive coding of experts' suggestions on factors contributing to integrated governance of PMO for effective OSC

Summarised quotes	Frequency	Open codes	Axial codes
Set portfolio key performance metrics align with portfolio goals	3	Portfolio performance metrics	Portfolio level monitoring
Implement management dashboards to visualize portfolio performance metrics	1		
Undertake regular reviews to ensure portfolio strategies are being met	2	Track portfolio strategies	
Set portfolio goals and strategies	1		
Clarify directions and decision-making procedures	2	Determining project governance policies	Enforcing governance policies
Develop a basis and framework for implementing project governance	1		
Ensure compliance with governance policies and procedures	1	Implementation of governance policies	
Implement governance controls consistently	1		
Prioritise the projects that support strategic goals	2	Systematic prioritization of projects based on strategies	Alignment of strategies with project execution
Prioritise projects for resource allocation	1		
Terminate projects that are of low priority	1		
Alignment of performance metrics of projects with strategies	3	Ensure projects support strategic goals	
Consult stakeholders regarding the strategic contribution of projects	1		

Enforcing governance policies: The second important factor in this research refers to "enforcing governance policies" that indicate the importance of utilizing organizational enablers for facilitating the role of PMO in embedding central governance. Authority, governance structure, and responsibilities need to be determined and integrated to enable effective project governance on all projects systematically. This finding of the current study revealed that a preliminary for integrated project management through central governance is setting a baseline and then regular control to ensure compliance throughout the organization. Robust governance policies clarify the roles and responsibilities of all stakeholders and equip the governance team with best practices to direct the multi-project environment toward PM excellence. Main contractors deal with the supervision of multiple suppliers and subcontractors (Mokhtariani, Sebt, and Davoudpour, 2017) which requires the incorporation of the perspectives of executives and project managers in governance policies. The governance team need to be assured of the implementation of policies by leveraging organizational enablers. The importance of governance policies has been acknowledged in the literature covering both the primary enablers, especially top management support, and compliance (Ayyagari, Henry, and Purvis, 2006).

Supportive culture plays an important role in facilitating the implementation of governance policies. The awareness of stakeholders on the roles and responsibilities and the requirements to accomplish them help the governance team to gain buy-in before taking any action and making major decisions (Desta *et al.,* 2006). The effect of supportive culture on organizational governance has been discussed and established in other contexts such as Information Technology (Arumugam, McKay, and Grainger, 2013) in so far as it can be presumed as an underpinning element for achieving successful governance outcomes. Considering supportive culture, the governance team is more likely to effectively cooperate with project/functional teams and make effective decisions (Oliveira and Martins, 2018).

Alignment of Strategies with Project Execution: Integrated project management through central governance is impossible without aligning operations with strategies via systematic feedback from execution and revising the governance policies and structure accordingly. Information systems are used to capture data from execution, analyse them, consolidate them, and report to senior managers for decision-making. Participants posited that effective governance requires to be continuously revisited and adapting to the recent needs and requirements of the multi-project environment. This feedback needs to be comprehensive and incorporate a broad range of both internal and external stakeholders. Effective feedback from execution constitutes another pillar of successful governance because the governance team is partially or fully accountable for the project outcomes. The governance team need to provide project teams with effective guidelines for mitigating risks and increasing the chance of successful delivery by supplying proper governance policies.

DISCUSSION

Execution teams need to manage multiple delivery methods at different stages throughout the project lifecycle, which necessitates the existence of clear guidance and policies to direct them towards successful outcomes. The effective delivery of individual projects starts with following the best strategies from the project definition stage toward design, procurement, construction, and handover, depending on the level of the project's independence and the number of project stakeholder organizations (Artto, Kujala, Dietrich, and Martinsuo, 2008). Project delivery in contracting companies is also inherent with active collaboration with the owner and other parties, handling cross-project dependencies (Bilgin *et al.,* 2017), resource allocation and management (Asgari, Afshar, and Madani, 2013) and tackling issues and delays throughout the execution (Kumar, 2016). According to the findings of this study, integration of outcomes related to involved disciplines requires adapting governance procedures based on recent needs and requirements of projects. Otherwise, it is likely that the execution team resists such policies due to their ineffectiveness and unnecessary bureaucracy (Figure 2).

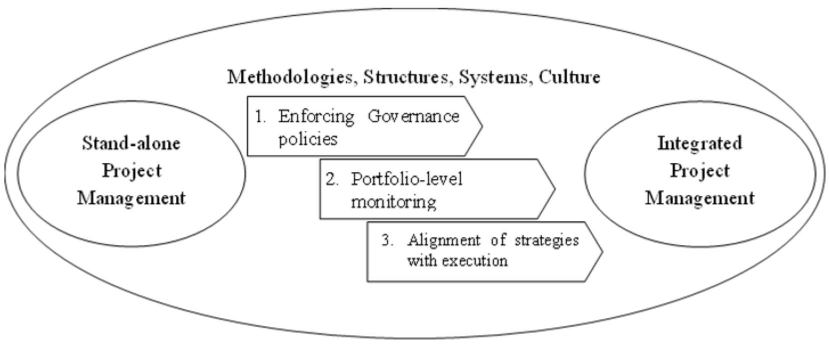

Figure 2: The transition from stand-alone to integrated project governance

A key tool that needs to be employed for obtaining feedback from execution includes information systems that collect and report performance data and share it with all stakeholders including the governance team. Such systems are indispensable parts of project governance due to the centralization of data and data circulation among decision-makers (Martinez and Ortiz-Marcos, 2019). The importance of implementing information systems in facilitating the stream of project information is also asserted in different independent studies (Philbin, 2018). Contractors deal with the coordination of part of the work completed by subcontractors and suppliers and integrate their respective outcomes to deliver the whole project (Mokhtariani *et al.,* 2017). The findings showed that information systems capacitate contractors to integrate their performance data for better analysis and feedback that is necessary for reviewing governance policies.

CONCLUSIONS

This research paper contributes to the body of knowledge by highlighting the central governance of PMOs to establish integrated offsite construction project management. Maintaining a high level of cross-project integration and consistency is vital in large construction projects that are multi-discipline and risky. Well-defined governance mechanisms contribute to consistency and integration in OSC projects. This study introduced aspects that need to be considered for this purpose. Effective governance structures determine the roles and responsibilities of stakeholders and provide baselines to align OSC operations with strategies. They constitute a suitable basis for achieving cross-project integration. The project governance team captures improvement opportunities and coordinates all involved parties to minimize risks and improve offsite tasks. Aligning OSC projects with strategies and obtaining feedback from execution also helps to realign policies with organizational needs and necessities. It was found that three elements are vital to induce integrated project management via central governance: (1) portfolio-level monitoring, (2) enforcing governance policies and (3) strategic alignment of projects with strategies. This study shed light on the impact of central governance on bringing separated elements of OSC project management together and aligning offsite operations with strategies. However, more research still needs to be carried out to investigate governance mechanisms and the best approach to implement them in project-based organizations.

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KNOWLEDGE TRANSACTION BETWEEN OFFSITE AND ONSITE INTERFACES

Kingford Mkandawire[1], Shabnam Kabiri and John Connaughton

School of Built Environment, University of Reading, White Knights, Reading, Berkshire, RG6 6AH, UK

Interface discrepancies continue to cause buildability problems when incorporating offsite elements/products into onsite construction. One important challenge in this regard is related to effective knowledge exchange across structural and organisational boundaries to coordinate and manage the interface discrepancies. Distributed Situation Awareness (DSA), with its focus on the knowledge transactions between social and technical systems, allows the analysis of knowledge exchange in the offsite and onsite interfaces. A case study of roof-hanger buildability incident is presented. The data are collected in the one case project in the UK through direct observations on-site, semi-structured interviews, and documents and emails. Three main phases were identified in the incident: The transition, response to the discrepancies, and reactive measures. The analysis shows that there was a decrease in coordination and knowledge exchange in all three phases. It is concluded that viewing the knowledge transactions in the incident from a socio-technical perspective made it possible to determine who knows what at a given time. This ultimately makes it possible to show knowledge interdependence in the project system.

Keywords: Distributed Situation Awareness; exchange; interface discrepancies

INTRODUCTION

Offsite elements have been adopted by the construction industry in a recent drive to modernise its operations and increase its productivity (Goulding *et al.,* 2015). Operations that were traditionally conducted on-site are instead done at an offsite manufacturing factory, with the offsite products transported and installed by a different organisation. Having operations of the offsite products done in the factory and installed directly onsite has been argued to provide advantages in terms of speed, quality, waste management, and cost (McCarney *et al.,* 2022). However, interfacing the offsite products supplied or installed by different manufacturers and subcontractors onsite requires careful coordination to deal with a range of interface discrepancies that give rise to potential buildability problems (Pan *et al.,* 2023).

Interface discrepancies across various building elements are caused by factors emerging from the design, manufacturing, and construction processes (McCarney *et al.,* 2022). Not all the individuals involved in the interfaces are aware of what was designed and produced. This fact can create challenges in interfaces. Project participants may have different interpretations of functional requirements, work to various technical standards, or have different work practices (Talebi *et al.,* 2021). The

[1] kingford.mkandawire@reading.ac.uk

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separation of design, manufacturing, and installation creates different functions and roles (Fellows and Liu, 2012), which can turn into organisational barriers to effective knowledge exchange, particularly in offsite construction (OSC) (Liu *et al.,* 2022). Some scholars argue that this is exacerbated by the adversarial, and short-term relationships that prevail in construction settings. (Fellows and Liu, 2012, Mccarney *et al.,* 2022).

The current and future success of offsite and onsite construction incorporation relies on the social and technical interdependencies that facilitates knowledge exchange (Liu *et al.,* 2022). The right knowledge being distributed at the right time among project interfaces facilitate organisational processes (Bosch-Sijtsema and Henriksson, 2014; Liu *et al.,* 2022). This paper explores how distributed knowledge calls the essence of coordination between interfacing organisations about building elements in instances of interface discrepancies.

To study knowledge distribution and exchange in the interfaces, the research introduces the concept of *installation gap*. The *installation gap* describes the 'space' in a workflow between building elements (offsite and offsite building elements or offsite and in-situ building elements). In this process, the focus is on the activities with finish to start relationships meaning the installation or construction of the second building element can start after the first building element is installed or constructed. A sociotechnical systems approach was adopted to view humans as assets rather than the source of the interface discrepancies. The primary research question is to explore how knowledge is distributed within the construction system when there is an installation gap.

LITERATURE REVIEW

Many performance problems with OSC are attributed to poor interface management in the design, manufacturing, on-site installation, and technological immaturity (Pan *et al.,* 2023; McCarney *et al.,* 2022). An interface is defined as "a boundary where interdependence exists across that boundary and where responsibility for the interdependence changes across that boundary (Healy, 1997, p.68). Pavitt and Gibb (2003) while exploring interface issues in Building Façade demonstrated that interface management can enhance communication and coordination for managing the organisational, contractual, and physical interfaces. Ahn *et al.,* (2017) found that current interface management practices are effective in addressing complexity factors related to scope, communication, and multiple project stakeholders, but they are not effective in dealing with project complexity originating from engineered items. In this specific research, this result was surprising given the availability of interface manager and interface coordinator roles within the case study of the research. This conclusion challenges the clarity of such roles, their responsibilities and, essentially, effective interface management practices. Further research can shed light on how the participants involved in the interfaces interacted and/or coordinated around the interface matters.

Interdependence, specifically, task interdependence, which is defined as the extent to which project members must interact and depend on each other for the work to be accomplished (Bygballe *et al.,* 2016), has been recognised as the leading element in interface management. Primarily, task interdependence is managed through coordinating, which is explicitly done through planning and communication or implicitly via anticipation of others' needs (Bygballe *et al.,* 2016). These studies describe how both planned and emergent structures can help with the coordination of the efforts of project participants who work interdependently on tasks (e.g., installation tasks). However, the focus on coordination and interaction among people as they work interdependently has focused less on the technical interdependence of the interfacing building elements which are the focal point of the task. As a result, interface discrepancies have been considered to emanate from people only, leaving out the interaction of the people and technical elements.

As more offsite products are being introduced into construction projects, interdependences among them or with the in-situ building elements spring up. Such interdependence is referred to as building elements interdependence in here. More specifically, building elements interdependence is defined as the interfacing building elements that are design, structural, and programmatically interrelated to the extent that one cannot be installed if the other has not been installed.

As offsite products continue to rise in the construction industry, understanding building elements interdependence may be as important as understanding task interdependence to address joints, connections, and interface issues (Pan *et al.,* 2023; McCarney *et al.,* 2022). Understanding the sociotechnical system in understanding building element interdependence will help to unpack how coordination happens and how coordination failures could be avoided. To do so, this paper adopts a sociotechnical system approach to examine knowledge exchanges that activate coordinating needs when incorporating offsite products into onsite construction.

Distributed Situation Awareness (DSA) Theory as a Theoretical Background

Distributed Situation Awareness (DSA) theory focuses on how information and knowledge are distributed across sociotechnical systems. The focus is on the awareness that is distributed across human agents (e.g., project participants) and nonhuman agents (e.g., artifacts such as tools, documents, and displays) of a system. Central to DSA is the notion of "transactions" between agents as the mechanism through which a system retains awareness while performing a task (Stanton *et al.,* 2006). A transaction in this context refers to an exchange of situation awareness between agents. It encompasses more than just the conveyance of information (Salmon *et al.,* 2009). In a transaction, agents communicate or coordinate with one another, exchange information, act on it once it has been combined with other information, and then transfer that information to other agents (Salmon *et al.,* 2009). Each agent has a unique interpretation of that information. For instance, information regarding a particular building element detail may rightly be used and interpreted differently by the subcontractor or trade as it is combined with other information to enable each to carry out their specific task. Both are utilising the same information for their respective purposes, including it in their respective schemas, and coming to their interpretations (Stanton *et al.,* 2006). Without any necessity for parity of meaning or purpose, elements of one agent's situation awareness can interact with those of another.

Reflecting on the aim of the study, using the lens of DSA and considering the incorporation of offsite products into onsite construction as a sociotechnical system, this research attempts to answer what transactions in awareness could result in better coordination based on the specific case of this study.

METHOD

Using the lens of DSA theory, the focus of the study is on the knowledge transactions between the project's sociotechnical system to manage interface discrepancies. The aim is to understand how knowledge related to interface discrepancies is transacted across the agents (Humans-Designers, Manufacturers, Main Contractors, Subcontractors, and nonhumans-drawings (2D and 3D), etc). Studying the knowledge transactions during the actual installation/construction tasks as a phenomenon involves direct contact and close interaction between the researcher and the project interfaces. The research adopts a longitudinal case study approach to investigate and describe the events as they unfold in the real-world context (Creswell, 2014). The data are collected for a period of 5 months in one case project in the UK through direct (nonparticipant) observation on-site, 6 semi-structured interviews, and document and email reviews. The project included the installation of Structural Insulated Panels (SIPs) for wall and roof panels and the timber cladding. To maintain focus on the interfacing issues happening during the installation tasks, the research targeted onsite participants from the Main Contractor, Manufacturer, and Cladding Subcontractor. Interviews were conducted face-to-face averaging a duration between 30mins and 45mins. By using active interviewing (Cicmil *et al.,* 2006), the participants were encouraged to share their reflections and accounts of the installation gaps during the installation tasks. In this case study project, there was an installation gap related to roof-hangers.

THE PROJECT AND ROOF-HANGER BUILDABILITY INCIDENT

The construction project is in West London, England, and is a new single-story school for children with special needs and disabilities. The project is a design and build contract, with a construction cost of £11.4million. The ground floor area is 2500m². Australian Construction Exchange (Aconex) was used for construction project information and process management (managing processes, documents, drawings, building information models, communications, workflows, and audit trails. During the installation works, there was a roof-hanger buildability incident because of the discrepancy between the manufacturer and the cladding subcontractor. The cladding subcontractor observed that the roof overhand constructed by the manufacturer was out of tolerance by 100mm as it was supposed to be 300mm from the wall, but it was 400mm. The tolerance issue had a negative impact on the cladding brackets as they could not be structurally approved to support the timber cladding. Hence, a 91m length of the roof-hanger had to be cut short to align with the timber cladding details.

ANALYSIS

For the analysis of this *installation gap*, using the DSA lens, technical agents including construction drawings (both 2D and 3D), sketches/representations, and information platforms were considered. DSA analyses include defining a system's awareness during several task phases and focusing on transactions between 'agents' (Stanton *et al.,* 2006). To do so, the roof-hanger buildability incident is grouped into three main phases: 1) the 'transition'- after the subcontractor completes work, 2) the response to the discrepancies, and 3) the reactive measures to the buildability incident.

To identify keywords that represented different informational pieces in all three phases of the incident, a content analysis was done. The DSA framework, which sought to distinguish between function words and content words, guided this action (Stanton *et al.,* 2006). To highlight the contextual pieces of information distributed in the system, a prepositional network is constructed from the information elements extracted in the content analysis of the transcribed interviews. These were compared with the observation notes and the email exchanges to increase the credibility and reliability of the data (Creswell 2014) .

A propositional network is described by Salmon *et al.,* (2009) as "a network showing the information underlying a system's awareness and the links between the different bits of information"(Salmon *et al.,* 2009, p. 60). Through this, a clear picture of the systems' awareness is shown, and it is possible to track the effects of transactions (or lack thereof) over time. The propositional network for the roof-hanger and cladding incident is presented in Figure 1.

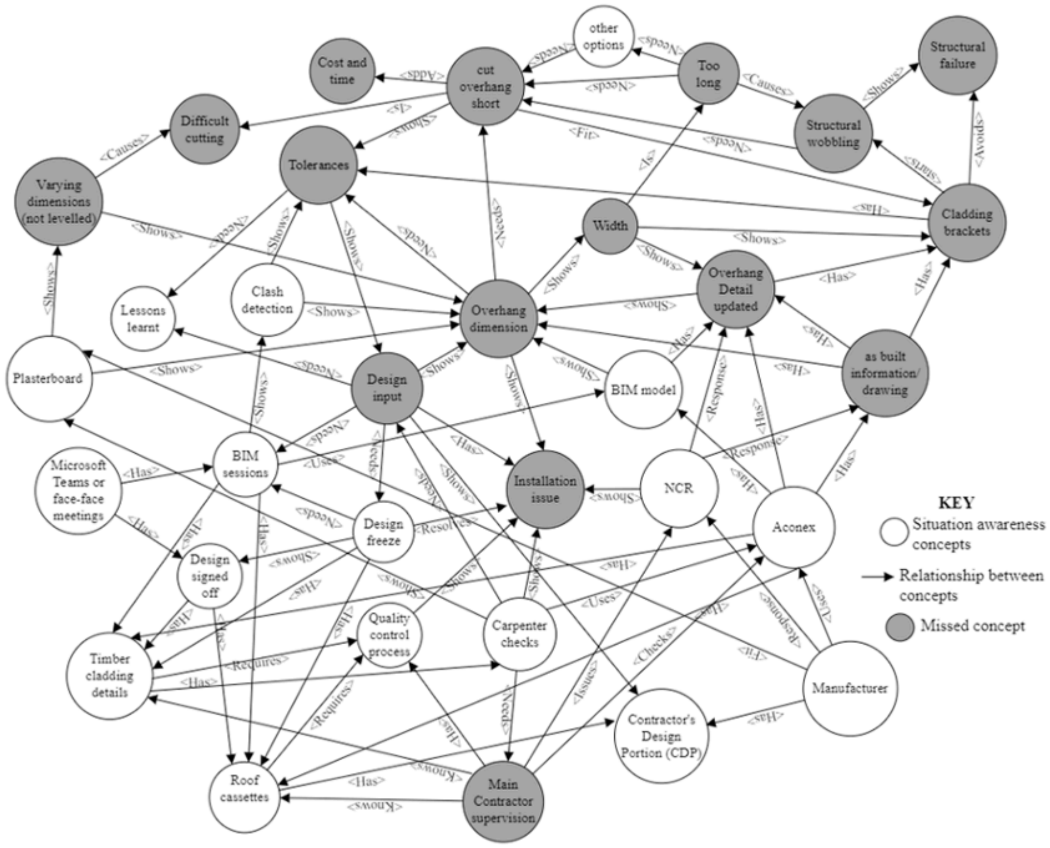

Figure 1: Propositional network for the whole roof-hanger incident

The analysis highlights which aspects of the communication between human and non-human agents underpinned the incident-that is, which information pieces were available or were not available to the key agents at the right time. Verbatim comments are also included in the analysis and findings to indicate the reflections, perspectives, and experiences of the human agents involved.

To begin with, an important concept within the network is overhang dimension which shows that the width was too long beyond the designed width to accommodate the cladding brackets. This transaction in awareness led to the discovery of the installation issue which triggered the need to cut short the overhang, a length of 91m. The Main Contractor and Manufacturer during the installation of the roof-hanger had (cladding brackets, overhand dimension, width, Aconex) information nodes. But they had no transaction awareness of the tolerances and the dimension width to enable the cladding brackets to fit and hold the timber cladding. The Main Contractor was not aware of what tolerances or width the Manufacturer was installing. Further, the Main Contractor was not aware of the Manufacturer's intentions around controlling the tolerances and width of the overhang. There was a shortfall of transaction awareness between the Main Contractor and the Manufacturer.

In addition, the finding puts into question the Main Contractor supervision within the network, which suggests an overreliance on the subcontractors to finish the task under minimal supervision as they are assumed to have the full knowledge of the task. This could have a negative implication on transaction awareness of what is being built and what was designed. It is observed that during the installation works, the Main Contractor was not aware that the roof overhang was not installed as designed. This is acknowledged by the Quantity Surveyor:

> What we should have done is measuring things ourselves and visiting the factory, which we should not be doing because they are deemed as a competent subcontractor...they are experts. This is a case of their ends - internal processing like undertaking checks and all that kind of stuff, making sure everything is according to the design. (Quantity Surveyor, Main Contractor)

The Main Contractor and Manufacture did not refer to or discuss the overhang dimension, which brings into question whether both were aware that the cladding brackets required a specific width to attain structural integrity. The Manufacturer acknowledges that the manufacturing and installation of the roof cassettes were within their tolerances (+/-25mm). When the Cladding Subcontractor was setting up the task for cladding installation and did the dimension checks, it was discovered that the plasterboards had dimension variations (between 40mm and 50mm). This relates to a lack of awareness regarding the purposes of the cladding brackets. If the Manufacturer and the Main Contractor did have knowledge of the purpose of cladding brackets, they could have discussed that dimension variations will lead to difficulties in fitting the cladding brackets or cause structural failure due to wobbling of the cladding brackets.

The concepts relating to design signed off, overhang detail updated, and as-built information/drawing shows shortfalls in human-to-human and non-human-to-human transactions in awareness. The Manufacturer is of the view that the installation task of the roof-hanger was done based on the design that the Main Contractor signed off. However, the Main Contractor insists that the installation task was not according to the design. Yet, the Main Contractor and Manufacturer access the same information sharing platform - Aconex. It is unclear why the Manufacturer and Main Contractor could have different information. The interview quotes the Senior Site Operation Manager from the Manufacturer suspecting that the Main Contractor changed drawing details in Aconex.

> The drawings we submitted were accepted and signed off by the Main Contractor, but at a later date they said the drawing needs to be something else. You will get (nearly) to the end of the job, and they will change. The model was different from how we interpreted it in the first place. They change the model and change over the surveyor who has a new pair of eyes and can claim that they do not know what went on and use that as a reason not to pay the money. The lesson is, do not work for this Main Contractor again. (Senior Site Operation Manager, Manufacturer)

If the model/drawing information was updated in Aconex, does it mean that Aconex did not generate an alert or notification to the relevant parties about this? Or does it not have an unalterable audit trail to capture and track any sudden information updates? Any cloud-sharing platform should have a prerequisite audit trail setting. This shortfall in transaction awareness between non-human-to-human could fuel uncountability and disputes in construction projects. If Aconex had generated an alert and audit trail, then any information updated could have been noticed by the interfacing parties. Moreover, it could be that the Manufacturer is not fully familiar with Aconex usage, or the Main Contractor did not check the settings. This questions the design of Aconex training, and whether more can be done to address the challenge that the Manufacturer or Main contractor faced. Furthermore, there was no transaction awareness between the Main Contractor and the Manufacturer on the design drawing and as-built drawing. The Project Manager outlines this:

> One of the responses we have got back in the non-conformance report (NCR) is that it is a changed detail. They cannot change the detail without us approving it. If they changed the detail and we approved it, then there is a bit of an argument and a bit of a slap on the back of the hand or for whoever signed that off, because that is not what we wanted and we need to learn from that, but the Manufacturer cannot update a detail in Aconex without us commenting against it. This was my argument back to them to say well, it still stands in your court because you might update the detail, but you did not send it to us. (Project Manager, Main contractor)

A final interesting concept is that of 'other options', which questions the effectiveness of the design and onsite meetings conducted online (through Microsoft Teams) and face-to-face when it comes to resolving interface issues at an early stage. The concept of 'other options' confirms the interaction and coordination aspect of making sure that the required width to fit the cladding brackets was achieved. The meetings initiating the reactive measures to resolve the incidents were mostly done face-to-face onsite. Importantly, it was only after the prevalence of the overhang incident that much emphasis and coordination was put on the fitting of the interfacing building elements. The finding could mean that during the design and onsite meetings, high coordination was more tied to task dependency whilst there were low levels of coordination between building element interdependence. Hence, when the knowledge of the discrepancies was activated between the interfacing parties, higher levels of coordination on the interfacing building elements were observed. The findings also suggest that online meetings (Microsoft Teams or Zoom) may be suitable for discussing task interdependence but not building elements interdependence. Senior Site Operation Manager reflected on online meetings:

> I feel like people are not committed in Microsoft Teams meetings. We are better off face-to-face. There are fewer sketches in Teams to emphasize your point and there is less motivation, and it is a bit like people are busy using their mobile phones.... there is a bit of frustration. Teams' meetings work well in some regards, and maybe other organizations prefer teams other than face-to-face meetings. (Senior Site Operation Manager, Manufacturer)

DISCUSSION

The analysis presented aids the understanding of DSA in examining the interface discrepancies by identifying a subset of knowledge transactional-related failures occurring in the construction sociotechnical system. The network constructed represents the pieces of information (concepts) that the interfacing organisations could have used to help understand the situation, respond appropriately, and prevent the incident. The pieces of information reflect knowledge transactions in the *installation gap* (between the overhang and timber cladding). In line with sociotechnical thinking, the research focuses on the interaction between agents rather than the agents themselves. For instance, the focus is not on the Manufacturer not being aware of something, but rather it is on the interaction between the agents that did not allow the appropriate knowledge transaction to be distributed as it should have been. This means that the sociotechnical system comprising the Main Contractor, Manufacturer, Cladding Subcontractor, Aconex, BIM models, and construction project systems did not facilitate appropriate knowledge transactions to avoid the incident.

The study shows that three classes of transaction awareness failure were uncovered namely, absent transactions, inappropriate transactions, and misunderstood transactions (Salmon *et al.,* 2016). These failed transactions have been described as the root of incidents occurring in sociotechnical systems (Salmon *et al.,* 2016). Absent transactions are instances in which a transaction in awareness was required but was not initiated. This includes scenarios in which the exchange should have occurred, but it did not due to a failure of some kind (e.g., inadequate details, inadequate quality control processes). Inappropriate transactions occur when a transaction in awareness is initiated but the transaction content is incorrect. This includes scenarios in which the human or non-human agent initiating the transaction (e.g., Aconex, drawings) provided incorrect information or the awareness being exchanged is incorrect. Misunderstood transactions occur when the receiver misinterprets the information or image being transferred.

Overall, the findings show the project system had low levels of coordination tied to building elements interdependence before the incident. This resulted in failing to capture the knowledge (i.e., tolerances, width) for coordinating both the Manufacturer and Cladding Subcontractor building elements. The findings are in line with Ahn *et al.,* (2017) that interface management practices are not effective in dealing with project complexity originating from engineered items/components. This could be that there is low knowledge exchange or unfamiliarity with the interfacing building elements leading to the complexities. When planning, designing, manufacturing, and installing building elements interfaces, the construction project system should embrace knowledge interdependence to address the interface discrepancies.

Knowledge interdependence between the agents describes the disparities between agents' knowledge and expertise as well as the potential outcomes of agents having compatible knowledge (Raveendran *et al.,* 2020). Previous research in modular construction highlights interface problems and recommends that improvements in the design, and more interaction and knowledge exchange between the design team, manufacturer, and different trades could avoid interface problems (Pan *et al.,* 2023). This was verified in the findings from the case study, which observed that interface discrepancies were addressed during the incident. This was because of low knowledge interdependence levels between interfacing parties at an early stage.

Lastly, the study highlights that online meetings could be best suited for coordinating task interdependence but not for coordinating building elements interdependence. Face-to-face meetings are effective for capturing patterns of knowledge transactions through sketches and other representations which were discussed as difficult to show during online meetings (Microsoft Teams/Zoom). The knowledge exchange during face-face meetings aids a higher level of common understanding to ‘fit together’ the interfacing building elements. Common understanding is high when agents in an interdependent task transact knowledge of the task that is to be done, how it should be done, and its aims and objectives (Bygballe *et al.,* 2016). Thus, information management systems (e.g., Aconex), drawings, BIM models, or other details drawn by the organisation to facility interface meetings should be designed to embody common understanding. This is because knowledge exchange is facilitated by different social and technical processes (Barley *et al.,* 2018).

CONCLUSION

The research presented in this paper viewed knowledge transactions in the buildability incident from a sociotechnical perspective. This made it possible to determine who knows what at a given time in the *installation gap*. The study shows three classes of transaction failures that contributed to the incident, absent transactions, inappropriate transactions, and misunderstood transactions. These transaction failures contributed to low levels of knowledge interdependence for coordinating the interface discrepancies.

The implication of this paper is on two themes, with an emphasis on 'Constructing the Future'. First, to avoid costly rework in OSC, the project system design should be flexible in balancing levels of coordination related to task interdependence and building elements interdependence to understand interface issues, joints, and connections. Secondly, by understanding why and how to interface discrepancies or buildability incidents occurred, it is possible to suggest ways of designing and developing systems (e.g., to increase salience including online meetings) and training procedures (e.g., Aconex usage) to facilitate higher levels of knowledge interdependence and coordination between interfaces.

One limitation of this study is that factors and behaviours influencing high or low coordination practices related to building elements interdependence were not considered. Future research should continue to delve into the role of transactional situation awareness to find out what factors influence the development of low versus high-coordinating practices and mechanisms for managing building elements interdependence in knowledge work. Such a study is crucial to advance the OSC field and bridge the gap between the concepts and approaches presented in the literature and what project participants experience (Cicmil *et al.,* 2006).

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PEDAGOGIC RESEARCH

WHEN ENOUGH IS NOT ENOUGH! EVALUATING THE MINIMUM ENTRY REQUIREMENTS FOR APPRENTICESHIPS IN IRELAND

Elma McMahon[1], John P Spillane and James G Bradley

Irish Construction Management Research Centre (ICMRC), School of Engineering, University of Limerick, Limerick, V94 T9PX, Ireland

In Ireland, enrolment in built environment apprenticeships requires the satisfaction of minimum entry criteria of at least five pass grades in the Junior Certificate examinations or equivalent. This study looks at the correlation between the academic performance in these examinations and successful completion of the apprenticeship process. It concerns 60 randomly selected carpentry and joinery, electrical and plumbing apprentices, registered between 2010 and 2016 with an expected completion date between 2014 and 2020. This paper presents a dataset for evaluating apprenticeship entry requirements and assessing the influence of STEM subjects on apprenticeship completion. The study found on average, 55% of candidates presenting with Junior Certificate completed their apprenticeship, growing to 100% as the candidates' prior academic achievement increased. Additionally, the impact of mathematics entry level was significant, with completion rates increasing to 100% when higher level mathematics was undertaken. Because of the lack of readily available data, limited research exists evaluating entry requirements and as such the key contribution of this research will be to provide a base for further investigations and increase eventual apprenticeship completion rates.

Keywords: Apprenticeship; barriers; learning analytics; vocational; education

INTRODUCTION

An apprenticeship is a structured further education and training (FET) programme which formally combines learning and training in the workplace and an educational setting (Education and Skills, 2013). Apprenticeship addresses the demands of the economy and prepares the apprentice for their future career. Under the Industrial Training Act 1967, An Seirbhísí Oideachais Leanúnaigh agus Scileanna (SOLAS) is the national authority with statutory responsibility for apprenticeships. There are eight built environment apprenticeships available within a total of 67 programmes. These are brick and stone laying, plastering, electrical, stonecutting and masonry, wood manufacturing and finishing, painting, and decorating, plumbing and carpentry and joinery. These adhere to a seven-phase, standards-based, on-the-job, and off-the-job strategy to achieve QQI (Quality and Qualifications Ireland) Level 6 certification (O'Connor, 2006) which is equivalent to Level 5 on the European Qualifications

[1] mcmahon.elma@ul.ie

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Framework. The minimum duration of an Irish apprenticeship is 208 weeks, a reasonable completion cut-off date of 234 weeks was selected to account for examination board approval and certificate issuance. Neuber Pohl (2021) acknowledged the possibility of taking the final exam after the apprenticeship contract concludes and permitted updates to the education variable within 183 days following the end of the apprenticeship period.

As with any system or programme, it is prudent to examine the model and learn from findings. Completion rates are one way of indicating success and can determine the fundamental health of the curriculum and delivery of the programme. Gaining an understanding of this process is critical in assisting government agencies and training providers to determine whether and when to implement specific measures to increase apprenticeship completion. From a purely financial point of view, the 2019 Review of Participation and Costs of Apprenticeship reported that the costs of an apprenticeship to Irish government was €7,159 to €9,877 annually (Moran, 2019). The academic achievement of apprentices is one of the primary goals of the Irish government (Department of Further and Higher Education, 2021). The Action Plan for Apprenticeships 2021-2025 has set a target to increase the number of apprentice registrations to 10,000 annually by 2025 (Department of Further and Higher Education, 2021) which represents a 18% increase from registrations in 2022. This is in addition to the 17,000 construction employees who will be required to achieve the national retrofitting of 500,000 houses (SOLAS, 2022). However, high completion and retention rates were found to be as important as increased registrations in order to address skills shortages (McMahon, 2022).

This study specifically examines carpentry, electrical, and plumbing trades, which collectively represent around 94% of registered apprentices within the built environment sector (SOLAS, 2023). These trades are crucial in addressing the shortage of qualified workers in the construction industry as outlined in government publications (Phulphagar, 2022). According to the findings of the research report titled "Construction in Ireland 2022: Building a Workforce for the Future," construction companies are facing significant challenges due to skills shortages, with 63% encountering difficulties in their endeavours to acquire the skilled talent they require (Autodesk, 2022). The primary factor cited by industry professionals for this is the scarcity of skilled labour, which either encompasses a general lack of skilled workers or the inability to identify individuals possessing the required skill set.

Carpenters and joiners contribute significantly to residential and commercial construction projects with their expertise in woodworking, framing, and finishing work. However, the shortage of qualified carpenters leads to increased competition and challenges in meeting construction timelines and quality standards. Electrical apprenticeships are vital in bridging the gap for qualified electricians responsible for electrical installations, maintenance, and repairs. With the growing reliance on technology and electricity demands, well-trained electricians are essential for the safe functioning of buildings and electrical systems. Similarly, plumbing apprenticeships address the need for skilled plumbers specialising in plumbing system installation, maintenance, and repair. Plumbers ensure proper water supply, sanitation, and drainage in various settings. The shortage of qualified plumbers can result in project delays and compromised plumbing systems. To alleviate the shortage, it is crucial to improve completion rates and produce more skilled carpenters, electricians, and plumbers which will ensure a sustainable workforce, contribute to the development of the construction industry, and meet the evolving needs of the built environment.

Various Irish Acts were implemented to attempt to control the entry requirements for apprenticeship including the 1931 and 1959 Apprenticeship Act and more recently the Labour Services Act 1987-Apprenticeship Rules 1993 which stated that an apprentice should have minimum five grade Ds in the Junior Certificate on entry or approved equivalent. The Department of Education's Junior Certificate is a set of examinations taken typically after three years in secondary school. STEM (Science, Technology, Engineering, and Mathematics) subjects were not statutory requirements to undertake an apprenticeship, a fact that remains to this day.

The goal of this study is to examine the completion rates of apprentices who come from the lowest academic entry pathway. The findings may be used to guide the creation of new policies and procedures targeted at improving apprenticeship standards, offering more direction to apprentices, and raising completion rates. By recognising the difficulties apprentices encounter and emphasising the need for more research to discover prevention and early warning techniques, this study will also add to the body of knowledge already in existence.

Apprenticeship Completion Factors

There exists evidence on the factors influencing apprenticeship completion in other countries, including United Kingdom (Daniel *et al.,* 2020, Gambin and Hogarth, 2016, Greig, 2019), Australia (Harris and Simons, 2005), Canada, (Laporte and Mueller, 2013), and Germany (Bessey and Backes-Gellner, 2015, Greilinger and Sandner, 2021). In a recent systematic literature review, McMahon *et al. (*2022) found that factors influencing completion included fundamental apprentice attributes, features of the apprenticeship programme and employer considerations, however, it is reasonable to suggest that non-completion can be because of multiple factors.

Studies have shown that apprentices who enter a programme with better scores in secondary school achieve higher grades and higher completion rates in their apprenticeship (Laporte and Mueller, 2013). Non-completion rates are higher for apprentices who arrive from the lowest secondary school track (Neuber-Pohl, 2021) . In Germany, it was found that when an apprentice's educational background and current performance matched the training provider requirements, the apprenticeship was less likely to be terminated quickly due to poor fit, and the probability of a fast termination reduced by 11.5 percentage points (Greilinger and Sandner, 2021). A study in University of Limerick found that the basic educational entry level was too low with up to 70% of apprentices with Junior Cert unable to complete theoretical exams (Buckley, 2008). While O'Connor (2006) reports that over 66% of registered apprentices complete their apprenticeship in Ireland, a later Oireachtas report declared trade completion rates of 65% in carpentry, 73% in electrical and 69% in plumbing (Oireachtas Report, 2019) however, these did not take in to account the entry pathway.

Hence, it is conceivable that there exists an increased risk of non-completion among apprentices entering at the lowest level of academic achievement. Building upon these observations, this study aims to investigate the potential association between the academic level of apprentices at the time of registration and their subsequent completion rates. In achieving this aim, the following research questions are posed:

1. What is the completion rate for carpentry and joinery, electrical and plumbing apprentices presenting with the Junior Cert alone?

2. Is there correlation between completion and the number of STEM subjects on registration?

3. Is there a relationship between academic performance in the Junior Cert and apprenticeship completion rates?

METHOD

This study utilised an ex post facto research design, which examines events that have already occurred. The data for this investigation was collected from applications and learner records in the SOLAS Apprenticeship Client Services System (ACSS), the national apprenticeship register. The study is part of a broader research project that has undergone review by an independent ethics committee.

In terms of academic entry levels, 22% of registered apprentices have completed the Junior Cert, 66% have completed the Leaving Cert, and the remaining entrants have gained access through alternative pathways (SOLAS, 2023). In the specific research area, 102 electricians, 33 carpentry, and 35 plumbing apprentices registered between 2010 and 2016 with only the Junior Cert qualification. For this study, 60 apprentices were randomly selected from this group. To minimise the potential impact of the COVID-19 pandemic, registrations made before March 2016 were considered, as colleges were mandated to close in March 2020.

Points were assigned to Junior Cert grades using the 2016 Leaving Cert points conversion table (Central Applications Office, 2023), as shown in Table 1. The conversion involved considering the eight best subjects, like the six best subjects in the Leaving Cert system. In this research, CSPE (Civic, Social and Political Education) results were assigned the same points as Higher Level, as there is no Common Level equivalent in the Leaving Cert. Furthermore, higher level mathematics received additional points in accordance with the Leaving Cert grading.

Table 1: Points Calculator for Leaving Cert (Central Applications Office, 2023)

Grade Achieved → / Subject and Level ↓	A1	B1	C1	D1	E
Mathematics Higher Level	125	113	91	81	33
Mathematics Ordinary Level	56	46	28	20	0
Mathematics Foundation Level	20	12	0	0	0
Other Subjects Higher Level	100	88	66	56	33
Other Subjects Ordinary Level	56	46	28	20	0

Table 2 provides a comprehensive overview of the range of STEM subjects pursued by apprentices at the Junior Cert level. Among all apprentices, mathematics was universally taken, followed by science and wood technology as the subsequent popular choices. Notably, 85% of plumbers and 65% of carpenters enrolled in three or four STEM subjects. It is worth mentioning that a sole electrical apprentice undertook all six available STEM subjects at the Junior Cert level.

Table 2: Number taking each individual STEM subject at Junior Cert Level from a sample size of 20

Subject → / Trade ↓	Maths	Technical Graphics	Science	Wood Technology	Metalwork	Technology
Plumbing	20	7	17	15	7	5
Electrical	20	11	12	16	6	2
Carpentry	20	7	18	16	9	0

Table 3 displays the breakdown of mathematical levels and grades undertaken by apprentices while completing their Junior Cert prior to registering for their apprenticeship. This shows that 5% of apprentices took higher level mathematics, 80% took ordinary level and 15% undertook foundation level mathematics.

Table 3: Mathematics Level and Award for each trade

Number in Each Trade → ↘				Electrical	Plumbing	Carpentry
Subject and Level and Points ↓						
Higher	Ordinary	Foundation	Points			
A			125			
B			113	1		
C			91	1		
D			81	1		
	A		56			1
	B		46	7	2	4
	C		28	7	7	7
	D		20	1	6	4
	E		0		1	1
		A	20			1
		B	12	2	1	2
		C	0		3	

FINDINGS

Table 4 presents the average Junior Cert points achieved, the number of apprentices achieving above average, and the range of points for each trade. Electrical apprentices demonstrated higher Junior Cert scores and a wider range of points compared to other trades. On the other hand, carpentry and joinery apprentices had the lowest average score, but their overall range of points was wider than that of the plumbing sector. The lowest set of calculated points observed was 178 in carpentry and joinery, while the highest was 780 in electrical.

Table 4: Average, number above average and range calculated Junior Certificate points for plumbing, electrical and carpentry and joinery

Junior Cert calculated Points → / Trade ↓	Average Points	Number presenting >average	JC Points range
Plumbing	363	11	199-562
Electrical	438	13	220-780
Carpentry and joinery	359	9	178-618

The findings indicate that the completion rate within 234 weeks for electrical apprentices with Junior Cert only is 65%, whereas the rates are 55% for plumbing and 45% for carpentry and joinery. The completion rates align with the average points, indicating a positive relationship between higher points and completion rates in all trades. There is a notable increase in completions with higher academic entry levels. For apprentices with entry levels below 300 points, only one-third successfully complete their apprenticeship, whereas those with over 500 points have a completion rate of 96%. This trend is observed across all trades, although carpentry apprentices with entry levels below 300 points face the highest risk of non-completion.

No significant correlation was observed between the number of STEM subjects taken and apprenticeship completions, as shown in Table 5. Taking more than four STEM subjects did not increase the likelihood of completing apprenticeship.

Table 5: Percentage of Completions in relation to number of STEM Subjects undertaken in the Junior Certificate

Number of STEM Subjects → / Trade ↓	2	3	4	5	6
Plumbing	100	33	55	100	N/A
Electrical	80	75	50	0	100
Carpentry	50	40	50	33	N/A

The analysis revealed a distinct correlation between the academic performance in mathematics and the successful completion of apprenticeships, as illustrated. Specifically, individuals who attained a grade below E in Ordinary Mathematics or failed to achieve an A grade in Foundation Mathematics exhibited an inability to complete their carpentry apprenticeships. Conversely, all electrical apprentices who undertook Higher Mathematics demonstrated a high rate of apprenticeship completion.

DISCUSSION

The initial inquiry focused on the rate of completion for apprenticeships among those who only possess a Junior Cert qualification. The research reveals that starting a plumbing, electrical or carpentry apprenticeship with only a Junior Cert result in completion rates of approximately 55%, 65%, and 45%, respectively. These figures are notably lower than those reported by O'Connor (2006), which indicated that over 66% of registered apprentices completed their training, and the more recent Oireachtas report that declared completion rates of 65% in carpentry, 73% in electrical, and 69% in plumbing (Oireachtas Report, 2019). However, it is important to note that these reports included those entering from all pathways.

The second research inquiry aimed to explore the possible connection between completion rates of apprenticeships and the number of STEM subjects taken by apprentices during their secondary education. Nevertheless, this study did not identify any substantial correlation between completion rates and STEM subjects, other than mathematics levels and outcomes. Apprentices presenting with foundation maths were of particular concern with only 22% completing their apprenticeship.

The numbers found with various STEM subjects prior to apprenticeship were comparative to those taking them in the general population. In 2016, there were 60,248 Junior Cert candidates. 27% of those undertook wood technology, 20% technical graphics, 13% metalwork and 6% technology (NCCA, 2017) . These four subjects are elective and are collectively described as the T4 subjects (Seery *et al.,* 2022). Additionally, in 2016, 99% undertook mathematics and 92% undertook science 55% of those undertaking mathematics did so at higher level (Department of Education and Skills, 2019). Choosing a subject is frequently influenced by the school and the options provided (Ryan *et al.,* 2022). One-third of secondary schools in Ireland are single-sex, and thus may not offer a full range of subjects (Clavel and Flannery, 2022). Single-sex schools may not provide metalwork or wood technology (Doris *et al.,* 2013). Apart from mathematics, STEM subjects are generally elective at junior cycle resulting in substantial participation differences across STEM subjects in Ireland (Seery *et al.,* 2022) who also state 80% of students undertaking T4 subjects are male. In 2021, the number of boys schools offering a STEM subject other than maths or science was 94.8%, compared to girls schools at 68.3% or mixed schools at 87.4% (Maxwell, 2023) .In this sense, subject selection may be influenced by the institution, rather than being a personal decision. Maxwell also reports that only 26.9% of third year girls undertook a STEM subject outside science or maths as opposed to 73.4% of boys.

The third question looked at academic performance within Junior Cert, this also found that those with elevated Junior Cert results had higher levels of apprenticeship completion, suggesting that the apprentice has more foundational knowledge and skills, necessary to succeed in the program. Our research showed that there was a clear relationship between mathematics level and result and apprenticeship completion. We also found that for the 60 randomly selected apprentices only 7% undertook higher mathematics. This could be indicative of previous negative experiences with maths or not seeing the relevance of higher maths to their trade. However, mathematics teaches critical thinking which is essential in any trade e.g., measurement, quantiles, calculation of voltage, current resistance etc. It is worth noting that 97% of the apprentices passed their chosen level of mathematics. Also interestingly, the only apprentices undertaking higher level mathematics were those from the electrical cohort with all completing their apprenticeship.

Outside of entry pathways, there may be differences in completion rates between the three trades included in an apprenticeship program, due to differences in the nature of the work, the availability of employment opportunities, and other factors. However, it's important to note that completion rates can vary widely depending on a range of individual and contextual factors. It is also possible that completion rates may be influenced by the nature of the trade itself. For example, the electrical trade may require a different set of skills or aptitudes compared to plumbing or carpentry, which could affect completion rates among Junior Cert holders.

CONCLUSION

The completion rates of apprenticeships in the construction trades pose a significant concern that demands attention, bearing substantial implications for the sector's workforce development and sustainability. The findings of this study hold the potential to inform policy makers in their decision-making processes regarding planning, funding routes, and policy adjustments, thereby fostering improved completion rates. By comprehending the intricate relationship between apprentices' academic entry levels and their apprenticeship outcomes, policy makers can formulate targeted strategies to enhance completion rates and effectively address the challenges encountered within the apprenticeship system. The research underscores the crucial significance of fostering collaboration between educational institutions and the construction industry. By recognising the profound impact of academic entry levels on apprenticeship outcomes, institutions can strategically align their curricula and entry requirements to precisely cater to the evolving needs of the industry, thereby ensuring that apprentices are equipped with the essential education and training imperative for their success. This collaborative endeavour effectively bridges prevailing skill gaps and satisfactorily addresses the burgeoning demands of the industry.

Identifying the factors influencing apprenticeship completion, particularly the role of academic entry levels, industry stakeholders can allocate resources more efficiently, ensuring the provision of essential support and training for apprentices. This focused allocation of resources can greatly enhance the learning experiences of apprentices and heighten their likelihood of successfully completing their apprenticeships.

To increase completion rates in apprenticeships, alternative strategies beyond increasing entry requirements can be explored for example apprentice support, educational preparation and flexible and sympathetic training and education models. Enhanced support systems, including individual academic and emotional assistance and resources for addressing challenges, can provide crucial support during apprenticeships. Pre-apprenticeship programs offer foundational training, skill development, and industry exposure, aiding prospective apprentices in making informed decisions and navigating their journey. Flexible training models, like blended learning or part-time apprenticeships, accommodate diverse learner needs and reduce barriers to completion. Strengthening collaboration between educational institutions, employers, and industry associations promotes seamless transitions, aligns curricula with industry standards, and ensures practical, on-the-job experience for apprentices. By implementing these strategies collectively, stakeholders can improve completion rates, foster equitable opportunities, and support apprentices throughout their training. A comprehensive approach that considers both entry requirements and additional measures is vital for success.

This study contributes to the existing body of knowledge by shedding light on the challenges faced by apprenticeships in the construction sector, highlighting the imperative for further research aimed at identifying prevention and early warning strategies. The research underscores the necessity for in-depth exploration into these strategies, enabling industry stakeholders to proactively implement measures that curtail apprentice dropouts and provide timely support to those at risk. By doing so, higher completion rates can be achieved, fostering the cultivation of a more competent and proficient workforce within the construction industry. Future research can explore the probability of completion by comparing apprenticeship performances across different entry pathways, strengthening the apprenticeship system and improving outcomes for both apprentices and employers.

Overall, this research provides a foundation for evidence-based decision-making, resource allocation, collaboration, and the development of strategies to improve completion rates and enhance the overall quality of apprenticeships in the construction industry. By implementing the insights gained from this study, the industry can foster a stronger and more sustainable workforce, ultimately benefiting all stakeholders within the construction sector.

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THE CHALLENGE OF COMPARING APPRENTICESHIP COMPLETION RATES: AN INTERNATIONAL REVIEW OF TERMINOLOGY

Elma McMahon[1], John P Spillane and James G Bradley

Irish Construction Management Research Centre (ICMRC), School of Engineering, University of Limerick, Limerick, V94 T9PX, Ireland

When considering construction apprenticeship 'success', two general categories can be distinguished, namely completion and non-completion. However international comparisons cannot be effectively established because of the differing terminology and definitions used by various researchers. Comparative investigations face challenges due to social and educational disparities, making direct evaluations misleading or ineffective. The aim of this paper is to communicate how different countries define 'completion' and 'completion rates', to find common ground between the definitions and recommend consistent terms for use in further Irish research. Research papers from five countries were selected: - Ireland, United Kingdom. United States of America, Australia, and Germany to analyse and compare completion terminology. The literature confirms a lack of consensus on the terminology as well as differing methodology for calculating completion rate. There is limited research on apprenticeship completion in Ireland and as such the key contribution will be utilising this research to create a definition of apprenticeship completion and completion rates for Ireland to make comparisons internationally with the eventual hope of increasing apprenticeship success in this country.

Keywords: apprenticeship, built environment, terminology, vocational, training

INTRODUCTION

An apprenticeship is a planned programme of education and training that combines classroom instruction with workplace learning (Education and Skills, 2013). The programme places a strong emphasis on practical learning experience and prepares apprentices for a particular occupation while also addressing economic demands. An apprentice must be engaged under a contract of employment that calls for at least 50% of their training to be completed on the job (Generation Apprenticeship, 2020). There are eight built environment apprenticeships available in Ireland, including electrical, plumbing, and carpentry and joinery, within a total of 67 programmes. These adhere to a seven-phase, standards-based, on-the-job, and off-the-job strategy to achieve QQI (Quality and Qualifications Ireland) Level 6 certification (O'Connor, 2006) which is equivalent to Level 5 on the European Qualifications Framework (EQF) (Mc Manus,

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[1] mcmahon.elma@ul.ie

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When comparing international apprenticeship systems, it is firstly important to outline the similarities. Apprenticeship systems will always have the following in common:

- Apprenticeship programmes involve a system of on and off the job periods.
- The objective of apprenticeship programs is to equip individuals with the necessary skills and knowledge for a specific trade or occupation.
- Assessments are conducted to evaluate the competency, knowledge, and skills of apprentices, encompassing written exams, practical assessments, and workplace observations.
- There will be an overall statutory body with responsibility for apprenticeship in each country/region e.g., SOLAS (Ireland), Institute for Apprenticeships and Technical Education (England), Skills Development Scotland (Scotland) and the Federal Ministry of Economics and Energy (Germany). Sometimes it is shared between two or more bodies e.g., federal and territory government (Australia) and Department of Labour along with industry bodies and unions (USA).
- Completion usually results in recognised vocational qualification which may be assessed against the European Qualifications Framework (see table 1). It is worth noting that while these countries have similar apprenticeship systems to Ireland, there are differences in the specific regulations and requirements and as such the process and criteria for completion may vary.

One way of measuring programme success is by evaluating apprenticeship completion rates, but these can be difficult to compare internationally due to the differing definitions and terminology used by researchers. Gaining an understanding of international completion and completion rates may help increase overall apprenticeship completion in Ireland through implementation of specific policies, for example, the Action Plan for Apprenticeships (Department of Further and Higher Education, 2021).

European Qualifications Framework Level (EQF) →	EQF 4	EQF 5
Timeline ↘		
Country ↓		
Germany	3/4 years	
England/Wales/N Ireland	2 years	3/4 years
Scotland		4 years
Ireland		4 years
USA (Equivalent EQF Level)	4 years	
Australia (Equivalent EQF Level)	4 years	

Table 1 Table of equivalence of international qualifications (McManus, 2014)

Clear delineation of completion terminology and definition is essential to maintain consistency and accuracy in their analyses, as noted by Larsen *et al.,* (2013) and Kehm *et al.,* (2019). Terminology plays a crucial role in determining completion rates, as it establishes the criteria for defining a completed apprenticeship. Variations in terms and definitions exist across countries and industries, further complicating the establishment of a universal definition. Additionally, discrepancies in assessment methods, survey techniques, and certification levels contribute to the challenge. Standardising terminology and definitions can promote consistent reporting of completion rates and facilitates effective evaluations of apprenticeship programme.

This study is part of a University of Limerick research project investigating apprenticeship completion in Ireland. A major challenge is the lack of consistent definitions used in international studies, hindering comparisons. To address this, a structured approach is needed to analyse different countries' definitions and methodologies for calculating completion rates.

LITERATURE REVIEW

There has been a noticeable increase in the quantity of studies published by countries on apprenticeship completion, particularly in the past two decades. These studies focus on the UK (Smyth and Zimba, 2019; Daniel *et al.,* 2020; Greig, 2019; Gambin and Hogarth, 2016), Australia (Zoellner *et al.,* 2017; Cebulla and Goodwin-Smith, 2015; Gow *et al.,* 2008; Mangan and Trendle, 2008; Harris and Simons, 2005), USA (Bilginsoy, 2018; Kelly *et al.,* 2015; Glover and Bilginsoy, 2005) and Germany (Neuber-Pohl, 2021; Bessey and Backes-Gellner, 2015; Greilinger and Sandner, 2021). A recent systematic literature review identified various factors influencing completion were identified, such as apprentice characteristics, attributes of the apprenticeship program, and employer considerations, however, non-completion may stem from a combination of multiple factors (McMahon *et al.,* 2022).

The term "completion rate" refers to the percentage of apprentices who complete their training programs within a specified time frame. As identified in Table 2, various countries and training systems employ different methodologies for calculating these rates so understanding the specific methodology used is essential. For instance, time-based completion calculates the rate based on the apprentice number who complete the programme within the required time, while competency-based completion considers apprentices who have demonstrated proficiency in required competencies. Many countries adopt a hybrid approach that combines both time-based and competency-based criteria for completion.

Country	Apprentice Completion and Apprentice Completion Rates
Ireland	Completion is determined by the Education and Training Board Results Approval Panel, verifying achievement of standards, on-the-job and off-the-job elements, assessments, and meeting minimum apprenticeship duration. Completion rates vary across trades and industries, with reported overall rates of 66%. O'Connor (2006). A later report indicated completion rates of 65% in carpentry, 73% in electrical, and 69% in plumbing, without specific time constraints (Oireachtas Report, 2019).
Australia	Apprenticeship completion is determined by fulfilling both on-the-job training under the guidance of qualified tradespeople and off-the-job training. Qualification acquisition requires successful completion of various assessments, including written exams, practical evaluations, and workplace observations. Completion rates in trade occupations beginning in 2017 was 54% (NCVER, 2022) and are calculated by monitoring the apprentices progress and their contracts over time.
USA	Completion requirements vary by trade and state. Apprentices receive a nationally recognised certificate or journey worker card upon successful completion which serves as evidence of their competence. Completion rates in the United States varied across states, with an average rate of 59.4% reported in a study by Glover and Bilginsoy (2005). The completion rate represents the percentage of apprentices successfully completing the programme within a specified timeframe.
UK	Gambin and Hogarth (2016) define completion as obtaining a recognised vocational qualification, while Daniel *et al.,* (2020) defines it as achieving specified learning outcomes. In Scotland, completion is determined by meeting standards set by the Scottish Qualification Authority (Greig, 2019). Completion rates of 57.5% (academic year 2019/2020) reported (Department for Education, 2023), with variations across industries (Gambin, 2016; Daniel *et al.,* 2020; Greig, 2019).
Germany	Completion marked by passing the "Gesellenprüfung" exam which includes practical and written components. Upon successful completion, apprentices are awarded the "Gesellenbrief," a certificate of achievement (Bessey and Backes-Gellner, 2015). In Germany, the completion rates for apprenticeships were around 75% (Neuber-Pohl, 2021). Completion rate calculation like the UK i.e., dividing the number of graduates by the number who started the program.

Table 2 Completion and completion rates in selected countries

The varying definitions of retention and completion rates in the Irish and international education systems also present challenges when comparing data (Van Stolk, 2007). In

Irish schools, retention rate refers to the percentage of students who stay until their Leaving Certificate (O'Brien, 2023). The Higher Education Authority acknowledge the difficulty of developing internationally comparable measures due to diverse entry systems, access to HE, and definitional and methodological complexities (Piggot and Frawley, 2019). A comprehensive investigation was conducted to analyse completion rates within the Institute of Technology sector, wherein the concept of completion was defined as the successful conclusion of a course within the stipulated timeframe or a permissible extension of up to one year beyond the designated duration (CODIT, 2006). Comparative research conducted in Australia, Ireland, the USA, and the Netherlands aimed to explore non-continuation rates in HE found that not all countries measure completion rates. In the USA, completion refers to graduating within 150% of the normal course duration while Ireland distinguishes between on-time and late graduation. The Netherlands defines graduation as "yield," representing on-time graduates, and retention as the number of students continuing, HE after the first two years of study. The Netherlands employs a definition of progress, tracking the number of students who remain in their courses and progress on schedule. Australia defines attrition as dropouts after the first year of HE and measures completion rates as the graduation rate after seven years of study (Van Stolk, 2007).

The literature highlights a lack of consensus on the terminology and methodology for measuring apprenticeship completion rates worldwide. Common elements of completion include meeting training requirements, passing exams, and fulfilling competency standards. Apprenticeship completion rates in Ireland are not extensively researched or reported compared to other countries like Germany, the UK, the USA, and Australia. This lack of information creates knowledge gaps regarding the effectiveness of the program. Despite the significance of completion rates in evaluating apprenticeship programs, there is a lack of agreement on how to define and calculate these rates across countries and industries and standardisation would improve comparability and usefulness of completion rate data.

The overall aim of this paper is to address the challenges associated with researching and comparing apprenticeship completion rates in Ireland and internationally. The study aims to establish a standardised definition of apprenticeship completion and completion rate in Ireland to enhance the comparability and utility of data in this area of research and as such the research questions are as follows:

RQ1: What are the current challenges and limitations in researching apprenticeship completion rates in Ireland, and how does the lack of a standardised definition and methodology hinder the comparability of data across programs?

RQ2: What are the commonalities and differences in international terminology and methodology used to define and calculate apprenticeship completion rates, and how can these findings inform the development of a more comprehensive and standardised definition for calculating completion rates in Ireland?

METHOD

This study employed a literature review approach, building upon the previous systematic literature review (SLR) of McMahon *et al.,* (2022). These 24 papers were re-examined to determine consensus on terms, definitions, and technical evaluation methods. The literature review involved searching and analysing relevant literature from academic databases, journals, reports, and publications to understand apprenticeship completion rates and associated definitions and methodologies. The

SLR allowed for a comprehensive examination of findings across countries, identifying similarities and differences in terminology, measurement approaches, and reporting practices. The search strategy was developed, incorporating keyword searches, database selection, and inclusion/exclusion criteria aligned with the research questions and objectives. The SLR facilitated a broad understanding of existing knowledge by examination of findings across different countries and regions. Comparative analysis involved identifying similarities and differences in terminology, measurement approaches, and reporting practices. Data extraction techniques were used to gather relevant information, which was synthesised to develop a standardised definition for calculating completion rates in the Irish context. The methodology acknowledges limitations, such as potential biases in the literature and the generalisability of findings. Despite not utilising a mixed-methods approach, the SLR methodology enables a thorough examination of existing literature, contributing to the establishment of a standardised Irish definition for apprenticeship completion rates.

This study adopts an interpretivist philosophical positioning, as indicated by the focus on understanding and interpreting social phenomena related to apprenticeship completion rates (Saunders, 2009) The utilisation of secondary data, such as existing literature and publications, aligns with the nature of the data being collected for comparative analysis within the context of the study. By employing comparative analysis, the study aims to uncover patterns and variations in apprenticeship completion rates across different countries and systems, providing valuable insights to address the research objectives, informing policy decisions and allows continuous learning of the apprenticeship system.

FINDINGS

The first research question addresses the challenges and limitations associated with researching apprenticeship completion rates in Ireland, focusing on the lack of a standardised definition and methodology. This absence leads to inconsistencies in how completion rates are measured and reported, impeding the comparability of data. Researchers encounter difficulties in obtaining accurate and reliable data due to the absence of a common understanding and approach to defining and calculating completion rates. Consequently, assessing programme effectiveness, identifying areas for improvement, and making informed policy decisions are hindered.

The second research question aims to identify commonalities and differences in international terminology and methodology for defining and calculating apprenticeship completion rates which will inform the development of a standardised definition in Ireland. Similarities across countries can establish a common framework, while unique approaches can be adapted. Considering international perspectives will lead to a more robust and consistent definition and methodology, improving data comparability and usefulness in Ireland and enabling cross-country comparisons.

As this paper is focused on examining various definitions and terminologies used to describe apprenticeship 'success', there are no empirical results to report. Instead, this section will outline the key findings of the literature review in relation to how different countries define 'completion' and 'completion rates' in their apprenticeship systems. Over twenty different terms were found, all arguably meaning the same thing. These are outlined in Table 3. While terminology like completion and non-completion seems to be universal, Germany tends to favour terminology like termination, USA favours words like quitter and Australia favours 'withdrawal'. In

Ireland, the term completion was favoured in the one paper found during the 2022 SLR. The most predominantly used term used was completer while cancellation was used frequently as well. Dropout, drop out and drop-out were used in different papers while potentially meaning the same thing.

Table 3: Terminology used in research from Germany, USA, UK, and Australia

Publication Title, Author and Year, Country	Terminology used in paper
Apprenticeship non-completion in Germany: a money matter, Neuber-Pohl, (2021), Germany	Early contract termination, successful completion, non-completion
How fast do apprenticeships come to a premature end Insights into the factors that determine the speed of the process, Greilinger and Sandner, (2021), Germany	Drop-outs, early terminations, premature terminations, fast terminations
Strategies for improving construction craftspeople apprenticeship training programme, Daniel *et al.,* (2020), UK	Completion, non-completion
An Investigation into apprenticeship completion and retention in Northern Ireland: A social exchange programme, Smyth, and Zimba (2019), UK	Completion, non-completion, retention, drop out
Factors affecting Modern Apprenticeship completion, Greig (2019), UK	completion
Unemployment, The Great Recession, and apprenticeship attrition in the US, Bilginsoy (2018), USA	Attrition, completion, cancellation
Regional disparities in apprenticeship attrition rates: heat and quarter four's significance in northern Australia, Zoellner *et al.,* (2017), Australia	Successful completion, withdrawals, cancellations, non-completion
Factors affecting completion of apprenticeship training in England, Gambin and Hogarth (2016), UK	Completion, success
Staying within or leaving the apprenticeship system? Revisions of educational choices in apprenticeship training, Bessey and Backes-Gellner (2015), Germany	Dropping out
Apprenticeships in homelessness: A quantitative study, Cebulla and Goodwin-Smith (2015), Australia	Dropout, completer, drop-out
When working hard is not enough for female and racial/ethnic minority apprentices in the highway trades, Kelly *et al.,* (2015), USA	Completion, termination
Retention and intentions to quit among Australian male apprentices, Gow *et al.,* (2008), Australia	Retention, early withdrawal
Hanging in there: What makes a difference in the first year of an apprenticeship, Hill and Dalley-Trim (2008), Australia	Cancellation, non-completion, withdrawal, non-continuing
Surviving apprenticeship training: A duration analysis of apprenticeship contracts in Australia, Mangan and Trendle (2008), Australia	Attrition, completion, drop out, non-completion, cancellation, withdrawals
Delivering Skills: Apprenticeship program sponsorship and transition from training, Bilginsoy (2007), USA	Quitters, completers
Exploring the notion of retention in apprenticeship, Harris and Simons (2005), Australia	Retention, completion, non-completion, cancellation, withdrawal
Registered apprenticeship training in the US construction industry, Glover and Bilginsoy (2005), USA	Completion, cancellation, attrition
General training by firms, apprentice contracts, and public policy, Malcomson *et al.,* (2003), UK	Completion, quitter
The hazards of training: Attrition and Retention in construction industry apprenticeship programs, Bilginsoy (2003), USA	Completion, attrition, retention, cancellation, desertion, exit
Do unions help or hinder women in training? Apprenticeship Programs in the US, Berik and Bilginsoy (2000), USA	Attrition, retention, completion, dropout, cancellation, voluntary quits

The review of apprenticeship completion in Ireland, Germany, UK, USA, and Australia reveals variations in the terminology and methodology used to measure completion. The review identifies key elements for a potential framework to compare completion rates across countries, such as standardising terminology, developing a common methodology, and accounting for differences in the structure and length in the programmes. However, it is important to note that this study does not guarantee the creation of a framework within its current scope.

The fundamental requirements for completion internationally consist of satisfying the mandated amount of both on-the-job and off-the-job training, successfully completing the final examination, and meeting the competency criteria established by the programme sponsor. It appears that certain countries have established a specific time completion criterion, so it may be reasonable to suggest a similar criterion for Ireland. In the USA, "college completion" refers to students who graduate within 150% of the standard programme length. Research in Irish Institutes of Technology's defined completion within the designated time frame or within one year beyond the given time frame. Neuber Pohl (2021) noted that the final apprenticeship exam could be taken after the apprenticeship contract ends and allowed for updates to the education variable within 183 days of the end of the apprenticeship period. SOLAS, who have statutory responsibility for apprenticeship say that the apprenticeship is completed when the apprentice has 'successfully achieved the required standard, completed all of the alternating on-the-job and off-the-job elements of his/her apprenticeship, and served the minimum 208-week apprenticeship period specified in the relevant Apprenticeship Programme' (Generation Apprenticeship, 2016) However, there is no upper limit, making international comparisons difficult. It would seem reasonable to allow a cut off limit of 234 weeks to account for examination board approval and certificate generation. It is proposed that the new apprenticeship completion rate for Level 6 QQI apprentices in Ireland is ' percentage of apprentices who complete their training programs within 234 weeks of registration with an extended completion rate of those who complete their apprenticeship within 260 weeks (5 years). This study is part of an ongoing research project at the University of Limerick investigating apprenticeship completion in Ireland. Preliminary unpublished findings indicate that within a 234-week period, electrical apprentices achieve a completion rate of 65%, plumbing apprentices demonstrate a rate of 55%, and carpentry and joinery apprentices exhibit a rate of 45% among those entering with the lowest educational entry level. However, it is important to note that these results do not provide an overall completion rate as apprentices with higher educational qualifications on entry to the apprenticeship programme were excluded from the initial analysis.

CONCLUSIONS

Apprenticeship completion rates and definitions vary widely between different countries and training systems and can be calculated using a variety of methodologies. The systematic literature review by McMahon *et al. (*2022) highlighted the importance of standardising terms to enable comparison across different studies. Defining "completion" is crucial, but interpretations may vary, causing different perceptions of fulfilment. Indicators like time to complete, employment status, and acquired skills are relevant but lack clear definitions and can be subjective. Additionally, completion should be assessed based on standardised criteria that encompass not only the duration of training but also the attainment of requisite skills and competencies. This comprehensive evaluation would ensure consistency and comparability across different apprenticeship systems.

When researchers, policymakers, and stakeholders have a clear understanding of the terminology used to define and measure completion rates, they can effectively communicate and exchange information which facilitates collaboration and the sharing of best practices, enabling a more coordinated and targeted approach to address challenges related to completion rates. This information can be used to set realistic targets, establish quality assurance mechanisms, and allocate resources effectively. Researchers and evaluators can analyse data and identify areas for improvement, leading to evidence-based recommendations for programme modifications and enhancements. Creating a new Irish definition of completion and completion rates is crucial for future research in this area to enable consistent and comparable analysis of completion rates in Ireland and globally. It will aid in identifying factors that contribute to completion and informing policy decisions to improve completion rates in Ireland.

This paper on apprenticeship completion rates contributes to the conference theme "Constructing for the Future" by providing insights and recommendations that can inform the development and improvement of apprenticeship programs. By addressing challenges, standardising definitions, and identifying effective strategies, this study contributes to building a strong foundation for the future of apprenticeship education. This is crucial for the Irish construction industry as it helps to address the skills gap by providing a structured training pathway for individuals to acquire the necessary knowledge and practical skills specific to the construction sector. Apprenticeships ensure a skilled workforce capable of meeting the industry's increasing demands and promoting productivity and quality in construction projects. Furthermore, apprenticeship education fosters career development and upward mobility opportunities for individuals, promoting long-term sustainability and growth within the construction industry in Ireland.

In summary, a clear understanding of terminology related to apprenticeship completion rates facilitates effective communication, enables comparative analysis, informs policy development, supports programme evaluation, and promotes stakeholder engagement. These factors collectively contribute to increasing apprenticeship completion rates by guiding evidence-based decision-making, fostering collaboration, and implementing targeted interventions.

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CONFLICT AS A CONTRIBUTORY FACTOR IN BUILT ENVIRONMENT APPRENTICESHIP COMPLETION IN THE REPUBLIC OF IRELAND

Tadhg O'Neill[1], Elma McMahon, John P Spillane and James G Bradley

Irish Construction Management Research Centre (ICMRC), School of Engineering, University of Limerick, Limerick, V94 T9PX, Ireland

The adversarial, conflict-stricken environment in which the construction sector operates, has long been noted by practitioners and academics alike. This high-tension environment is often noted as an inhibitor in the recruitment and/or retention of labour. Apprenticeships are an essential source of labour for the Irish construction industry; there are 66 apprenticeships available, 8 of which are directly involved in the built environment. These include apprentices in carpentry, plumbing, and electrical. As part of a wider research plan into apprenticeship completion rates, the relationship between organisational conflict and apprenticeship completion is investigated. 75 questionnaires are completed at Phase 6 of training within an education centre. Participants are allowed to detail their experience with organisational conflict and the influence in which it has on their apprenticeship. The findings indicate that 64% have experienced organisational conflict within their profession, with 20% admitting it caused them to question their career choice. These findings will allow for increased ability to manage and mitigate the influence of organisational conflict on apprenticeships, with the goal of increasing completion rates, which are currently at 70%.

Keywords: adversarial; conflict; vocational; education; training; quantitative

INTRODUCTION

An organised programme of education and practical training known as an apprenticeship, formally combines training in the workplace, with a learning environment (Education and Skills, 2013). Apprenticeships place a strong focus on experiential learning, while addressing economic demands and educating the apprentice for a particular career. Employed under a contract of employment, apprentices must complete at least 50% of their training in the workplace (Apprenticeship, 2020). Apprenticeship training programmes offer companies a defined framework in which to foster loyalty and increase the diversity of applicants to their organisation, making it an appealing method of labour sourcing (Department of Further and Higher Education, 2021). Within the 66 apprenticeships in Ireland, there are 8 Built Environment Apprenticeships. These are electrical, plastering, plumbing, brick and stone laying, plastering, stonecutting and masonry, wood

[1] Tadhg.oneill@ul.ie

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manufacturing and finishing, painting and decorating and carpentry and joinery. These follow a standards-based, 7 phased model, to Level 6 certification (O'Connor, 2006). The governing organisation for statutory apprenticeships in Ireland is SOLAS, which has the backing of companies, educators, the Government, and labour unions.

O'Connor (2006) outlines that statutory apprenticeships are a crucial component of the further education training sector, while simultaneously providing essential labour to the workforce. Consequently, the retention and subsequent completion of built environment apprenticeships is critical to keeping up with increasing labour demands of the industry. A blanket study carried out by CPP Global, (2008) found that 85% of employees admitted to having to deal with conflict, with a further 29% insisting they felt they had to deal with conflict constantly. Studies such as De Dreu, (2006), Vodosek, (2005) and Meier, *et al.,* (2013) show correlations between conflict and lowered performance, poor well-being, and negative emotions. Considering this Brockman, (2014) stated that to run an efficient business the prevention and management of conflict is quintessential.

In January 2022, a systematic assessment of the literature on apprenticeship completion was conducted, looking at findings from 24 papers published between January 2000 and December 2021. According to the findings of the research, there are three primary groups for the causes of completion: Apprentice-related characteristics, curriculum and programme quality, and employer-related concerns (McMahon, *et al.,* 2022). Subsequently, this paper aims to investigate the influence of workplace conflict on apprenticeship completion rates. This is achieved by answering the concise research question of whether conflict plays a role in built environment apprenticeship completion rates. In organisational conflict literature there is a certain element of confusion as to the correct application of certain terminology. Terms such as conflict, dispute and disagreement are often used synonymously by researchers (Ejohwomu, *et al.,* 2016). It is vital to a comprehensive study that there is clarity in the terminology used and subsequently for the purposes of this paper the term conflict will be defined in accordance with Marquis and Huston, (2009), who defines conflict as, 'internal strife caused by disagreements between two or more persons over ideas, ideals, or feelings.

LITERATURE REVIEW

When carrying out a comprehensive critique of the literature it is important to provide context to the literature which is being discussed. As part of this pilot study, literature on organisational conflict and studies on apprenticeship completion rates are reviewed to create a foundation of knowledge onto which the research is built. The construction industry has long been noted for its conflict burdened environment and the adversarial nature in which it operates (Vaux and Dority, 2020). The sectors' ability both domestically and abroad to create disputes is unparallel (Spillane, *et al.,* 2011). Projects are fast paced, complex by nature and rely heavily on the cooperation of a multitude of stakeholders whom all have varying interests. When misaligned, the varying interests and objectives of these stakeholders contribute to the adversarial environment which manifests as conflict, and subsequently poor performance (Vaux and Dority, 2020). Employees spend between 25 to 50% of their day dealing with interpersonal conflict in some capacity (Hahn, 2000). Often, in industry, personnel are instructed to ignore and or avoid conflicts, however (Gorse, 2003) found this can induce significant stress and damage professional relationships of those involved. There are also strong indications that the erosion of these professional relationships correlates with the prospect of inferior project performance (Meng, 2012). In addition to this, interpersonal conflict has been cited as a "top occupational stressor", having high correlations with negative physical health and well-being (Brockman, 2014). Rispens and Demerouti, (2016) described workplace conflict as being "omnipresent" and although conflict at work is not sought after, there is much research to suggest they have become commonplace in all work environments (Narayanan, *et al.,* 1999) (Keenan and Newton, 1985). The implications of such conflict on employees in a construction context has been the subject of an abundance of academic research with a variety of results. With studies such as Zhang and Huo, (2015) focusing on the performance implications of interpersonal conflicts, with results indicating predominantly positive correlations between increased conflict levels and decreased performance. With apprentices being a primary labour source of the sector, conflict which involves apprentices can have major implications on projects performance while simultaneously influencing potential training completion.

Studies have been done that provide insight into the variables affecting apprentice completion (Bednarz, 2014, Bilginsoy, 2003, Coe, 2013, Donkor, 2012, Gambin and Hogarth, 2016). According to Snell and Hart (2008), apprentices who are dissatisfied with the quality of on-the-job training had a higher likelihood of intending to leave their apprenticeship. This is because these apprentices perceived the training component to be inadequate. Smyth and Zimba (2019) identify several factors that were frequently mentioned in determining whether to continue with an apprenticeship, including employer support, lack of recognition, relevance of training, apprentice pay, support from supervisors, and support from trainers. Despite high intentions of completing their apprenticeships, many participants reported facing challenges during their training that influenced their thoughts of leaving. The paper does not provide specific numerical data on the percentage of apprentices who completed their training after considering leaving. However, the study did find that perceived organisational support (POS) and leader-member exchange (LMX) factors, such as support from trainers and supervisors, were important factors that influenced apprentices' intentions to complete their apprenticeship and stay with their employer after completion. This suggests that strategies aimed at enhancing these factors could potentially improve completion and retention rates. A positive LMX relationship means that the apprentice feels supported, respected, and valued by their supervisor or trainer, which can lead to higher job satisfaction, higher intentions to complete the apprenticeship, and higher retention rates.

An Australian study aimed to identify factors that contribute to apprentices' decisions to remain in or leave their apprenticeships, with a focus on motivation style, coping style, employment experiences, financial responsibility, and demographic factors. The hypotheses proposed specific relationships between these factors and apprentices' thoughts towards remaining in their apprenticeship (Gow *et al.,* 2008). The Apprentice Experience Questionnaire (AEQ) was created specifically for this study to evaluate the experiences and turnover cognitions of apprentices. The questionnaire also included questions related to personal aspects, such as perceived social support and living arrangements, as well as work-related aspects such as relationships with colleagues. It was divided into three sections, with the first two sections consisting of short answer or direct response questions, and the third section consisting of a five-point scale (ranging from strongly disagree to strongly agree). Questions such as 'I am satisfied with my apprenticeship' were asked as part of this Likert scale. 61% of respondents said that they had not thought about leaving the trade, 38% had.

There is a significant contrast in how satisfied completers and non-completers are with their employment experience. Bednarz (2014) stated that most completers (80%) reported being satisfied with their overall employment experience, whereas only 42% of non-completers expressed the same level of satisfaction. Non-completers had lower satisfaction levels across every aspect of the employment experience, including working conditions, supervision, relationships with co-workers, and employer-provided training, with differences ranging from 20 to 30 percentage points across the board. She also found that in 2010, 10% of non-completers did not get on with their boss or co-workers, 3% worked in poor working conditions and only 2% were not happy with the on-the-job training. Interestingly only 5 % cited pay as a factor in non-completion.

The study by Greilinger and Sandner (2021), investigates the factors that lead to the early termination of apprenticeships in Germany. The authors analyse data from a survey of 7,469 former apprentices who terminated their training early and examine factors such as gender, migration background, academic performance, and employer characteristics. The study reveals that the median duration of premature termination of apprenticeships is 12 months, with reasons such as lack of motivation or interest, poor performance, and conflicts with employers being the main causes. The authors also find that gender, migration background, and academic performance significantly affect the termination process. Overall, the study highlights the need for interventions to support at-risk apprentices and provides valuable insights into the factors that contribute to the early termination of apprenticeships.

METHOD

A questionnaire is developed to align with the research objectives, incorporating relevant themes, concepts, and variables identified through the literature review. The questionnaire serves as a reliable instrument for data collection, enabling a systematic exploration of the research area. It allows researchers to gain valuable insights for future research on apprenticeship retention and completion rates. The questionnaire structure follows a logical flow, with questions organised thematically based on the literature review findings which allows a comprehensive exploration of the research topic while allowing for efficient data collection and analysis. Participants areprovided with a comprehensive explanation of the research objectives, applications, and their rights and responsibilities before completing the questionnaire. The questionnaires are administered through the user-friendly online platform Microsoft Forms. Likert scales are chosen as the primary instrument for measuring affective variables, considering their widespread implementation and ability to capture participants' attitudes and perceptions. Open-ended questions are included to gather more detailed insights. This approach aligns with the recommendations of Nemoto and Beglar (2014), who advocate for the combination of Likert scales with other methods to gather comprehensive data. Likert scales are commonly used to measure affective variables (Nemoto and Beglar, 2014). Originally developed in 1932 with five points, they have been adapted to include different numbers of response options, ranging from two to eleven points (Taherdoost, 2019). However, the inclusion of multiple response options, typically five, ranging from "very satisfied" to "very dissatisfied," is sufficient for achieving precision and reliability in responses, as the gain in precision diminishes beyond five options (Fitzpatrick, 1991). The questions address issues and themes highlighted in the literature, aligning with similar works such as Ejlertsson *et al. (*2018), which explores work satisfaction.

Ethical considerations are prioritised, ensuring participant anonymity and obtaining informed consent. To ensure participant comfort, anonymity is maintained in accordance with Harvey (2011), as participants tend to feel more at ease when their responses are not recorded. Data access is restricted to authorised research personnel to safeguard participant data. The population under study encompassed Phase 6 apprentices in the fields of carpentry, electrical, and plumbing, who were actively enrolled in Ireland in January 2023. At that time, the population sizes were as follows: 176 for plumbing, 608 for electrical, and 160 for carpentry, constituting the total Irish population. A non-probability sampling technique was employed to select the sample, implying that participants were not chosen randomly from the population. Rather, they were selected based on their availability to Dundalk Institute of Technology (DKIT) and their willingness to participate. The sample size for each trade at DKIT consisted of 32 individuals, with 23 participants from plumbing, 24 from electrical, and 28 from carpentry. For more detailed information, please refer to Table 1. While 75 participants is statistically significant, it is important to note that while the sample provides valuable insights into the research topic, there is a need and justification for future research with larger and more diverse samples to confirm and extend the study’s findings.

Population & Sample Size →	Phase 6 Ireland	Phase 6 DKIT	Sample Size	Participants
Trade ↓				
Plumbing	176	32	32	23
Electrical	608	128	32	24
Carpentry & Joinery	160	32	32	28

Table 1: Population and sample size of electrical, carpentry and plumbing apprentices in January 2023

FINDINGS

Participants firstly identified which apprenticeship they were enrolled and at what phase they were currently at with all participants being in phase 6. Twenty-one questions then followed centred around issues / themes and concepts identified in the literature.

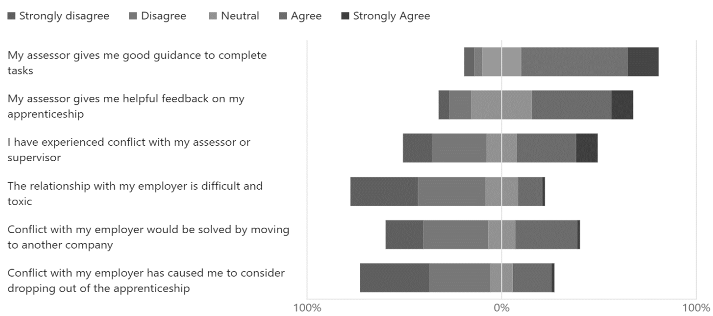

Figure 1: Assessor Support

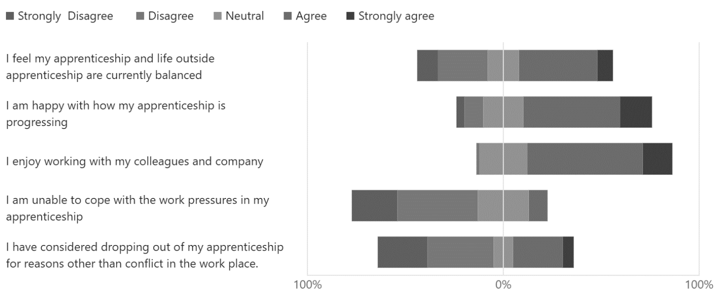

Figure 2: Apprenticeship Balance

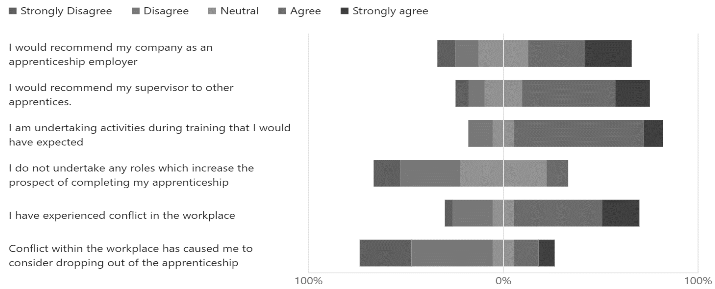

Figure 3: Company Support

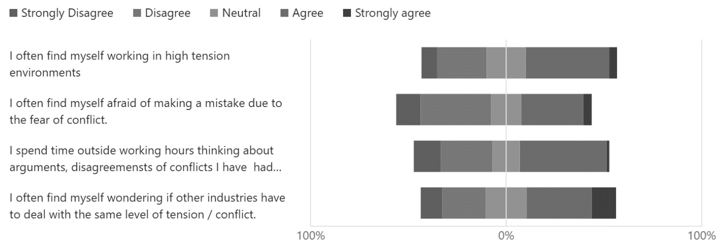

Figure 4: General Concerns

In accordance with Meng, (2012) remarks labelling conflict as 'omnipresent' in the construction sector 71% of the workforce sampled experience conflict in one way or another. However, the implications of this conflict and moreover the correlation to thoughts of dropping out seem to vary drastically, with 11.4%, 20% and 1.4% remaining neutral, agreeing, or strongly agreeing that conflict is a specific reason for their consideration of leaving their apprenticeship. O'Neill's, (2022), work aligns in this regard with the study showing that the escalation / outcome of interpersonal conflict in construction is contingent on an incalculable number of factors.

DISCUSSION

To follow a systematic presentation style the discussion is under the same headings under which the questionnaire is carried out. Assessor support allows participants to express their level of satisfaction with the guidance and general care in which they have receive from the assessor. Overall, the results indicate a predominantly positive apprentice - assessor relationship within the built environment with 55% of apprentices agreeing that their assessor gives good guidance in the completion of their tasks and a further 16% strongly agreeing. However, 15% say that would not recommend their supervisor to other apprentices. Although 71% of respondents express positive feelings to the support provided by the assessor and a further 20% remaining neutral. This is a welcome finding as Bednarz, (2014), shows a high percentage of completers having a positive relationship with their assessor. The data shows that 42% of apprentices acknowledge experiencing conflict with their assessor. Despite the existence of this conflict only 1.4% strongly agreed that the relationship between them and their employer is toxic. When asked is conflict with their employer has ever caused them to consider dropping out of the apprenticeship 20% of participants agreed.

Apprenticeship balances refers to the apprentices' views on their ability to balance their apprenticeship with all aspects of life, including during working hours. When asked if they were unable to cope with the work associated pressures involved in their apprenticeship, 41% disagreed with a further 23% strongly disagreeing. 74% of participants expressed that they enjoy working with their current environment and

65% are happy with the progression of their program. Life outside of work possess a different set of challenges for apprentices due to the acclimation to long working hours and physical demands resulting in 25% of respondents disagreeing that they have a good balance between work and life outside the industry. Interestingly, 35% of apprentices admitted to considering dropping out due to reasons other than conflict which is 10% above that of which conflict has influenced the same considerations.

In relation to company support, 53% of respondents agreed that they would recommend their current employer to other apprentices. Respondents were typically happy with the activities in which their employer was having them carry out with 77% agreeing to being content with the activities during training. However, 11% did admit to carrying out activities which they felt did not increase the prospect of completing their apprenticeship. This is cause for concern with previous research by Snell and Hart (2008) showing that those with a satisfaction towards on-site training having more frequent thoughts of non-completion. Employers instructing apprentices to carry out works outside the remit of their training is often a result of labour shortage which is currently close to an all-time high. 65% of apprentices admit to experiencing conflict in the workplace again which is higher than that who has experienced conflict with their assessor (42%). The theoretical distinction between intra vs inter-organisational conflict is important, however this paper is focused on the participants experience with conflict rather than the persons whom it was with.

'The construction industry is often noted for its high-tension conflict burdened environment', Vaux and Dority, (2020), the findings of this paper compound this statement with 47% of respondents admitting to working in a high-tension environment. Interestingly, the influence of this tension of the apprenticeship program from a learning point of view seems minimal with 64% alluding to conflict not influencing their fear of making a mistake. The high levels of conflict in the built environment are irrefutable with 46% of respondents spending time thinking about workplace conflict at home and 46% of participants often pondering if all industries experience similar levels of conflict. Apprentices were given the option to further discuss their personal experience with conflict throughout the time of their apprenticeship with 37 out of 75 making further comments. Many participants (22) stated that they had not experienced conflict or had experienced very little with comments like ‘no conflict’ , ‘none’ ‘manageable as it only lasts a day’, ‘okay’ , ‘haven’t had much thanks god’, ‘never had much’ , ‘never had much, only a few small arguments’ ‘ No conflict in my apprenticeship, it’s only the lads who are babied at home have conflict as they expect the bosses to babysit them like their mothers would’. 11 discussed conflict and made comments like ‘Have had 3 different employers, usually conflict stems over pay i.e., not getting correct rate, OT (overtime) rates etc’, ‘My first employer me and him had big arguments every day for 3 years and when I finally quit I was going to drop out of my apprenticeship then I met my new employer’, ‘Just topical things like work being wrong or taking too long to do something would end in fights’ , ‘Mostly down to pay and time served’, ‘Nothing much just usual giving out if stuff not done or goes wrong’. The remaining 5 made comments regarding matters outside the scope of this research and so are not included in this discussion.

When looking at the different apprenticeship programs in isolation 58% of electricians indicated experiencing conflict with their employer with half of those agreeing that this has caused them to consider leaving their apprenticeship, however 50% would still recommend their company as an apprenticeship employer. Plumbers in general indicated higher levels of conflict in the workplace and with their employer than electricians or carpenters with 34% starting that they felt like leaving their apprenticeship because of conflict within the workplace. 87% of carpenters disagreed their relationship with their employer was toxic and difficult as opposed to 52% of plumbers or 58% of electricians. Carpenters overall seemed to be happier in their apprenticeship with 79% happy with how their apprenticeship is progressing and 71% enjoying working in their company. Only 65% of plumbers indicated that they enjoyed working with their colleagues and company. The higher levels of conflict reported by plumbers in general is also concerning, with over a third indicating that they have considered leaving their apprenticeship because of conflict within the workplace. The high level of satisfaction reported by carpenters in their relationship with their employer is certainly encouraging and suggests that the carpentry industry may be doing a better job at creating a positive and supportive work environment for their apprentices. However, it is important to note that the overall experience of carpenters is likely to be influenced by a range of factors beyond just their relationship with their employer, such as the quality of supervision, training, and work tasks.

CONCLUSION

This paper contributes to the understanding of the role in which conflict plays in apprenticeship completion rates. Unresolved conflict has an array of negative impacts in the workplace, including diminished productivity, decreased job satisfaction, increased absenteeism and in worst cases, and in this context - non completion of the apprenticeship. There is a significant percentage of apprentices who have experienced conflict with their assessor or employer, but only a small proportion of them described it as difficult and toxic. This compounds previous works that small levels of conflict are not uncommon in the workplace, and not necessarily a cause for serious concern. However, the fact that a significant proportion of apprentices (20%) have considered dropping out because of workplace conflict or employer conflict is noteworthy. This suggests that conflict within the workplace or with an employer can have a significant impact on an apprentice's motivation and engagement in their apprenticeship. The impact of which such conflict has on individual apprentices can vary due to several factors such as personality, life outside of work, mental health and a plethora of other factors outside the scope of this study.

Overall, these findings suggest that while conflict within the workplace or with an employer can be a significant factor in an apprentice's decision to drop out, it is not the only factor, and other factors may also play a role. It is encouraging to see that most apprentices are satisfied with their employers, supervisors, and workplace, and that their expectations for the role they would undertake during their apprenticeship have been met. However, the fact that 21% of apprentices would not recommend their company as an apprenticeship company is a concerning figure. This suggests that there may be some issues with certain employers or workplaces that could be improved to ensure a more positive experience for apprentices. Although it is positive to see that many apprentices are enjoying their apprenticeship and are satisfied with how it is progressing, it is vital that the sector adopts a continued pursuit of improvement philosophy and continues to self-educate and adopt change which continues to facilitate both the needs of the apprentices and the industry. This paper also provides a foundation for future works around conflict in built environment apprenticeships. Further works to investigate the factors which result in conflict escalating to a point where an apprentice considers resigning would provide invaluable knowledge to potential employers as to how to manage and mitigate these factors. It would also allow for governing bodies, such as SOLAS, to create framework and or policy around reoccurring factors.

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UNDERGRADUATE BUILT ENVIRONMENT COURSES AND THE POST-COVID LEGACY FOR LEARNING

Barbara Vohmann[1]

School of Engineering and the Built Environment, Anglia Ruskin University, Bishop Hall Lane, Chelmsford, CM1 1SQ, UK

Accredited undergraduate built environment courses are designed to prepare students as industry practitioners with appropriate knowledge, skills, and competencies, and accordingly students undertake real-world practice-based learning activities. During the lockdown of the COVID-19 pandemic, learning was, by necessity, moved to online. New problems and solutions evolved for tutors and students as all had to revise their approach. This presented challenges, there was a need to make enhanced use of technology and to encourage students to take a different approach to their learning. This paper seeks to better understand students' perceptions of learning in the enforced online experience and explore whether students had changed their learning approach in the online environment, to better understand their perspective. From this, it was hoped to gain insight as to whether any pedagogic adjustments would benefit from being developed in the post-covid era. Data for this study was gathered through an online survey of undergraduates in their final year of a built environment course and was conducted in the post-Covid era. Findings suggest that students had recognised the value of dialogue, had become more independent as learners, and were more proactive in their learning.

Keywords: built environment; education; undergraduate; learning

INTRODUCTION

Preparing undergraduates as effective industry practitioners is a goal of undergraduate built environment courses. Given that the construction industry generates considerable employment and wealth for the UK economy (Rhodes 2019), ensuring that graduates are suitably equipped with appropriate knowledge, skills and competencies as industry professionals is important. Built environment courses are designed to help students develop such professional practice attributes. It is also valuable that students can manage their own learning (Bjork *et al.,* 2013), developing skills of self-management and greater independence. Such self-management is also an attribute of effective professionals; in turn, this attribute also supports student achievement (Vosniadou 2020).

During the March 2020 to December 2021 pandemic with resulting lockdowns and restrictions (Institute for Government 2022), learning was by necessity moved to an online experience at UK Higher Education Institutions (HEIs). Tutors had to devise new means of engaging students and providing a suitable learning experience.

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[1] barbara.vohmann@aru.ac.uk

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Electronic resources proved invaluable during this time, for example facilitating online lectures, tutorials, and meetings. However, the online environment held some challenges for practice-based disciplines which are seeking to develop students as industry practitioners. Practical learning activities were much more difficult - impossible in some cases - to meaningfully replicate. Although recordings of real-world professional practice activities could be - and indeed were - provided, offering students with opportunity to undertake those practical activities was no longer possible. This carried implications for students' learning and development in readiness for industry. Further, not only were students unable to effectively practice as practitioners, but they were now physically isolated from their peers and tutors. This represented a further challenge for all as students were no long part of a face-to-face learning community. Online learning was not the same learning experience as face-to-face; students could not so easily discuss their work with their peers nor have informal unscheduled drop-in sessions with tutors to discuss or ask questions concerning areas of uncertainty.

For students, moving to online learning was not a choice they had made, and they might not have been well equipped to deal with this new enforced situation. There was also an implicit assumption that students each had sufficient electronic and other resources to be able to work solely online. Yet this new situation meant that students were by necessity obliged to rely more on their own resources, both physical and psychological. It remained difficult to know to what extent, if any, physical isolation, or any other influence of the online experience, held for students. However, the situation presented a once-in-a-lifetime opportunity to examine students' perceptions of themselves as learners and their perceptions of their inline and face-to-face learning experience.

Importantly, it was useful to better understand whether or in what way the resources developed during the online experience were valuable. There was a very real concern that online learning could result in students becoming passive rather than active learners. Understanding what students value from their online experience could usefully be developed and exploited to their advantage as a post-Covid legacy. Much work regarding the influence of the pandemic on learning explores the psychological impact of the experience and student perceptions of online learning (Zhang *et al.,* 2022). This paper is concerned to more effectively understand how tutors may use this unusual opportunity of the pandemic for the benefit of future built environment students and of society. Being able to use resources and provide a learning environment which supports students' preparation for industry as practitioners is vitally important for effective development of the next generation of practitioners. This work explores the online experience of built environment students as learners to develop a better understanding of how to use resources and pedagogy to better support their learning. This work is both timely and important given the prevailing economic, ecological, and political circumstances and with the uncertainties these hold. Students are the industry practitioners of tomorrow, and understanding how better to support their learning today is important.

Objectives of this paper are first, to examine through a literature review, effective learning and assessment, remote learning, and the learner and self-regulation. This is in the context of means by which students may be supported in their development in preparation as industry practitioners. Second, to gather data to examine student self-perceptions as learners and their perceptions of the online learning experience and resources which best supported them.

This research is part of a larger project, exploring learning for built environment undergraduates and is undertaken at a UK university. Students on construction management and surveying honours degree courses at this HEI study either part-time day release, as a degree apprentice, or on a full-time basis. These honours degree courses are all accredited and there is focus on real-world industry activities - the significance of employability and practitioner knowledge and skills is central. Employers are encouraged to engage with course tutors and additionally there are bi-annual employers' meetings between tutors and employers to discuss the learning experience provided.

Theoretical Perspectives

Effective learning and assessment
Learning may be considered most effective when it is the result of a deep approach to learning and there is a conceptual change in the learner (Biggs at al 2022). The teaching-learning environment is one contributor to learning in so far as an environment perceived positively by students encourages a deep approach (Asikainen and Gijbels 2017). Deep learning is concerned with trying to "understand ideas and seek meaning" of the work (Prosser 1999: 3). Deep learning is associated with engaging with the learning, making meaning from it, whereas in a shallow or surface approach the learner merely seeks to use the minimum of effort required for completion of the learning activity (Prosser and Trigwell 1999). In shallow or surface learning the learner merely is concerned to memorise or pass rather than understand the work (Asikainen and Gijbels 2017). However, as Boud and Falchikov (2007) observe, assessment more than teaching is central to student learning. This highlights the significance of assessment as an influence over the learning activities undertaken by students, those activities on which students focus. Therefore, to encourage deep learning, assessment design needs careful consideration. The value of constructive alignment (Biggs 1996) should be recognised here. Constructive alignment aligns teaching, learning and assessment. The rationale for this is that as the student focuses on assessment activities, by aligning these with teaching and learning goals so the learning experience is strengthened. This alignment encourages students to take a deep approach to their learning as they complete assessment tasks which are aligned with the teaching and their learning goals.

In turn, this suggests that for built environment students, the nature of the assessment they undertake carries substantial consequences for their learning. Encouraging deep learning is essential for built environment undergraduates who are developing as industry practitioners. Consequently, fostering students' ability to respond to diverse challenges and deal with complex problems is integral to their preparation for industry. Assessment design then becomes of utmost importance - it will influence the learning activities undertaken, the knowledge and skills development of students.

As assessment forms the focus of students learning activities, to promote effective learning assessment should require students to engage with challenging real-world activities. Active learning, for example problem-based learning, would need the student to actively engage with generating solutions and consequently be more likely to use higher level skills in response (Biggs 2011). Real-life problems in an area relevant to the discipline are invaluable to help develop students' higher-level skills and understanding (Sadler 2016). Indeed, as Gleason (2018: 7) notes, "Assessments are most effective when they are grounded in project-based learning and authentic experience". Such problems challenge students and develop their competencies, while simultaneously seeking to prepare them as practitioners. For example, they support students' development of professionalism and leadership attributes, valuable competencies (CIOB 2018). Although Race (2010) notes that a shallow approach to learning can produce good grades, nevertheless it is necessary in accredited courses that students develop students' knowledge and skills as industry practitioners. Such practice is best undertaken, at least in part, through appropriate assessment activities which encourage deep learning and real-world activities.

Authentic assessment draws from and replicates real world activities, and which may involve problem-solving (Connolly *et al.,* 2023). Authentic assessment aligns with employability skills and for the student is thus meaningful (Bain 2023) as it combines assessment with professional practice, developing student competencies in readiness for industry. As such, assessment designed around professional practice activities holds merit for students learning and development in readiness for industry; it allows them to engage in problem-based learning, to develop as practitioners. For built environment students then, authentic assessment is vitally important for their development and preparation as industry practitioners. As assessment focuses students learning activities, so assessment should be authentic to industry practice and constructively aligned with teaching and learning.

Remote learning in lockdown

During lockdown, tutors found they had to create, at almost no notice, an effective online learning experience as the government required people to stay at home except for limited purposes (Cabinet Office 2020). This held some challenges for tutors and students alike, for example not everyone had adequate connectivity at home. Further, the limited amount of notice regarding the shift to online learning meant that tutors had no prior training on how to provide such a resource for a solely online delivery. Although there were opportunities to engage with training, tutors had to quickly make decisions about how to modify their pedagogy to accommodate the online learning experience (Gillis and Krull 2020). Notwithstanding these challenges, tutors were able to provide a resource considered by students as effective. For example, use was made of recordings of practice-based activities and assessment wrapped around these recordings.

Remote learning also meant that supporting learners in their development was more difficult particularly with practice-based work. Supporting learners until they can perform independently (Shvarts and Bakker 2019), becomes difficult to fully implement as such activities could not be undertaken during lockdown. In many instances, the learner could not authentically undertake practice-based problems nor challenges. To compound this problem, tutors could only support at an electronic distance.

There were further practical problems, aside from technological issues such as connectivity, included the need for students to adapt to online learning, and to develop their independence as learners (Lischer *et al.,* 2022). This meant that students were in a new, unplanned, and largely unknown learning environment. Although all knew how to use online learning technology, it was the pedagogic challenges which, it could be argued, were most difficult; students - and tutors - had no experience of this environment. It could be argued that this lack of experience or opportunity to prepare for the online environment was itself problematic.

The learner and self-regulation

The context in which learning takes place has an important role to play. It is known that being part of a learning community supports learners (Hardre *et al.,* 2013). However, during lockdown, such community was, by necessity, dramatically changed. Students now found themselves working at home, with only online resources. Many aspects of the normal campus-based experience were no longer available. This meant that students were left much more to their own devices and resources. They were isolated physically from their peers and tutors. Communication was now only electronic, and some students may have been better positioned than others in this respect.

This meant that students had to dig into their own resources, importantly this included independence of learning. Independent learning comprises several elements, including active learning, self-direction, thinking for oneself; self-reflection, is an important feature of such independence (Taylor 2018). Independent learning is the ability of the learner to "apply disciplinary insights themselves" (Knight 2007: 30). This ability, to apply disciplinary insights, is essential for professionals. As part of being independent, it is important to develop the skill of reflection, which is important not only for learning but also for development as an effective industry practitioner (Schön 1983).

Self-regulation concerns planning and adapting one's thoughts feelings and actions to achieve goals (Brydges and Butler 2012). Developing students self-regulated learning attributes can be influenced by 'relational connections' (Singh 2018). Self-regulated learning skills are also important for student achievement (You 2016). Being or becoming a self-regulated learner helps students to understand how they may improve (Nicol and Macfarlane-Dick 2006). Yet developing self-regulation through an online learning environment is particularly challenging - there is limited scope for informal exchanges and students are more isolated than otherwise.

In summary, the abrupt switch to an enforced online environment created problems for students on practice-based undergraduate courses; this included built environment students. The students were now in an isolated learning environment where development and practice of their industry knowledge and skills was, by necessity, curtailed. Many - not all - professional activities were no longer possible. The opportunity to constructively align teaching, learning and authentic assessment was absent in some cases or had been diminished in others. Students were effectively reduced from engaging in activities to becoming mere observers. Although observation has its place in education, the absence of hands-on activity was not ideal. Students, now more than ever, would profit from being self-regulated learners, yet this was precisely at a time when supporting their development of such self-regulation skills had become more challenging.

METHOD

The research method was concerned to examine the perspectives of those involved, and it was considered that an online self-completed questionnaire (Clark *et al.,* 2021) was most appropriate. It was the most practical way to gather data from numerous students and would be anonymous which also help alleviate potential issues around power relations and imbalance.

Free text questions were used, the object being to reduce any influence of the researcher and such open-ended questions would better allow respondents to answer as they chose rather than selecting from alternatives (Clark *et al.,* 2021). It was noted that as the target students were near the end of their course, they would be busy as they had a dissertation in addition to other units of study to complete. There were six questions to encourage students to complete the survey as it was not onerous, and the questions would not be too time-consuming to complete (Walliman 2006).

The population was the final year of undergraduates on the courses under study, giving a total of 132. All were invited by email to participate. The rationale for selecting these students is they had experience of university study before, during and after lockdown, meaning they were able to draw from these different experiences of higher education. The students were self-selecting and not a random sample; it is recognised that this may not have been a representative sample and so may involve a degree of bias (Fellows and Liu 2015). This means findings should be treated with caution as potentially the participants may not have been representative of all students.

After securing institutional ethics approval, data was then gathered. The survey was conducted on the JISC onlinesurveys platform, which was institutionally required. The survey was open during March 2023. First, the survey provided information regarding the survey and its purpose, with the first question seeking consent to participate. Skip logic meant that anyone who declined consent was automatically thanked for their time and locked out of the survey. Following this there were the six free-text response questions of the survey, see below.

1 After lockdown and returning to face-to-face teaching, what aspects of the learning experience were you pleased to regain?

2 Thinking about your answer to the last question, why are these things important or useful to you?

3 Describe how your approach to studying changed during and then after lockdown.

4 Independent learning is where you have control and ownership of your learning. How did you manage yourself to study independently during lockdown?

5 Now that lockdown is behind us, what influence, if any, would you say lockdown has had on your approach to studying?

6 Thinking about your studies, what are the most important things a module tutor can provide to support your learning?

At the close of survey, there were 17 completed responses. It is recognised here that this represents a limitation, and that this work must be judged considering this point.

Inductive thematic analysis was used to analyse the data to allow the researcher to identify and report patterns within the data using the survey questions as a guide and subsequently refined (Novak *et al.,* 2022). The researcher reviewed the data and analysis, checking that they had been meticulous and 'accurate' in conducting the analysis. Despite this, it is worth remembering that in thematic analysis, the researcher makes decisions, and consequently this point must be - and is - acknowledged (Braun and Clarke 2006).

FINDINGS

Students reported that the tutors provided a good online experience. Indeed, some indicated they would have been happy to continue solely online for the rest of their course, although their reason for this was often influenced by the desire to save travelling time. Nevertheless, this suggests that tutors had indeed been effective in responding to the challenges presented.

The real-life aspect of the learning experience was something students missed. It is unsurprising as they are on professionally focused courses, and being able to undertake such professional activities underpins their course. This fed into other aspects of the learning experience, in particular dialogue.

Opportunity to engage face-to-face with tutors to answer queries and receive feedback were greatly missed during lockdown. "Chatting face-to-face with the lecturer when needed" and "easier feedback opportunities with lecturers". Dialogue is an important part of learning, and it appeared that only when it was compromised did students more fully recognise its value.

Students overwhelmingly appreciated being back with their peers and valued the human interaction dimension of their learning. They appreciated being able to discuss much more easily with tutors and that a face-to-face learning environment experience was more engaging. A number also noted that they were able to discuss the learning activities with their peers, which helped them to "share ideas". Engagement as part of learning was also recognised. "Engagement with other students is important … to discuss what you are learning and get different opinions on topics". Perhaps this is not an unsurprising finding, but it was interesting to note their perception of social aspect of their experience and their recognition of the learning value of discussing with tutors as well as their fellow students. Yet lockdown meant that tutors were having to support students at arm's length, and students had a perception of this gap in their experience.

As regards self-regulation, some students recognised they had challenges managing their own time and their own learning activities. For example, "more discipline to time management". It is valuable that students recognise the importance of this, even though some considered it a challenge in which they did not perform well. However, some students reported that they were able to 'dig into' this resource to good effect.

Unexpectedly there was a perception that the physical learning environment influenced students' experience and was not solely concerned with resources. For example, "hard to motivate myself … partly down to not being able to physically be in a learning environment". That the physical environment could be so powerful an influence was unforeseen. There were also practical challenges and an underlying sense of a less than ideal study setting; "I sometimes had to lock myself in the spare room … Everywhere was closed including the library".

It was interesting that students recognised the value of discussion, including with their peers. This suggests that they were beginning to appreciate that learning is not an instructive and passive process, but something they actively engage with. Providing a learning environment which builds on the student's own contribution, which requires them to be active learners, is supportive of learning. Embedding this within the physical and online environment offers scope to further develop students. It was interesting that feedback, not well evaluated at HEIs through the National Student Survey (OfS 2023) was something students mourned. It may be that students recognised they did receive feedback and its value, but only when it was, by necessity of remote learning, it was less easily accessible. Alternatively, that they valued discussion but did not perceive it as feedback.

It was perhaps unsurprising that students' responses were varied in respect of how they were able to manage themselves on this isolated environment, and that some had fared better than others. For some learners, it appeared that the physical environment they suddenly found they were working in impinged on their ability to self-regulate. This is worth further investigation, to explore the nuances of physical environment on self-regulation and subsequently on learning. Part of this may have been sub-optimal settings, for example working in their own bedroom. However, some was 'place' not suggesting 'study here' rather than any physical deficiencies of the space. However, it was surprising as to the extent of influence the physical environment exerted, whether off or on campus. This highlights the significant role that the built environment plays in learning, not simply providing a physical resource which might include objects to help learning for example books, but in terms of messages communicated to learners about activities to undertake.

CONCLUSIONS

The findings of this paper suggest that to help prepare students as industry practitioners and develop their skills as independent self-regulated learners, continuing to provide a variety of online resources.

Self-regulation, which is an important attribute, was, sometimes, embedded within perceptions of the physical environment. This is worth further research to better understand nuances of this and appreciate how students may be better supported to become more self-regulated, both for their learning and their professional practice.

Attention should be given to the role that the physical environment plays, in both obvious and not so obvious ways, and which should be given space in the higher education landscape. Findings of this work, although to be treated with caution, suggest that there may be scope to enhance the learning environment. Given the important role of the built environment in the UK economy, this is an important point as supporting development of the next generation of practitioners may have long-term implications for the efficacy of the industry.

Each of these components - physical space as a resource and as a psychological support, encouraging feedback discussion with peers and tutors, further promoting development of self-regulation, and authentic assessment design are important. The post-Covid legacy, it is suggested here, should offer weight to combining each of these 'invisible' attributes to support students develop their self-regulation and preparedness as industry practitioners.

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PERFORMANCE

CONSEQUENCES OF POOR MANAGEMENT OF ACCULTURATION ON LARGE INFRASTRUCTURE PROJECTS

Gasper Akuhe[1], Apollo Tutesigensi[2] and Muzafalu Kayondo[3]

[1&2] *School of Civil Engineering, University of Leeds, Woodhouse Lane, Leeds, LS2 9JT, UK*

[1&3] *Uganda Electricity Generation Company Limited, PO Box 75831, Kampala, Uganda*

Schedule overruns on construction projects are still rampant despite the numerous research studies on the causes of delays and the identification of avoidance strategies. However, there has been a proclivity for most of the previous research studies to solely focus on the general causes of delays while ignoring the interrelated and reciprocal impacts of various delay factors on other causes of delays. This has restricted understanding of the prescription of appropriate mitigation strategies since delays are caused by several interrelated events that influence each other. To address this gap, research was undertaken to establish the causation mechanisms of delays on a large infrastructure project. A single case study approach focusing on a large infrastructure project was adopted. Secondary data in the form of project documents were collected and analysed using thematic analysis. The findings of this study revealed that poor management of acculturation was a root cause of construction delays on this project. This research argues that reducing construction delays can be facilitated by developing and maintaining project culture.

Keywords: Acculturation; delays; infrastructure; project culture; project schedule

INTRODUCTION

As an indicator and regulator of economic growth, the construction industry continues to attract a fair share of investment and its growth worldwide is on an upward trajectory (Alinaitwe *et al.,* 2013; Flyvbjerg, 2014; Wang *et al.,* 2022). However, management-related challenges are still pervasive and continue to derail the performance of the construction industry, especially when assessed from the perspective of schedule delays, cost overruns, and benefits shortfall (Flyvbjerg, 2014; Durdyev and Hosseini, 2020). The inability to complete infrastructure projects on time is still a persistent problem worldwide and, even worse, in developing countries (Doloi *et al.,* 2012; Alinaitwe *et al.,* 2013; Durdyev and Hosseini, 2020). Love *et al.,* (2013) also urge construction industry practitioners to consider project delays when examining project performance issues due to their critical influence on the productivity and financial performance of the various project parties. Additionally, project delays have detrimental implications for all project parties and stakeholders as they bring about adversarial relationships, claims, litigation, and financial loss

[1] akuheg@gmail.com

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(Alinaitwe *et al.,* 2013). As such, the construction industry is in an intense period of introspection on how it can improve project schedule performance.

As indicated in most research studies on project performance, construction delays have become a ubiquitous feature within the construction industry (Durdyev and Hosseini, 2020). A project delay is defined as an overrun beyond the scheduled project completion time (Assaf and Al-Hejji, 2006). Construction delays can happen due to various factors caused by any of the parties involved in the project (Love *et al.,* 2013).

Numerous research studies have investigated the factors contributing to project delays while considering country, region, project type, procurement methods, and stakeholder perspectives. These studies have consistently identified poor contract administration, ambiguous contracts, unrealistic schedules, unclear project scope, poor communication, poor quality and rework as the most common causes of construction delays (Doloi *et al.,* 2012; Durdyev and Hosseini, 2020).

According to Durdyev and Hosseini (2020), several causes of delays are interrelated and influence each other; therefore, investigating the influence of each cause separately is an oversimplification of the problem and a gap in the knowledge that needs to be filled. However, there has been a proclivity for most of the previous studies to focus solely on the general and proximal causes of delays, while ignoring the interrelated and reciprocal impacts of various delay factors on other causes of delays. This has, in turn, restricted understanding of the prescription of appropriate mitigation strategies.

Therefore, despite the continued manifestation of project delays and their known detrimental effects on construction projects, it is strongly accepted that schedule overruns can be mitigated or even entirely avoided with the adoption of appropriate strategies. To achieve that, it is important to establish the causation mechanisms for delays on the project to identify the underlying root cause for the delays along a chain of several interrelated delay events, unlike most previous research studies that have solely focused on the identification of general and proximal causes of delays. This will enable the identification of potential intervention points along the chain where appropriate mitigation strategies can be implemented to disrupt the delay mechanisms and prevent potential delays.

Furthermore, a review of the literature on the causes of construction delays has also revealed a paucity of information on issues related to the project culture, contractual relationships, and project delivery methods (Durdyev and Hosseini, 2020).

As such, this study aims to identify the causation mechanisms of construction delays on a large infrastructure project to better understand the underlying root causes of delays and adopt appropriate mitigation strategies that can disrupt the delay mechanisms and enable better project schedule performance.

Project Culture

Culture is broadly defined as the unique configuration of artefacts, espoused values, norms, beliefs, behavioural patterns, and underlying basic assumptions that characterise how groups and individuals combine to get things done (Schein, 2010). Culture can manifest through any of these dimensions at various levels i.e., national, industry, organisational, project and individual levels and understanding culture at any level requires some understanding of all the levels (Ankrah *et al.,* 2009; Schein, 2010).

Artefacts are defined as tangible signs and creations that manifest the culture of any group. Cultural artefacts at the national level can manifest through their unique physical architecture, art, symbols, emblems, and administrative structures while at the organizational level, they can manifest through organization charters, logos, and organograms, among others. At the project level, artefacts can manifest through project organograms and governance structures among others.

Culture can also manifest through behavioural patterns, values, and norms. Just like artefacts, behavioural patterns, values, and norms also manifest differently across the national, organisation and project levels.

Cultural norms are expectations of behaviour and thoughts based on shared beliefs within a specific group. Norms are also standards for appropriate and inappropriate behaviour that govern what is (and is not) acceptable in interactions among people (Nguyen and Watanabe, 2017). Norms can manifest at the national level through national communication practices, for example, the national language, national standards, and regulations, among others. At an organisational level, norms manifest through organizational rules and procedures. At the project level, which is the focus of this study, norms can also manifest through the adopted communication systems e.g., adopted language and the project standards. These project norms are usually prescribed in the project contract, which all project parties must adhere to and if not done is regarded as an anomaly/noncompliance. The norms in a project setting can be defined in the contract e.g., all project communications shall be in the English language, and all project procedures and practices will adhere to the set standards, say, ISO standards. As such, clear emphasis must be placed on implementing the set norms.

Culture is complex in the sense that it arises from different sources/levels but there is also interplay in the sources. It is difficult to study all dimensions. At best, we can isolate certain aspects and explore them. Any of these cultural dimensions can be studied to describe and make any key phenomena, in this case, project delays, comprehensible (Schein, 2010). According to Ankrah *et al.,* (2009), cultural dimensions can be contextualised based on their relevance in a particular setting. Therefore, in this study, the cultural dimensions of norms i.e., language and standards will be explored in the context of project delays.

Acculturation

Berry (1992) defines acculturation as "the process of cultural change that occurs when organisations/individuals from different cultural backgrounds come into prolonged, continuous and first-hand contact with each other''. Large infrastructure projects usually involve multinational organisations, and their success depends on all participants' collaboration. However, the challenges of cultural complexity arising from the various project teams' backgrounds are notorious for large infrastructure projects and managing any cultural differences carefully is crucial to the attainment of successful outcomes (Schein, 2010). As such, acculturation is a significant aspect in a multi-stakeholder and multi-dimensional project environment, that needs to be managed in a proper way to ensure project management success.

Multinational organizations need to cultivate cultural sensitivity, flexibility, and global learning capabilities to manage multicultural issues/acculturation, foster a fully integrated project team and enhance project performance (Ochieng and Price, 2010). This, therefore, implies that project teams can undertake an assessment of their cultural orientations and based on that, forecast the probable project performance and where necessary, take actions to improve their cultural orientation to enable better project performance (Ankrah *et al.,* 2009).

Hence, construction projects and culture are inseparable and significant in project management success (He *et al.,* 2020). Culture has a significant impact on project management and has been identified by many authors as a key factor for cross-organization cooperation and even project management success.

METHOD

This study adopted a single case study to establish the causal mechanisms of construction delays on a large infrastructure project. A case study approach was adopted due to its suitability in acquiring a deep understanding of real-world problems and phenomena (Yin, 2018). Furthermore, a case study approach enables the investigation of underlying reasons as to why and how events occur (Eisenhardt, 1989) and provides exemplary knowledge (Thomas, 2010). Therefore, the adoption of a case study approach was appropriate to achieve the goal of this research, which was to establish the causation mechanisms of construction delays on a large infrastructure project to enable the adoption of appropriate delay mitigation measures.

The selected case study is a large public infrastructure project still under construction in a developing country. It is being implemented under an EPC contract involving multi-national stakeholders i.e., the contractor, project manager, a panel of experts, and project management consultants. The project client is the government represented by the sector ministry and its two subsidiary agencies for their respective components of the project.

A cross-sectional study involving a critical review of secondary data obtained from the case study project documents was undertaken. The documents included project progress reports, project letters, project minutes of meetings, project implementation schedules, project contracts, audit reports, experts' review reports, and extension of time (EoT) reports. Due to ethical considerations, all project parties are not identified, and all project data are anonymized throughout this study.

The study aimed at establishing the causation mechanisms of construction delays on a large infrastructure project. The project documents were analysed using thematic analysis. The thematic analysis facilitated by NVivo involved familiarization with data, coding to group data with similar patterns, and identification of emerging themes. The thematic analysis was done inductively (Saunders *et al.,* 2019) to identify potential links/evidence of delay causal factors for the studied case study project delays.

FINDINGS

A preliminary analysis of the case study project documents revealed the project had experienced numerous delays amounting to a schedule overrun of almost 100% of the original project duration. These delays were attributed to numerous factors, including poor contract administration, incompetency of the owner's engineer and contractor, rework arising from poor quality, and failure to manage acculturation. However, Durdyev and Hosseini. (2020) emphasize that project delay causative factors are multidimensional, interrelated, and do not adopt a one-size-fits-all approach. As such, Durdyev *et al.,* (2017) recommend prioritising the establishment of the underlying causative factors for delays to enable the project team to focus and optimise the scarce project resources while implementing the delay mitigation strategies. This prompted the establishment of the delay causal mechanism for the studied delays to ascertain the influence of the different delay factors on each other. With due consideration given to the multinational nature of the case study project, the focus of this study was narrowed down to project culture and management of acculturation in relation to other delay causative factors.

Project culture can manifest through different dimensions such as norms, artefacts, espoused beliefs, and values (Ankrah *et al.,* 2009; Schein, 2010). Any of these cultural dimensions can be studied to describe and make any key phenomena, in this case, project delays, comprehensible (Schein, 2010). Additionally, the boundaries for this study were set within the post-contract award stage. As such, data analysis was undertaken qualitatively to group the findings into themes based on the manifestation of the project culture through the cultural dimensions of norms i.e., Language and Standards/codes which were also clearly defined in the project contract respectively as English and (British, American and ISO) standards, although, any other international standards were also acceptable as long as the contractor could verify its suitability against the contractually accepted standards (British, American and ISO).

Acculturation

Multi-cultural organizations working together on a project poses a much larger cultural challenge which needs to be managed carefully (Schein, 2010). This study adopted Berry's acculturation model considered at an organization level (project as a temporary organisation), for the multi-national project organisations involved in this project whilst only focusing on two cultural dimensions of norms i.e., standards/codes and language (Ochieng and Price, 2010; Dai and Cai, 2017). These cultural dimensions were explored from the concept of dimensionality i.e., how the origin and destination cultures of the different project multi-national stakeholders dealt with each other to adopt any of the four acculturation strategies of separation, assimilation, integration, and marginalization (Berry, 1992) as depicted in Figure 1.

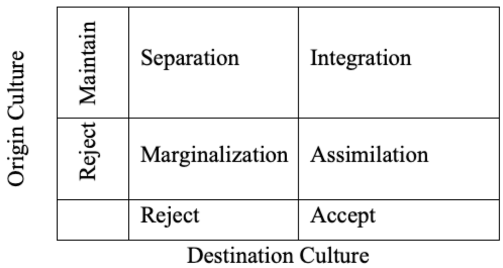

Figure 1: Berry's acculturation strategies

The established delay causal mechanism revealed the failure to manage acculturation as potentially one of the underlying root causes for the studied delays among other root causes. Delays due to suspension of works, rework, and delayed approvals/decision-making were identified as the immediate causes of the failure to meet the project deadlines. The causation mechanism for the studied project delays is illustrated in Figure 2.

Management of Acculturation with Respect to Norms (Standards/Codes of Practice)
The project client is the government of a developing country without relevant standards for this kind of infrastructure project but usually adopts British, American and ISO standards for most of their infrastructure projects. During contract negotiation, the project consultant's origin standards (hereinafter referred to as "I" standards) upon which the tender documents were mostly developed, and the project

contractor's initial proposal to adopt their origin standards (hereinafter referred to as "C" standards) were all rejected.

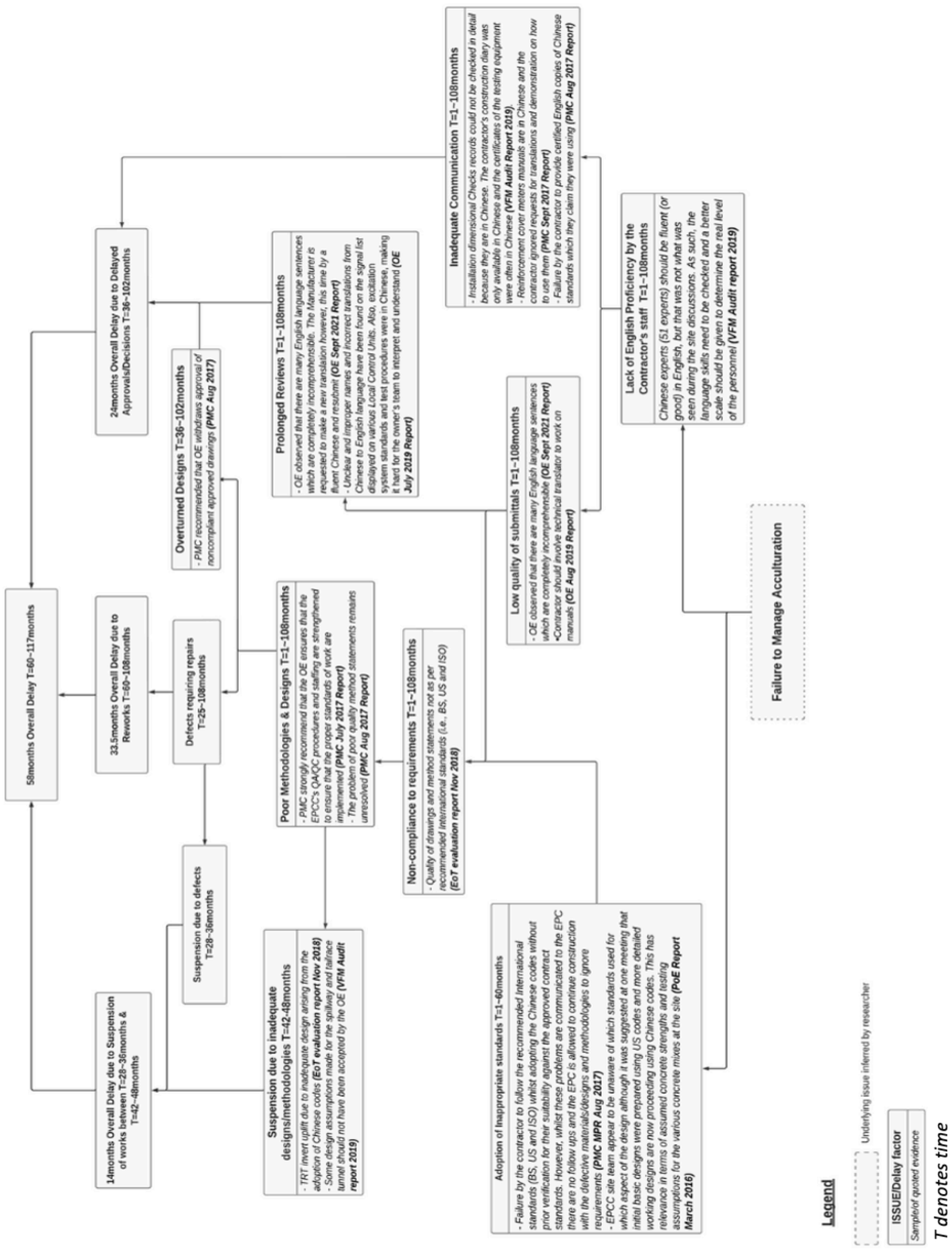

Figure 2: Causation mechanism for the studied project delays

All parties agreed that only US, British, and ISO standards should be adopted for the project, although, a provision was introduced in the contract to allow for any other standards if only the contractor could take responsibility for their verification of suitability against the contractually accepted standards (US, British, and ISO). According to Berry's acculturation strategies (Figure 1), the origin cultures for both the consultant and contractor were rejected while maintaining the destination culture for the project client. As such, the procurement process resulted in an assimilation strategy as outlined in the signed project contract. This is not a problem as the purpose of tendering is to enable the client to identify someone with whom a contract could be entered into (Siegel, 2019). However, the amendment of the adopted standards in the minutes of negotiations was only stated generally and, the detailed employer's statement of requirements, where some of the "I" standards were implicitly considered were not amended accordingly. Siegel (2019) argues that the quality of the employer's requirements is the foundation for the subsequent phases of the project as it influences the design and construction quality. This was the first manifestation of poor management of acculturation because insufficient steps were taken to harmonise the contract documents with the desired acculturation strategy.

The project acculturation status matrix on the cultural dimension (norm) of standards/codes in Table 1 reveals an acculturation gap in the current and desired acculturation strategies of the contractor and project manager, which resulted from a separation strategy being adopted instead of the client's preferred assimilation strategy outlined in the contract.

Table 1: Acculturation status matrix for the dimension of standards/codes

Acculturation Status → Project Parties ↓	Separation	Marginalization	Assimilation	Integration
Contractor	C		D	
Project Manager*	C		D	
Client			C, D	

C = Current; D = Desired

** The project manager referred to here is the 1st Owner's engineer*

Adoption of Inappropriate Standards

The failure to manage acculturation on this project manifested through the standards' cultural norm as the contractor persistently adopted the inappropriate "C" standards without taking the necessary steps to verify their suitability against the contractually accepted standards. This was evident in Figure 2 as analysis of the causal mechanisms for the studied project delays revealed that failure by project parties to proactively close and manage this acculturation gap led to the suspension of works and rework due to non-compliance, and delayed approvals/decision-making, as further explained below.

Delays Due to Suspension of Works, Rework, and Delayed Decision-Making/Approvals

Several delays amounting to more than 48 months resulted from rework and suspension of works on site. Over 300 non-compliances to quality and performance requirements were issued to the contractor and required rework, hence causing delays. These non-compliances were mostly attributed to poor methodologies and inadequate designs arising from the contractor's persistent application of the "C" standards against the contractually accepted standards, and the project manager's negligence of duty of due care to enforce compliance. For example, the "C" standards were inappropriately adopted in the design of the tailrace tunnel concrete lining which eventually failed and caused a delay of over 6 months. They were also adopted in the poorly designed and executed anchor bars, as well as rebar splicing and welding works that later required rework. The contractor mixed different standards in their QA/QC procedures without matching the testing equipment to the adopted standard's testing procedures, resulting in numerous concrete defects. The project also experienced delays amounting to over 24 months due to delayed approvals for the designs and methodologies. The delays in approvals were partly attributed to non-compliant submittals to the accepted standards. Most project delays manifested due to prolonged reviews and resubmissions arising from the inappropriate use of the "C" standards. Further project delays amounting to over 18 months occurred when certain approved designs had to be overturned later after establishing, they were non-compliant with the accepted standards.

The persistent adoption of the "C" standards as demonstrated above implies that the contractor imposed their origin culture on the project resulting in a separation strategy instead of the project's desired assimilation strategy. This was a manifestation of poor management of acculturation because the contractor took insufficient steps to harmonise the adopted standards with the desired acculturation strategy. This can be attributed to the contractor's lack of cultural awareness and knowledge of the contractually accepted standards. It also means that the contractor did not understand that an acculturation process needed to happen. As such, the contractor did not cultivate the intercultural competence of his employees through recruiting adequately and conducting intercultural training to expose, prepare and enhance their understanding of the desired cultural aspects (Dai and Cai, 2017). It is thus possible that adherence to the desired acculturation strategy by the contractor could have prevented most of these delays.

Management of Acculturation with Respect to Language

Lack of English Language Proficiency

To function effectively, project teams must establish a system of communication and a common language. This is usually established through the project contract by the client (Schein, 2010). As such, the project's desired assimilation strategy meant that the project client's destination culture in terms of the cultural dimension of language (English) was maintained while rejecting the contractor's origin culture (hereinafter referred to as "M" language). However, the failure to manage acculturation on this project also manifested through the language norm i.e., lack of English language proficiency by the contractor. This was evident as further analysis of the causal mechanism for the studied project delays in Figure 2 revealed that failure by project parties to close and manage this acculturation gap led to low quality of submittals, inadequate/ineffective communication, prolonged reviews, overturned designs, all culminating into delayed approvals/decision-making as further explained below.

Delayed Decision-Making/Approvals

The project acculturation status matrix on the cultural dimension (norm) of language in Table 2 reveals an acculturation gap in the current and desired acculturation strategies of the contractor, which resulted from a separation strategy being adopted instead of the project's preferred assimilation strategy outlined in the contract.

Table 2: Acculturation status matrix for the dimension of language

Acculturation Status → Project Parties ↓	Separation	Marginalization	Assimilation	Integration
Contractor	C		D	
Project Manager			C, D	
Client			C, D	

C = Current; D = Desired

Based on the results of the study, it was discovered that the contractor did not fully embrace the assimilation strategy and instead opted for a separation strategy. This was evident in their hiring of some sub-contractors and workers who were unable to communicate fluently in English, resulting in inefficiencies in the work processes. As a result, project documents such as manuals, letters, reports, and method statements were of low quality and often had to be resubmitted/clarified. Some project documents such as installation dimensional checks, construction diaries and equipment testing certificates were entirely in the "M" language. The contractor also failed to provide translated and certified English copies of some of the adopted "C" standards and test procedures, which made it difficult for the owner's team to interpret and understand. Some of the contractor's equipment such as cover meters, rebound hammers, batching plant control panels, and calibration equipment had an "M" language interface that other project parties could not interpret. All this constrained supervision and delayed decision-making, hence contributing to project delays as depicted in Figure 2.

As such, the failure by the contractor to put in place measures such as translation of "C" standards, manuals, and appropriate recruitment of staff/workers fluent in English, was another manifestation of failure to manage acculturation on this project. The contract was clear on the language to be adopted, however, the contractor lacked cultural sensitivity to comply with the contract language. This gap could have been closed by ensuring the contractor cultivates the intercultural communication competence of his employees through intercultural training to enhance their language competence and cross-cultural communication skills (Dai and Cai, 2017).

CONCLUSIONS

This research has established a causation mechanism for the studied delays on a large infrastructure project and identified a potential root cause for the delays along a chain of several interrelated delay events, unlike most previous research studies that solely focused on the identification of general and proximal causes of delays. The study has also enabled the identification of potential intervention points along the chain where appropriate mitigation strategies can be implemented to disrupt the delay mechanism. The failure to manage acculturation was identified as a potential root cause of delays in this study. Therefore, effectively managing acculturation in multi-stakeholder and multi-dimensional project environments can help reduce construction delays, as project culture plays a key role in project performance, as previously stated by He *et al.,* (2020). Based on the findings of this study, the researchers recommend the following measures to manage acculturation and improve schedule performance on similar projects:

- When forming multicultural project teams, it is important to have members with demonstrated cultural intelligence (Schein, 2010). However, this may not always be possible due to limited/scarce resources. In such cases, intercultural competence training can be provided to team members to improve their understanding, awareness, and sensitivity towards different cultures. This can help bridge cultural gaps and promote harmonious relationships within the project team.
- It is also recommended to include measures in project contracts that ensure compliance and continuous improvement towards achieving the desired acculturation strategies. This may involve incentives and disincentives to encourage better management of acculturation.

Therefore, as we seek to construct for the future, the findings of this research can serve as a basis for promoting or recommending cultural changes within the construction industry and inspire researchers of project performance to focus more on the "softer" aspects, such as culture.

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PERCEPTIONS AND UNDERSTANDINGS OF CONSTRUCTION SITE PRODUCTIVITY: INSIGHTS FROM THE DANISH CONSTRUCTION INDUSTRY

Jan Bronke[1] and Nicolaj Frederiksen[2]

[1] *Department of Building Construction, UCL, Seebladsgade 1, 5000 Odense C, Denmark*

[2] *Department of the Built Environment, Aalborg University, A.C. Meyers Vænge 15, DK-2450, Copenhagen, Denmark*

Productivity has been a recurrent topic in construction management research for decades. While an impressive number of inquiries have explored construction sector productivity from an ex-post perspective by measuring inputs and outputs of resources in construction activities, less attention has been invested in understanding construction site perceptions of productivity and understandings of how to improve productivity. The aim of the study is to contribute to existing literature in two ways. First by providing insights into the different perceptions of productivity among craftsmen and construction managers. Second by demonstrating how ambiguous understandings of productivity adversely affect the planning and execution of construction activities and thus complicates productivity improvements. The empirical material conducted through semi-structured interviews is analysed through a theoretical framework based on extrinsic and intrinsic motivation. The findings show that the construction managers embrace the idea of monetary rewards as an approach to address productivity issues. Analogously, the craftsmen request and highlight better communication between construction managers and craftsmen as well as increased influence on the planning and execution of construction activities as ways to improve productivity.

Keywords: category; motivation; productivity; qualitative research

INTRODUCTION

Construction productivity has been a recurrent topic in construction management for decades (Hasan *et al.,* 2018; McKinsey Global Institute, 2017). A simple definition of the term is that productivity refers to the amount of output per input of a unit of labour (World Bank, 2021). In context of construction, productivity is often measured in the form of hours required to perform certain activities (Hasan *et al.,* 2018).

According to Kenley (2014), researchers have mainly examined construction productivity either at the level of the industry, firm, project, or activity. Based on this division, Kenley (2014) criticises previous studies for not adopting a systemic perspective on productivity, which is considered a prerequisite for understanding how to improve productivity in the construction industry. In a similar vein, Haugbølle and

[1] bron@ucl.dk

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colleagues (2019) argue that construction productivity can be roughly divided into two streams of analysis. One stream has touched upon productivity at the macro-level, i.e., input-output studies of national accounts (e.g., Chia *et al.,* 2014; Neve *et al.,* 2020).

The other stream has been concerned with productivity at the micro-level, i.e., studies of how technologies, practices and processes in construction activities affect construction site productivity (e.g., Heigermoser *et al.,* 2019; Olivieri *et al.,* 2018). Based on the two streams of analysis, Haugbølle and colleagues (2019) express the need to bridge macro and micro studies of productivity to improve the measurement of construction output - thus echoing the argument of Kenley (2014) that studies on construction productivity should adopt a more systemic approach taking different levels of analysis into account.

The study takes its starting point from the assumption that productivity can be considered an established yet contested category in the construction industry. As an established category, productivity is a persistent and widespread concept in the industry on which groups of actors share meaningful consensus (Negro *et al.,* 2011). However, as a contested category, productivity captures multiple levels of scope and spans multiple groups of actors (as demonstrated by e.g., Haugbølle *et al.,* 2019; Kenley, 2014) who draw different beliefs, expectations, and behavioural patterns from the category (Durand and Paolella, 2013). This means that the category of productivity possesses heterogeneity and ambiguity, which is potentially difficult to reconcile and thus provides a fertile ground for category contestation to occur (Colyvas and Powell, 2006).

Drawing on literature from category research and self-determination theory, the aim of the study is to explore how productivity, as a distinct category, permeates the project level and consequently 'disciplines' (Kennedy and Fiss, 2013) groups of actors by providing category content (i.e., beliefs, expectations, and behavioural patterns in relation to productivity). In addition, we have a special interest in two groups of actors - 'project management' and 'craftsmen' - both of which can be considered members of the productivity category (Negro *et al.,* 2011) and associated with the project level. In this way, the study adopts a constructivist approach to productivity and contributes to construction management research with new understandings of productivity as a situationally contested, negotiated, and defined category (Colyvas and Powell, 2006; Kennedy and Fiss, 2013) rather than a static, 'ready-made' category (e.g., Heigermoser *et al.,* 2019; Neve *et al.,* 2020).

Theory

This section outlines the theoretical basis of the study. The section starts by elaborating on the core assumptions from category research and the relevance for the study at hand. A branch of self-determination theory is then introduced as a complementary framework to gain a deeper understanding of the underlying implications of category membership in relation to motivational orientations among groups of actors.

Productivity as a Category

In the words of Durand and Paolella (2013, p. 1100), categories represent "a meaningful consensus about some entities' features as shared by actors grouped together as an audience". In this way, categories can be seen as 'social agreements' about which beliefs, expectations and behavioural patterns that are consistent with its label, i.e., "the category's descriptive tag" (Negro *et al.,* 2011, p. 1449). Likewise, these shared agreements about category content reflect both the cognitive and normative conditions for membership (Durand and Khaire, 2017) and offer a lens for interpreting reality (Kennedy and Fiss, 2013; Negro *et al.,* 2011). Recent studies within this area have explored how categories emerge, change, dissolve, are merged or contested (cf. Delmestri *et al.,* 2020). Studies have also articulated the importance of categories in terms of defining interactions and exchanges between organizations (Durand and Khaire, 2017) and thus in influencing organizational outcomes (David *et al.,* 2023).

Categories can vary significantly. In their stocktaking paper on the current and future research paths on category research, Delmestri and colleagues (2020) make a distinction between market categories, organizational categories, and professional categories. Although this distinction should not be considered the universal truth, it nicely demonstrates the breadth and varied nature of categories. In context of construction, market categories may include contract award criteria, forms of contracts or forms of tenders. Organizational categories may include sectoral affiliation, stakeholder base or core business. Finally, professional categories may include educational background, occupation, or trade union affiliation.

A common assumption in the literature is that actors (organizations and individuals) are members of multiple categories (Durand and Paolella, 2013), and thus draw on different cognitive and normative sources at the same time. Another widespread assumption is that categories are not necessarily as homogeneous and stable as they may appear but can possess considerable heterogeneity and ambiguity (Colyvas and Powel, 2006) and be emerging and changing (Durand and Khaire, 2017; Kennedy and Fiss, 2013). Applying these insights to the productivity category under scrutiny, it can be said that productivity represents one of many categories in the construction industry that actors orientate themselves towards in pursuit of efficiency, elimination of waste and economic gains (Hasan, *et al.,* 2018; Kenley, 2014; McKinsey Global Institute, 2017). Moreover, the productivity category spans different members who draw different beliefs, expectations, and behavioural patterns from the category. For example, in Denmark, productivity has been a recurring topic among policymakers, industry associations and firms for more than a half century. Over the years, productivity improvements have been highlighted both as a means of increasing Danish exports (Kristensen *et al.,* 2005), increasing efficiency at the construction sector level (Gottlieb and Frederiksen, 2020) as well as increasing craftsmen efficiency at the project level (Neve *et al.,* 2020). However, we still have little understanding of how different groups of actors (members) put category content on productivity into practice, and what motivational consequences it has when different, disparate interpretations of the content collide.

Extrinsic and Intrinsic Motivation

Self-determination theory originates from the 1970s comparative studies of extrinsic and intrinsic motivation, which spawned a growing awareness of the importance of intrinsic motivation for human behaviour (e.g., Deci, 1971). Extrinsic motivation refers to the effort of individuals to do 'something' because it is associated with a separable outcome (Ryan and Deci, 2000). Analogously, intrinsic motivation refers to the effort of individuals to do 'something' because it is considered inherently rewarding or enjoyable (Ryan and Deci, 2000). A central argument in self-determination theory is that people have three innate psychological needs that, if met, will results in individuals are likely to be intrinsically motivated, i.e., they will perform activities because they consider them rewarding or enjoyable (Amabile, 1997). Conversely, when these needs are not met, individuals may become extrinsically motivated, i.e., they perform activities for external reasons such as to obtain monetary rewards or avoid sanctions (Ryan and Deci, 2000). The three psychological needs - autonomy, competence, and relatedness - are briefly elaborated in the following.

Autonomy refers to the need for individuals to feel in control of their own lives and decisions (Baard *et al.,* 2004). It is the feeling that one is acting in accordance with one's own interests and values, rather than being controlled by external factors (Deci, 1971). Autonomy is considered important because it allows individuals to feel a sense of ownership over their actions, which in turn can increase intrinsic motivation and engagement in activities. When individuals feel that they are acting autonomously, they are more likely to experience positive emotions, perform better and persist in challenging tasks.

Competence refers to the need to feel capable and effective in one's activities (Ryan and Deci, 2000). It involves a sense of mastery and the feeling that one's efforts are producing desirable results. Competence is important because it allows individuals to feel a sense of accomplishment and self-efficacy, which is said to increase intrinsic motivation and engagement in activities. When individuals feel competent, they are more likely to take on challenging tasks and persist in the face of difficulty. Amabile (1997) explains that a mixture of expertise, creativity skills and task motivation is a source to 'professional creativity', which is considered a source of problem-solving and thus a way of feeling capable.

Finally, relatedness refers to the need to feel connected to others and to be a part of social groups (Baard *et al.,* 2004). It encompasses a sense of belongingness, intimacy, and social support. Relatedness is important because it allows individuals to feel supported and valued, which in turn can increase intrinsic motivation and well-being. When individuals feel connected to others, they are more likely to engage in prosocial behaviours, cooperate with others, and experience positive emotions.

We use insights about the three psychological needs as we believe they can enrich our understanding of the productivity category and how category content affects motivation. Specifically, by using self-determination theory in combination with category research, it is possible to better understand the motivations and experiences of individuals that are members of the productivity category.

METHOD

One of the authors collected the empirical material for the study in spring 2020 using a research design based on semi-structured interviews and a questionnaire. In Denmark, project managers usually have an educational background in which they have been introduced to, and thus are familiar with, the interview method. In contrast, craftsmen have rarely used (as an interviewer) or been the subject (as an interviewee) of the interview method, which means that they are likely to consider the interview situation as 'foreign' and uncomfortable. The research design was therefore chosen to ensure that the collection of empirical material was conducted with respect for the informants' different needs and preferences, and not because we had a particular interest in generating qualitative as well as quantitative data.

A total of seven semi-structured interviews were conducted with project managers employed in medium-sized or large contractor firms in Denmark (five unique firms). The interviewees were appointed in collaboration with a contact person from each of the firms. Our only selection criterion was that the appointed project manager had to have sufficient knowledge of the day-to-day work on construction sites in Denmark to be able to reflect on our interview themes. The interviews were conducted based on an interview guide (Kvale and Brinkmann, 2009) consisting of an initial set of 25 interview questions, which were categorised under the following four themes: (1) personal information, (2) construction site productivity, (3) means of rewarding and punishing and (4) motivation. It was not intended that all interviewees should be asked all 25 interview questions. Instead, the set of interview questions served as a catalogue where the interviewer could find inspiration for formulating questions as the conversation progressed (Rubin and Rubin, 2012). All the interviews, each of which lasted approximately one hour, were audio-recorded and selected passages of the conversations have subsequently been transcribed. In addition, all interviews were conducted on a construction site at the request of the interviewee.

The questionnaire consisted of 19 questions based on two different types of questions (Krosnick and Presser, 2018). These questions were structured around the same four themes as the interviews. The first type of questions was closed-ended multiple-choice questions, where the informant was asked to select one option, for example regarding their professional affiliation (bricklayer, carpenter, plumber, etcetera) or the most common way of rewarding (bonuses, gifts, praise, social events, etcetera). The second type of questions was open-ended questions, where the informants were asked to provide an answer to the question in their own words. Here, the informants were among others asked which measures that could increase productivity among craftsmen and which efforts that could foster intrinsic motivation. The questionnaire was physically handed out to craftsmen working on four different construction sites and 62 of the 73 craftsmen filled it out. Although the questionnaire was distributed randomly among the craftsmen on the construction sites, it turned out that 48% of the informants were carpenters.

FINDINGS

This section elaborates on the different perceptions and understandings of the productivity category, category content and the implications for intrinsic motivation among project managers and craftsmen working at the project level.

Project Managers

The project managers frame productivity as an expression of how well a project performs in relation to the vertices of the 'iron triangle', i.e., the due date, agreed budget and determined quality level. By extension, a productivity improvement is referred to as an improvement within one of the vertices of the iron triangle without causing significant harm to the others. However, one of the project managers explains that productivity improvements are difficult to achieve because the individual construction crew pursue their own craft-specific goals at the expense of the specific project's overall objectives. As explained by the project manager: "A major problem is that the craftsmen often pursue improvements within their own domain without considering whether it could potentially harm the overall planning of the project". In a similar vein, another project manager explains metaphorically: "They [the craftsmen] have to play together on the same pitch instead of playing separately on each half of the pitch".

Project managers who are to put category content on productivity into practice must thus facilitate coordination among the different construction crews and their activities in pursuit of the overall project objectives. This is perceived to be a responsibility of the project managers themselves, which means that the craftsmen are rarely involved, or given voice, in the overall coordination and planning of construction site activities. In addition to the craftsmen who are merely pursuing own craft-specific goals, all the project managers highlight poor design as another main reason why productivity improvements are difficult to materialise. Examples of this, which are emphasised by the project managers, are missing or wrong information from consultants, continuous changes in drawings and discrepancies between project descriptions and the actual progress and conditions of the project. Poor design is considered a source to several extra tasks that overload the project managers and consequently decrease the focus on delivering results in accordance with the iron triangle.

The project managers have a need to feel in control when it comes to the overall planning of the project and decisions made in relation to ensuring the progress of the project. The craftsmen's efforts to realise their own craft-specific goals and poor project design, however, complicates decision-making, thus reducing the project managers' autonomy. Hence, the project managers experience a need to demonstrate professional creativity, i.e., devise novel ideas that are appropriate for solving the experienced problems (cf. Amabile, 1997), thus mitigating high project complexity and poor design.

Craftsmen

The craftsmen frame productivity as being synonymous with effective execution of their own craft-specific activities carried out by the construction crew. A productivity improvement according to this perception is thus associated with highly efficient performance of specific work activities, often measured in time spent per activity. This perception can be grounded in the fact that most of the craftsmen (the informants who completed the questionnaire) work on medium-sized or large construction sites where piecework is common, i.e., the craftsmen are paid according to each activity performed. The questionnaire responses reveal that two thirds of the craftsmen always or often do piecework, while the last third never do piecework. In addition, the responses also show a high monetary focus with 44% of craftsmen highlighting bonuses as the most common way of rewarding and 40% emphasising wage as the most important thing about their job.

Craftsmen who are to put category content on productivity into practice must thus demonstrate that their own craft-specific activities are efficient compared to an industry baseline while demonstrating fine craftsmanship. A common way to demonstrate this is by achieving a higher wage compared to a regular hourly wage. An obvious downside to this, however, is that an increase in productivity within the individual construction crew does not necessarily lead to an increase in productivity in the project at large. Instead, it requires an ongoing adjustment between the progress of the craftsmen's activities and the overall planning of the project. However, only 20% of the craftsmen respond that they regularly contribute to solutions that go beyond their own crafts-specific activities and benefit the project at large. When the craftsmen are asked (open-ended question) which conditions that counterpoint productivity improvements, the following three conditions are mentioned most frequently: (1) unrealistic planning by the construction management, (2) lack of updated drawings and (3) poor communication among construction crews as well as between craftsmen and project managers.

The craftsmen have a need to feel in control in relation to the craft-specific activities in the project and affect the overall coordination and planning that interfere their own activities. However, the craftsmen explain that they experience being shielded from the overall project planning and only are given voice when the project managers need craft-specific knowledge to ensure project progress. The craftsmen have a strong relatedness to the construction crew and secondarily to the project. In addition, 80% the craftsmen emphasise that most of their activities are 'simple' routinised work and therefore do not require their full competences.

DISCUSSION

This section begins with an overview of the main findings extracted from the empirical insights (see table 1). Next, it discusses construction site productivity as a contested category and the motivational consequences that different perceptions give rise to. Finally, it reflects upon the relevance of the new understandings on construction site productivity in relation to future construction management inquiries.

Table 1: Overview of main findings

	Project managers	Craftsmen
Scope of attention	Overall objectives of the project	Crafts-specific goals (self-interest)
Rationale for decision making	Ensure project interest	Ensure crew interest
Perception of productivity category	Deliver according to the iron triangle by coordinating activities between different construction crews	Deliver according to own crew-specific goals, mainly determined by the piecework system
Motivational orientation	Intrinsic	Extrinsic and intrinsic
Autonomy	Have a sense of control over the project at large and feel that decisions are made on an informed basis that reflect own interests and values	Have a sense of control over own craft-specific activities and having a voice in relation to the overall coordination and planning of construction site activities
Competence	Competences are being activated due to an experienced complexity in the project, which requires a high degree of professional creativity	Competences are not being activated as most craft-specific activities prescribe 'simple' routinised work. The craftsmen's competences are only activated when there are deficiencies between project design and actual progress of the project (i.e., misalignment between drawings and practice)
Relatedness	Part of the construction management	Part of the construction crew before being part of the project
Extrinsic focus	-	Performing activities with the highest possible efficiency in order to maximise wage during piecework despite detriment to the overall planning and progress of the project
Intrinsic focus	Performing activities in relation to coordination and planning of construction site activities because of a genuine interest in making the project succeed	Performing activities based on the desire to demonstrate fine craftsmanship

Construction Site Productivity as a Contested Category

The empirical findings reveal varying interpretations of productivity and its practical application. These differences encompass productivity scopes (project versus crew), perceptions of productivity (performance according to iron triangle versus piecework system), and motivational orientations (intrinsic versus extrinsic). For example, project managers and craftsmen hold divergent views on productivity improvements. While project managers emphasise monetary rewards as the primary motivational factor, craftsmen place importance on increased involvement in project coordination and planning, and improved project design. A project manager's account illustrates how attempts to boost craftsmen's motivation and productivity by raising wages did not yield the intended effects.

Contesting Future Inquiries on Productivity in Construction Management Research

Considering productivity as a contested category in construction management research is essential to advance and challenge prevailing understandings of productivity. By recognising that productivity is not a static, 'ready-made' category (Heigermoser *et al.,* 2019; Neve *et al.,* 2020), but a situationally contested, negotiated, and defined category, construction management researchers can delve deeper into the multifaceted nature of productivity. For example, construction management researchers can explore how different groups of actors define and assign content (i.e., beliefs, expectations, and behavioural patterns) to the category of productivity (Kennedy and Fiss, 2013). Situational factors that increase complexity (Frederiksen, 2021) at the project level and thus affect construction site conditions as well as organisational cultures can also be examined to obtain a deeper understand of how project complexity affects productivity perceptions on the construction site. Construction management researchers can also develop alternative measures based on qualitative indicators that capture the multidimensional aspects of productivity, thereby going beyond the traditional metrics such as hours required to perform certain activities (Hasan *et al.,* 2018). Finally, embracing productivity as a contested category emphasises the need for strong collaboration between researchers, professionals and policymakers in co-developing policies, strategies and practices that can purposefully and effectively improve productivity.

CONCLUSIONS

The aim of the study was to explore how productivity, as a distinct category, permeates and affects groups of actors associated with the project level. The starting point of the study was to consider productivity as an established yet contested category in the construction industry. Drawing on literature on category research and self-determination theory, the study concludes that productivity is perceived differently by project managers and craftsmen.

Most notably, project managers' scope of attention is at the project at large while the craftsmen's scope of attention is bounded by their own craft-specific activities. Accordingly, productivity improvements among the project managers are directed towards the vertices of the iron triangle whereas productivity improvements among the craftsmen are directed towards crew interests. A consequence of this is that efforts to improve productivity by one group of actors opposes the opportunities to improve productivity by the other group of actors. The different perceptions of productivity set up different needs in relation to autonomy, competence, and relatedness. As shown in the study, these different needs collide when they meet in practice which complicates the effort to motivate the individual. For example, the project managers' need to feel in control over the project reduces the craftsmen's opportunities to be involved in the overall coordination and planning. Moreover, the project managers consider themselves part of the project at large while the craftsmen consider themselves as a part of a crew before being part of the project.

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EXPLORING ON-SITE INSTITUTIONAL LOGICS AND CONTRADICTIONS: HOW INSTITUTIONS ARE REPRODUCED ON THE CONSTRUCTION SITE

Jan Bronke[1]

Department of Building Construction, UCL, Seebladsgade 1, 5000 Odense C, Denmark

Construction projects are often depicted as temporary project-based organisations with a high level of conflicts. These organisations are compositions of several firms and professions who mobilise different institutional logics in their everyday work. However, it is not clear whether these conflicts stem from competing and potentially contradictory institutional logics. To better understand whether conflicts on the construction site result from incompatibilities between logics, this paper investigates the presence of logics on construction sites in Denmark. The study uses a sample of 10 semi-structured interviews conducted with site managers and craftsmen. The findings suggest that conflict arises due to competing institutional logics. For example, at the level of the craftsmen, the focus is on self-interest, while at the level of the managers, the focus is on the general project. This demonstrates that multiple competing institutional logics exist on the construction site and trigger conflicts during the everyday work. The study contributes to the construction management literature with insights on how contradictory logics affect construction site activities.

Keywords: conflicts; site; institutional contradictions; logics; relationships

INTRODUCTION

The construction industry is a micro-cosmos with various professions and interests colliding. The industry has been viewed as a stage of conflict where the combatants are the project management and the craftsmen. Conflicts seem to be a natural part of the construction site (hereafter 'the site') and have negative influence on the productivity and work environment (Gorse, 2003).

To remedy these issues, a series of development programmes have been launched in the Danish construction industry since the early 1990s. An early example of this is the introduction of Lean Construction (Wandahl, 2014), which amongst other things introduces the craftsmen as a part of the project planning team by involving them in site board meetings. This have become an integral part of managing the site today, but also has the potential for conflict due to different views on planning. A more contemporary example is the introduction of strategic partnering, where large clients, consultants and contractor organisations enter long-term collaborations based on a series of interrelated projects (Frederiksen, 2021).

[1] bron@ucl.dk

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Common among these is their focus on improving productivity by changing the traditional way in which the industry works in terms of planning, management, and cooperation, e.g., by focussing on the early and proactive involvement of contractors, sub-contractors, and the craftsmen. Moreover, the programmes have been predicated on the willingness and ability of the individual craftsmen and site managers to cooperate to drive changes by altering their behaviour and work practices.

The question is, however, whether these efforts to involve the craftsmen in the overall planning on the site introduce new clashes between the different actors on the site and lead to conflicts, especially if contradictory interests are involved (Gadolin, 2018). Scholars typically research topics such as conflict and productivity on the site drawing on motivational and behavioural theory and practices (Gorse, 2003). In contrast, the interest of this paper is to understand whether our pursuit to be more productive and effective leads to conflicts due to embedded contradictory or competing institutional logics (hereafter 'IL'). In doing so, the paper adopts an institutional theoretical approach to gain insights into whether conflicts arise in the interaction between different IL and the more resilient aspects of these fundamental structures in the industry. The institutions examined are the labour market, regulatory systems and trade unions and organisations. As they each play a significant role in defining and organising the construction industry and defining how the actors interact with each other. These institutions set the rules and provide contractual tools for the industry and can be defined as institutions (Kadefors, 1995), each with their own institutional logic. This paper draws upon seminal research on institutions (Friedland and Alford, 1991; Thornton *et al.,* 2012; Kadefors, 1995) and IL (Gadolin, 2018; Glaser *et al.,* 2016; Thornton, 2002), to identify prevailing IL on the construction site.

This study examines a sample of the predominant institutions in the construction industry, all with a high focus on maintaining traditional work structures, and then empirically researches how those institutions interact on the site. This is interesting because these institutions are exposed to conflicting requirements from different institutional environments (Pache and Santos, 2013), all colliding on the site. The institutions are relevant and chosen as they represent governance mechanisms that are implemented to manage activities and practices in an institutional field and are guided by different IL (Frederiksen *et al.,* 2021) that affect all levels (i.e., client, consultants, and contractors). This paper has a specific focus on the site and therefore primarily considers the interactions between contractors and sub-contractors.

Theory

Institutions

It is difficult to find a prevailing definition of institutions in the literature. Scott (2003, 779) defines institutions as "…systems composed of regulative, normative and cultural-cognitive elements that act to produce meaning, stability and order". Friedland and Alford (1991, 232) describe institutions as shaping the organisation and the individual's behaviour, stating that Western societies have five central institutions: (1) the capitalist market, (2) the bureaucratic state, (3) the nuclear family, (4) democracy and (5) Christianity. Furthermore, they describe how individuals and organisations conform to several of these institutions at the same time, which can potentially lead to contradictions if they are not compatible. Later Thornton *et al.,* (2005, 2012) added corporations, professions, and communities to this list of formal institutions. Furthermore, the nature of institutions is conflicting as they prescribe different accounts of actions in practice (Seo and Creed, 2002). For example, they may differ in terms of control mechanisms and principles for organising, which can potentially be contradictory.

The concept of contradiction is significant for understanding institutional theory because it is through conflicting institutions/logics that organisations change and develop in new directions (Scott, 2003). When multiple IL are mobilised in practice, i.e., structures, norms and routines are adopted on the site, there is a risk that institutional contradictions appear. This is what Seo and Creed (2002) describe as institutional contradictions and human practices within multiple levels of incompatible institutional arrangements. Furthermore, Kadefors (1995) states that institutions represent the power relations and the control systems within the relevant environment, thus defining the predominant institutional logic or interest of the organisation.

Looking at the theoretical understanding of institutions, it can be stated that the construction industry has multiple institutions present, such as the labour market, regulatory systems, and trade organisations/unions. Furthermore, these multiple institutions constitute the backbone of the traditional industry and have the potential for conflict, when mobilised in practice.

Institutional logics

The reason why an organisation conforms to an IL is because it is a source of legitimacy. IL can be defined as the practices, assumptions, values, beliefs, and rules that shape and frame a particular social world or context (Glaser *et al.,* 2016, 36) or as providing a link between individual agency/structures and cognition and socially constructed institutional practices and rules (Thornton *et al.,* 2012). Most neo-institutional scholars focus on the macro level and the relation between society and individuals (Glaser *et al.,* 2016). Research has shown that "… institutional logics provide socially shared frameworks that shape and direct individual actions" (Glaser *et al.,* 2016, 38).

Therefore, it is relevant for this paper to research ILs on the micro level to understand how the IL formed by the structures of society are reproduced on the site. The conflict of ILs is always present, as explained by Gadolin (2018, p 128), "…the professional logic represents occupational control of work whereas the managerial logic represents managers' bureaucratic control of work". Thornton *et al.,* (2005) provide an example of this, describing the tensions that arise when two coexisting and competing ILs exist within architecture. Specifically, they describe how an aesthetic IL contradicts with an efficiency IL, leaving the architect to choose between reputation or economic interest and control. The most predominant and often temporal rationality for the architect prevails: if the firm needs income, the latter usually wins. A similar conflict can also be observed between the institutions of the profession and the capitalist market (Thornton *et al.,* 2012) on the site, where craftsmen face conflicts of ILs in choosing between the logic of professionalism and quality or the capitalistic IL of the market and self-interest/maximising income. The latter choice of the craftsmen can conflict with the site manager's project IL (Gottlieb *et al.,* 2020) or as referred to in this paper, the managerial IL (Gadolin, 2018) consisting of rules and norms e.g., time plans and budgets.

Actors belonging to highly professionalised employment, such as the craftsmen, accept the managerial IL to a lesser extent, as it would require acknowledging the managerial IL as a legitimate source of controlling work. In so doing, the professional employees would minimise their control over their own work (Gadolin, 2018), which can lead to conflict with the site or contract management.

METHOD

The research design is based on qualitative interviews that focus on the perceived significance for the respondents (Kvale and Brinkmann, 2015). Consequently, "… Knowledge arises in an individual based on experience and reason" (Salmons, 2016, 34), making this method relevant for understanding how the participating craftsmen and site managers perceive and interpret the institutions on the site and within the company.

The respondents (site managers) were selected from two large companies that fit the study's profile. The site managers from the first company were chosen by the company to represent them, while the second company was contacted via email, and three site managers agreed to do the interview. In total, ten interviews were conducted and used as empirical data in this paper. All interviews were recorded. In general, the distribution of experience ranged from 2.5 years to 15 years for craftsmen and from 1.5 years to 45 years for site managers. All respondents are referred to by code: the craftsmen as C1, C2, C3, C4 and C5, and the site managers as M1, M2, M3, M4 and M5.

The interview conversations were conducted as semi-structured interviews (Kvale and Brinkmann, 2015) to explore the opinions and experiences of the interviewees. To understand how multiple ILs are mobilised on the site, it is necessary to comprehend the on-site interactions and the presence of how regulatory, normative, or cultural-cognitive conceptions of institutions, which define the embedded rules or routines for different actors. Therefore, the interview guide focused on gaining insights into the pressures, that might be caused by the institutions. Asking open-ended questions, aiming to minimise any influence on the respondents. The questions were divided into two categories: (1) internal pressures, often related to normative or cultural rules that are created and replicated on the site, and (2) external pressures, often seen as regulation that impose rules or structures onto the site and over which the craftsmen or managers have little control.

The analysis is a comparative analysis where the responses collected from craftsmen and managers were coded, compared, and then analysed to identify comparable responses. Through these responses, the institutions and ILs mobilised on the site were identified. The method used for processing the interviews was to summarise them, extracting and coding only the essence of the respondents' statements, and then comparing the statements from the interviewees. For example, different ways of describing quality or describing how piecework agreements are viewed by the individuals. These statements were then sorted into themes, which were compared to the theory. A simplified data structure inspired by Gioia *et al.,* (2013) was used to analyse the statements from the site. The purpose of comparing the statements is to identify alignment or misalignment between managers and craftsmen in their understanding of their work life, thereby creating the possibility of conflicts. The ex-post analysis of the data involved three steps: (1) going through all the empirical data and placing the statements into categories, (2) condensing the categorised statements into themes and (3) the final step is what Gioia *et al.,* (2012) refer to as the aggregate dimension, where the themes are analysed using theory. As an example, (1) all statements regarding piecework are coded and (2) condensed into a self-interest and an economic theme (3) hereafter, using theory to extract which institution (market) are behind the theme. This procedure was replicated for all the significant statements gathered in the empirical dataset.

ANALYSIS

In the following analysis, the significant findings from the interviews will be presented and analysed. Using the analysed theme (3) in the data structure, the following institutions (e.g., Market as in the example) are analysed to find in which way they are reproduced on the site.

The labour market

A simple definition of the labour market, according to the Employment Relations Research Centre (2019), is "the total trade in labour in a society where the price of labour is determined by supply and demand". However, according to the Danish Ministry of Children and Education, the labour market currently faces significant challenges, partly due to the declining influx of newly graduated professionals. This is particularly concerning for professional trades such as carpenters, bricklayers, engineers and constructing architects (National Economic Council of the Labour, 2021). This issue is also reflected in a survey done by Autodesk Construction Cloud in 2023, where 84% of the responding construction companies claimed to have difficulties recruiting skilled workers. The shortage of workers can lead to conflicts, as the low capacity may result in fewer or less qualified individuals available to handle the projects. The market logic represented by the labour market reflects market institutions and significantly influences economic dynamics, material security and work (Friedland and Alford, 1991).

Conflicts arise on the site due to the representation of the labour market. The site managers have observed instances where trade managers struggle to exert control over the craftsmen. According to (M4), if a problem occurs and the site management rejects work based on quality criteria, the craftsmen may refuse to redo the work, and the trade manager (the manager of the sub-contractor) lacks the authority to compel them. The situation is compounded by a scarcity of skilled workers, which undermines the control system. Certain groups of craftsmen are in short supply, making it difficult for the trade manager to impose sanctions as they are unable to find replacements. As a result, this misalignment creates conflicts with the trade manager's managerial IL.

Regulatory systems

The Danish building code, building standards (e.g., description of services), standard descriptions (e.g., AB18 and ABR18) and project contracts are formal institutions (Kadefors, 1995) and the regulatory system represents the institution of the state, which is based on a logic were the aim is "rationalisation and the regulation of human activity" (Friedland and Alford, 1991, 248). These institutions standardise quality and output, such as the project documents/materials and role expectations (descriptions/ drawings/bid lists). One such standardising regulatory mechanism is the tendering system, which also has an agenda of creating competition. Therefore, clear work and role definitions within the project contracts are required to minimise conflicts (Thompson *et al.,* 2000) but the embedded tensions that the tender system creates amongst the project actors present a significant issue, because these often-contradictory institutional logics behind can create e.g., miscalculations, due to different commercial goals (Jefferies and Schweber, 2022) and transfer them onto the site. Regulatory systems are represented on the site in three ways.

First, in terms of time and economy, the craftsmen have highlighted that inadequate planning and communication from the site management are among the primary causes of conflicts on the site. This observation is supported by most managers. M1 emphasized that "time is a killing factor, which leads to errors," while M2 and M3 stated that "everything needs to be built in half the time and at half the price." This implies that there is persistent external pressure from clients to reduce costs and accelerate construction timelines. According to M2 and M3, this pressure stems from the tendering process, which prioritises the lowest price. These pressures have direct internal consequences on the site. Site managers describe a distinct managerial IL where economics, time plans, and the final product take precedence over everything else. However, to achieve success, managers believe that fostering a good relationship with the craftsmen is essential.

Second, in relation to communicating the often-complex project material, because of the negotiated tender contract, all managers emphasized the importance of prioritising communication with the craftsmen and maintaining an open-door policy. They actively engage in assisting the craftsmen with tasks such as interpreting drawings and coordinating time plans even though it is not a part of the site manager's responsibilities.

Third and finally, when it comes to productivity the craftsmen state that they see morning meetings such as Kanban board, from the LEAN concepts, as effective for enhancing site communication and fostering professional discussions. The managers (M1 and M2) used the concept themselves. On the site this creates a shared sense of direction: "We must solve it together…" (M5) and most managers have some experience of working with involving the craftsmen in problem solving, as we saw introduced in the development programmes (LEAN), and there is an expectation that both craftsmen and managers participate in the detailed planning stages: "… we must reach a common goal" (M5 and C1). When it comes to the tender form there was large variation in the respondents' answers. The craftsmen did not see it as a source of conflict but answered that it was their trade managers' responsibility; this shows that the craftsmen have a focus on their role (profession/capital logic) not on the overall project. However, managers with greater responsibility and experience, such as M2 and M3, considered the tender process a major source of conflict, particularly due to economic pressures and strict time plans. It appears that the level of involvement in and proximity to the tendering process or the project contract correlates with the level of conflict experienced. Here an internal conflict in the companies shows, where the bid departments have a market IL focusing on profit and short-term winnings for the company, while the site managers have a managerial IL focusing on the execution and cohesion on the site. This seems to be the case on the site the interviewees worked on: "…it [the bid] can destroy an entire project and here the bid department plays a significant role - as they often take a short-term view of the economy" (M3). Each IL represents a distinct type of structure or mechanism of control and governance (Thornton *et al.,* 2005) and the conflict seems to arise from the clash between a market logic and a managerial logic in relation to clients tender, is evident within the management group but not perceived by the craftsmen. Discussions about economics, quality, and time primarily occur between site managers and trade managers, aiming to minimise conflict between site managers and craftsmen.

Trade unions and organisations

Trade unions and organisations represent the interests of the workers and companies and negotiate on behalf of the entire construction industry. Trade unions and organisations negotiate collective agreements for all craftsmen in the industry, after which the individual companies negotiate local agreements with the craftsmen (and the local trade unions). Piecework agreements for projects (negotiated between the craftsmen and the company) are signed for parts of or for the whole project, forming an additional agreement to the contract between client and company and therefor has the potential for conflict. Trade unions and trade organisations represent the institution of the corporations and professions (Thornton *et al.,* 2005, 2012), thus mobilising a market IL "…the accumulation and the commodification of human activity" (Friedland and Alford, 1991, 248). Building on Kadefors' (1995) understanding of institutions as power relations and control systems, trade unions and organisations are represented on the site in two ways:

First, piecework is highlighted as one of the main sources of conflict. According to (C4), there is always conflict associated with piecework agreements. He personally views this agreement form positively due to the monetary incentive and does not consider the conflict as negative, but rather as a natural part of the work. However, none of the other interviewees supported this perspective, despite some of them also working on piecework agreements. (C1) stated that piecework has a negative impact on cooperation and coordination. He believes that the focus on financial gain hampers mutual respect and fosters indifference towards other groups of contractors, leading to conflicts between the market IL (self-interest) and a professional logic (quality/reputation). Most managers agreed with (C1) and expressed a generally negative view of piecework, noting that it creates conflicts between different trades and undermines their willingness to collaborate on-site. (M2) states that not all tasks are suitable for this agreement format except straightforward jobs, such as plastering walls.

Second, looking at quality, the craftsmen demonstrated high levels of professionalism. However, some expressed frustration that time and economic pressures compromise quality. This sentiment was conveyed by (C4), who mentioned that work is only redone if it fails to meet project criteria, indicating a prioritisation of the market IL over the professional IL. Statements such as "Quality comes before everything else" (C2), "The most important quality you have as a bricklayer, is your professionalism and that you can be proud of your work" (C4) highlights the importance placed on quality by the craftsmen. Although quality is significant to (C4), he describes an economic culture within his firm where trade management focuses on time plans and monetary considerations, indicating a conflict between professional and managerial IL (Thornton *et al.,* 2012). This internal conflict forces craftsmen to choose between prioritising higher earnings or delivering high-quality work. The managerial IL and market IL creating conflict between management and trade organisations (piecework) is recognised by both groups.

DISCUSSION

If we consider that "institutions act as patterns for actions" and "homogenise human behavior" (Kadefors, 1995, 399), it becomes interesting to examine the prevailing institutions on the site and their potential for driving change. Therefore, investigating the relationship between ILs and goals and seeing if management establish goals that emerge from the ILs that are prominent in their given settings.

Drawing from Kadefors' (1995) concept of power relations and control systems as institutions, it appears that challenges in recruiting and hiring craftsmen have resulted in an unequal power balance between craftsmen and their management. This imbalance, as described by several site managers (M3, M5, and M4), enables trade managers to exert some control over the quality of craftsmen's work, leading to conflicts between site managers and trade managers.

The construction industry's difficulty in attracting the new generation poses a significant problem, especially considering the increasing complexity (M2), rapid changes in technology, commercial practices such as sustainability. These factors further complicate dynamics on the site and necessitate greater cooperation among involved actors in areas such as planning and detailing. It is crucial for the parent company to acknowledge the need for change and recognise that the current focus in tender forms (lowest prices and piecework agreements) generates conflicts. Craftsmen (C1, C4, and C3) and site managers (M3 and M2) support this perspective, emphasising the importance of prioritising project relations and considering options like reusing subcontractors to ensure quality and trustworthy collaboration. Such strategies align with development programs like TRUST, which advocate for strategic partnerships with the same actors over a period of four years.

Many of the institutions observed on the site stem from a pursuit of productivity through control and standardisation, as evident in regulatory systems and piecework agreements. These institutional arrangements often give rise to conflicts between different ILs as illustrated in table 1.

Table 1: Institutional logics on the construction site

	Site Manager	Bid Department	Craftsman	Trade Manager
Guiding institution	The regulatory systems	The regulatory systems	The trade unions and organisations	The labour market
Institution (representing)	Bureaucratic state	Bureaucratic state	Capitalist market	Capitalist market
Institutional logics	Managerial Logic	Market Logic	Market Logic	Market Logic
Source of authority	Top management	Top management	Trade union	Top management
Basis of strategy	The overall project	Short-term profit	Self-interest	Maximise profit
Source of legitimacy	Purpose and responsibility	Ensure profit to the company	Personal expertise	Ensure profit to the company
Economic system	Managerial	Managerial	Professional	Managerial
Basis of attention	Tender specifications	Profit	Quality and profit	Profit

CONCLUSIONS

The empirical data implies that multiple societal institutions are present on the site and create conflicts on the site. This is also documented by and presented in the literature used in this paper. This study shows that each institution has a predominant logic amongst the respondents and sets the rules either regulatory, normative, or cultural-cognitive for the actors on the site. This paper concludes that there are conflicts on the site stemming from contradicting ILs and that the craftsmen and managers prioritise IL differently. The level of conflict depends on the level of engagement with the institution e.g., managers are more involved in the tender system and therefore, more prone to conflict within that institution, whereas the craftsmen have minor involvement with the tender systems and therefore, perceives little or no conflict, within that institution. Based on the institutions and their embedded logics presented on the site, it can be concluded that conflict is created on all levels and within and between the companies.

Looking at the empirical data collected in this paper there is an indication that the construction industry has created structures that lead to conflicts in the pursuit to be more productive and effective.

This study contributes to the calls for knowledge on the projects level (Gadolin, 2018; Jewer *et al.,* 2023) as the individual project is weakly described by institutional theoretical scholars (Glaser *et al.,* 2016) and by using an institutional lens it has shown which dynamics or logics are mobilised on the site.

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STRATEGIC PLANNING PRACTICES IN CONSTRUCTION FIRMS: A SYSTEMATIC REVIEW

Noel P Clarke[1], John P Spillane, James G Bradley and Shane Carmody

School of Science and Engineering, University of Limerick, Limerick, V94 T9PX, Ireland

Strategic planning aids enterprises to formulate a strategy, providing direction for future firm performance. However, strategic planning research has developed encompassing diverse subject matters. This has allowed scholars to thrive without being constrained, allowing multiple research perspectives. Numerous theories have been developed as the field has matured over the last fifty years in the business environment. This proposition holds true for the construction industry where these theories have been borrowed and adopted, resulting in an unclear landscape of how strategic planning practices occur in such firms. To answer this question a systematic literature review was conducted. Using the keywords "strategic planning" and "construction industry" between the years 2000-2022, a total of 511 papers were identified. After screening fifty papers were deemed appropriate for the study. Themes identified are strategic planning practices, human resource management, sustainability/environmental, strategic tools, alliances, performance, innovation, and theories. Strategic planning research is in decline, yet research of this subject has the potential to aid in a defined future for those who operate in the construction industry.

Keywords: performance; strategic management; systematic literature review

INTRODUCTION

Strategic management consists of planning, implementation, and evaluation. Integral to strategic management is strategic planning (Lu, 2010). Strategic planning establishes where a firm is currently positioned, determines a desired future, and sets objectives of how to get there (Murphy, 2013). The process of strategic planning in the construction industry has tended to focus on operational planning and elemental forecasting, centring on the resources needed for specific projects, suggesting a need for companies to redirect their thoughts from tactical to strategic thinking (Danosh, 2005). The business environment in which construction firms operate adds to the complexity of the strategy process (Adesi *et al.,* 2019). Additionally, in the construction industry, uncertainty demands the need for strategic planning but also negates its effectiveness (Danosh, 2005), resulting in a complex multifaceted process with characteristics differing between firms (Murphy, 2013). The value of strategy for Greene *et al. (*2008) lies in its ability to enhance organisational performance, however it is constantly evolving, and firms need to be able to reconfigure their operating routines to cope with changes in their environments. Price (2003) suggests conceptually there is no one right way for a firm to develop a strategy; the key is

[1] dromclar@gmail.com

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selecting the tools and techniques best suited to a firm's individual needs, raising the question of how firms enact strategy planning in the first instance. Although a relatively young subject, strategy research has enjoyed success. However, a paradox exists as the field is fragmented and lacks coherence (Nag *et al.,* 2007). Such an example is presented by Chinowsky (2000), who views strategy as not containing universal truths or theorems like mathematics, resulting in areas such as operations, logistics, finance, psychology, sociology, and human resource management being formalised as domains within the field. However, within the construction industry, Green *et al. (*2008) makes the argument that generic strategy literature comprises of competing theories and perspectives with little agreement on how strategy occurs at firm level.

The value of strategic planning implies an association with positive company performance. The resultant literature has brought to light strategic planning adoption is a complex process in construction firms, with two key issues arising: (1) a wide-ranging overview of how strategic planning occurs in firms is lacking and (2) establishing the theoretical typologies used by those responsible for strategic planning in their organisations. To answer these issues this paper adopts a systematic literature review (SLR) synthesising strategic planning practices and the theories used, where comprehensive literature of this nature is scant to realise the full benefits of strategic planning in the construction industry.

METHOD

This study aims to provide a comprehensive investigation and review of strategic planning practices and the theories employed by organisations in previous research papers, compile the results and discuss the findings in one paper for the benefit of academics and industry professionals. Existing literature has focused on specific aspects of strategy planning. The research method adopted for this is a systematic literature review, where the adoption of a systematic literature review (SLR) can provide knowledge advancement on a wider scale than empirical studies, by employing a thorough, transparent and replicable process, and identifying future research possibilities (Folstad and Kvale, 2015; Tranfield *et al.,* 2003; Xia *et al.,* 2018; Xiao and Watson, 2019); to provide summary evidence of existing works. Furthermore, utilising a narrative review adopts a narrative synthesis approach (Denyer and Tranfield 2006), to identify and synthesise construction industry strategic planning practices and the theories at an organisational level which can contribute to the success of construction firms.

The review is implemented in three stages as consistent with recommendations of (Mostafa *et al.,* 2016; Tranfield *et al. (*2003), (1) planning the review and search (2) visual examination and (3) content analysis. The search for publications is carried out using Scopus and Web of Science databases. Scopus is selected based on it containing a larger number of articles than its counterparts (cf. Chadegani *et al.,* 2013; Guz and Rushchitsky, 2009) and has been a reliable database for past review studies (Hosseini *et al.,* 2018; Yin *et al.,* 2019). A second database, namely Web of Science, is selected to adequately identify all the information needed for the review (Bramer *et al.,* 2017). The authors cover the literature published between 2000-2022, a period where strategic planning research has developed and matured, having received much attention from researchers and industry participants. The search is conducted to find Boolean keywords "strategic planning" and "construction industry" anywhere in the papers. The downloaded articles were managed and processed using

Zotero software. Books, editorials, and conference papers are omitted at this stage to ensure only peer reviewed journal articles are included, returning 463 articles in Scopus and 48 articles in Web of Science, resulting in a total of 511 papers. At this stage all articles are screened for duplication. This returned a total of 499 papers. The next step is to remove irrelevant papers. This includes papers that are outside the remit of construction management, national level strategy papers and the language restricted to English. This involved (1) reviewing all the article titles to identify if they fitted the research scope, (2) the abstracts were read and any papers deemed unsuitable were removed (Asadi *et al.,* 2021).

This yielded a total of 50 papers for inclusion, 47 from Scopus and 3 from Web of Science. The final stage of analysing the selected articles is content analysis. Content analysis allows researchers to examine large volumes of data, examine trends and emerging patterns using coding units (Stemler, 2001). During the descriptive phase, a matrix is developed containing author name, title, journal, year of publication, research methods employed, and notes on content. The second phase of content analysis occurs inductively, prior to the literature review, to classify themes, like that of Xia *et al. (*2018). The selected publications establish seven themes under which strategic planning studies are conducted, as shown in (Table 1), where SP, denotes strategic planning and HRM, human resource management. If a paper reveals details incorporating more than one theme, then the dominant theme is grouped accordingly. These themes indicate the different categories under which strategic planning research have been conducted over the period 2000-2022. The literature is further synthesised deductively to identify strategic theories that have been used in construction management research. On this basis an appropriate classification system, is proposed in (Table 2).

RESULTS

The yearly distribution of published journal articles (Fig. 1) indicates strategic planning research held significance from the years 2003-2009 contributing to the existing body of research. From the year 2009 until present, research is in decline which publications limited to 1-2 per year.

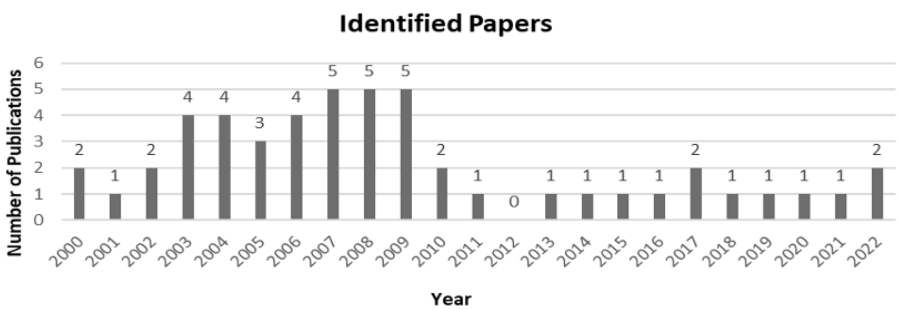

Figure 1: Number of identified papers published yearly from 2000-2022

Distribution of Articles by Research Category

In terms of the categories strategic planning, practice research dominates with over sixty percent of the literature which shows the significance of this concept. Performance measurement is the second most researched area with ten percent of the literature. Innovation and the use of strategic tools in construction organisations were discussed and sustainability in construction organisations is now being planned for, although this is a recent development as research on this topic began in 2016. Human resource management is the least researched category with only four percent of the literature, with no research being conducted since 2009. Strategic alliances also receive only four percent of the existing literature, like human resource management where no research has been conducted since 2009.

Table 1: Number of identified papers published yearly from 2000-2022

Area of study	’00-’01	’02-’03	’04-’05	’06-’07	’08-’09	’10-’11	’12-’13	’14-’15	’16-’17	’18-’19	’20-’21	‘22	Total
S P Practices	3	4	2	5	5	2	1	2	2	1	2	1	30
HRM				1	1								2
Sustainability/Environmental				1					1	1			3
Strategy Tools			2	1		1							4
Alliances			1		1								2
Performance		1	2		2								5
Innovation		1		1	1							1	4
Total	3	6	7	9	10	3	1	2	3	2	2	2	50

Distribution of Articles by Theory Use

Five strategic theories have been used in strategic planning research (Table 2). Porter's generic strategies are the most popularly used to understand how construction organisations develop a market strategy. Miles and Snow typologies also used to understand market positioning, were the second most used. Looking inside the firm to understand strategic planning dynamic capabilities and the resource-based view receive significant attention, with Porter's five forces model receiving the least discussion.

Table 2: Strategic Planning Theories

Theory	Description	Reference
Miles and Snow Typologies	Firms are defenders, reactors, or prospectors.	Murphy (2013); Phua (2007); De Hann *et al.* (2002)
Porter's Generic Strategies	Cost leadership, differentiation, market/product diversification	Claver *et al.* (2003); Cheah *et al.* (2007); Ho (2015); De Hann *et al.* (2015)
Porter's Five Forces	Threat of new entrants, threat of substitutes, bargaining power of suppliers, bargaining power of buyers.	Ho (2015)
Dynamic Capabilities	Firms continually adopt to changing environments by reconfiguring their operating routines.	Green *et al.* (2008); Aghimien *et al.* (2021)
Resource-based strategy	Firm-specific capabilities are developed for competitive advantage.	Ngowi *et al.* (2002); De Hann *et al.* (2015)

DISCUSSION

Strategic Planning Practices

Strategically, the first step for firms is to determine currently where their strengths lie, where gaps exist and what their priorities will be in answering these questions (Chinowsky, 2001). Price (2003) describes strategic management practices as developing but provides a recommendation for improvement with the development of frameworks bespoke to individual companies and an increased use of strategy tools for measuring performance beyond financial analysis is needed. Similarly, Ngowi

(2002) suggests firms should create firm-specific capabilities. Paradoxes exist in strategy development such as rational versus generative strategies; deliberate versus emergent; revolutionary versus transformational; strategic fit versus strategic stretch; and strategy versus organisational effectiveness, where the optimal balance varies in different organisations (Price and Newson, 2003). Ozorhon *et al.* (2005) suggest organisational memory plays a role in strategy formulation where strategies that are formulated come from organisational learning in previous projects. Similarly, Greene *et al.* (2008) see path dependency as important in shaping strategic choice whereby strategy develops over time through actions rather than a formalised approach.

Human Resources Management (HRM)
A company's productivity is closely related to its people and strategies; human resource management is therefore of importance to construction enterprises (Tabassi and Abu Bakar, 2008). Construction is a multi-project environment which can lead to inappropriate resourcing decisions failing the needs of construction organisations and their employees; thus, decision making can be improved by using human resource planning, performance/career management, team deployment, employee involvement, training, and development (Raiden *et al.,* 2008). Human resource management is typically emergent rather than deliberate or strategic (Brandenburg *et al.,* 2006); with little opportunity to contribute towards strategic planning (Raiden *et al.,* 2008).

Sustainability/Environmental
Environmental and sustainability issues are becoming recognised as strategic issues for construction firms. Managing environmental issues at a strategic level may contribute to competitive advantage by maximising tendering opportunities as they play an increasing role in the values of clients, the public and employees (Fergusson and Langford, 2006). Market demands drive sustainability practices for firms implying a short-term approach to sustainability in the industry; however, for firms who do not proceed opportunely and plan strategically, a disadvantage may occur where competitors have already transformed their practices accordingly (Giannoni, 2017).

Strategy Tools
The role of the mission statement; why the organisation exists, vision statement; the organisation's ideal future and strategy which defines how to get to the stated future are important management tools (Naaranoja *et al.,* 2007). Construction is a sector that is dominated by project-based organisations (Simu and Lidelow, 2018). In this vein, Dikmen *et al.* (2005) reason quality function deployment (QFD) as a strategic tool to increase quality in projects would ultimately aid construction firms in their strategic objectives by minimising quality-related costs. Knowledge management as a tool can enhance strategic decision-making capabilities; examples being lessons learnt about market selection, bidding, and so on, so that even if failure occurs, it can be used as a tool for future decision making (Ozorhon *et al.,* 2005). Lu (2010) suggests strategic planning presents as both an art and a science. Moreover, the use of strategic management tools appears to be limited with SWOT analysis being dominant, leaving scenario planning and risk planning tools being used sporadically at project level (Murphy, 2013).

Alliances
A strategic alliance is a long-term relationship formed between two parties (or more) within a supply chain to develop mutually agreed strategies in terms of goals and objectives for the involved parties to pursue jointly (Cheng *et al.,* 2004: 460). The

formation of alliances is based on interdependencies and strategic needs (exogenous approach) and the social relations network which the firm is embedded (endogenous approach) (Castro *et al.,* 2009).

Performance
Strategy requires performance measurement. Financial based performance measures are no longer adequate to measure strategy (Bassioni, *et al.,* 2004). Luu *et al. (*2008) identifies four categories (1) innovating organisational structure (2) effectively managing processes at construction sites (3) setting up cost control and (4) improving equipment management. Whilst adept at performance measurement, these solutions also help firms to identify strategies. Anikeeff and Sriram (2008) suggest entrepreneurial orientation and a lean organisational structure benefit performance and a strategy to contract out construction activities allow firms to stay nimble, manage costs and structurally readjust to market fluctuations. Claver *et al. (*2003) whilst investigating performance in strategic groups 'the set of firms that follow similar strategy across strategic variables', find variance in performance can be linked to internal resources (human resources, technology, reputation, management, innovation, culture).

Innovation
Innovation is the implementation of new processes, products, or management approaches to increase efficiency, whereby companies are now looking to tools such as re-engineering, lean production, information technology, TQM and so on to remain competitive (Seaden *et al.,* 2002). Lim and Ofori (2007) describe three classes of innovations that are specific to business strategies in the construction sector; (1) innovations that customers are willing to pay for, (2) innovations that reduce contractors' costs, (3) and innovations that develop intangible benefits such as improved reputation and credibility. For Manley *et al. (*2009) high innovators develop strategies around (1) investment in R&D (2) participating in partnering and alliances, (3) ensuring project learnings are incorporated into business processes (4) monitoring international best practice and (5) recruiting new graduates.

Theory Research
Academic have developed theories to explain strategy in the business environment, such theories have been offered to explain strategy in the construction industry. Strategy development requires market analysis, theories such as Porter's (1980; 1985) typologies classify generic strategies that firms can adopt as low-cost leadership, differentiation and focus. De Hann *et al. (*2002) recognises the framework as a good starting point for market positioning but does not address internal capabilities. The Miles and Snow typologies explain organisational types classifying them as either defenders, reactors, or prospectors (Murphy, 2013). Porter's (1980) five forces framework explores the relationships that exist in market environments (Ho, 2015). Internal to the firm, resources are needed to exploit market positioning. The resource-based view Barney (1986), allow firms to exploit competitive advantage by developing firm-specific capabilities which are unique (Ngowi, 2002). Dynamic capabilities emphasises that firms reconfigure their operating routines to changing environments Teece (1997) and provides valuable insights into how strategy is enacted in contracting firms (Green *et al.,* 2008).

The importance of strategic management has been well documented (Cheah *et al.,* 2007) yet strategic planning research is in decline which is a concern as there is little agreement on how firms enact strategy (Green *et al.,* 2008). At present evidence is lacking for this proposition, resulting in a missed opportunity for academics to aid firms in the construction industry improve their performance. Theory adoption in research can aid in understanding and explaining elements of strategic planning such as market positioning, developing internal capabilities, sensing opportunities and organisational learning. However, as note of caution (Cheah *et al.,* 2004) contests a one size fits all formula for successful strategy is elusive. Factors such as operations, financial, technological, and human-related are all critical to success; thus, common dichotomies fall short in this regard. Strategic planning research has developed into different areas in the construction management sphere. Identifying and filling these areas for construction firms and formulating a strategy is the difference between firms that succeed and those that are at the peril of the marketplace (Chinowsky, 2000).

CONCLUSION

This paper had the objective of finding the developments and the theories used in strategic planning in the construction industry from 2000-2022. To achieve this aim, strategic planning literature was systematically reviewed and synthesised. This resulted in strategic planning research being categorised under seven themes: practices, human resource management, sustainability/environmental, strategy tools, alliances, performance, and innovation.

Strategic planning research was in a period of growth from 2000 to 2009. However, since 2009, research output has dropped significantly, especially in relation to performance, innovation, human resource management and strategic alliances, resulting in a missed opportunity for academics to aid those in industry by providing a deeper understanding of strategic planning needs in their organisations.

Strategic planning is a concept that captures elements relating to operations, financial, technological, and human resources which are all critical to developing a successful organisation. Strategic planning offers companies the opportunity to define their desired future state, however, this depends on the type of strategy implemented by the company. In this vein those responsible for strategic planning must understand market analysis and how to develop their internal capabilities to adopt to their environment. The previous may not guarantee success, nonetheless this paper advances strategic planning knowledge for those in industry and academics by considering the concepts and theories that are relevant to strategic planning in the last two decades.

This paper is not without limitations. The main theme of the study is on matters relating to strategic planning in construction firms. Addressing further keyword combinations and additional databases may bring a more complete paper to fruition, but due to template stipulations was beyond the scope of this study.

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THE 'US AND THEM' DIVIDE ON CONSTRUCTION SITES: AN UNDOCUMENTED PHENOMENON

Eamonn Colbert[1]

Department of Construction Management, Nottingham Trent University, 50 Shakespeare Street, Nottingham, NG1 4FQ, UK

Much of the construction industry experiences an underlying sense of ‘us and them’ between various parties. This undertone spans across relationships between the site and office teams or even client and contractor. Literature on theory, education, industrial relations, and management show that the phenomenon exists, yet relatively little remains published and documented for the wider construction sector. Using an inductive approach, this research addresses this knowledge gap by showcasing that the culture exists and is prominent among those working in the sector. The findings indicate that although it is an underlying industry trend, real solutions are difficult to pinpoint due to differences in project goals, individuals’ perceptions, hierarchies and even personality types. Discussion is generated by to the lack of published literature on this phenomenon along with cultural issues affecting its spread among different personality types of construction projects, and the emergence of sets from interviews. This research discusses the complexities which contribute to the invisible divide within the construction workforce, consequently both practitioners and academics could possess greater ability to stimulate true collaboration.

Keywords: behaviour; culture; phenomenon; undocumented

INTRODUCTION

On a large majority of construction sites around the UK there is an undercurrent of 'us and them'. Varying project targets, priorities and conditions can influence the behaviours of individuals which can cause a rift between the parties involved in any project. Payment terms, completion dates and resources can drive a friction wedge between the principal contractor and their supply chain, while different nationalities, unequal pay and working goals can affect the split within and between the workforce and construction teams. While understood and acknowledged by many, this split is one that remains to be thoroughly documented within the sector. The divide and differences in culture and personalities of those involved in the management of the project (predominantly office-based staff) and those executing the delivery of the construction (site-based workers) needs addressing, with a view to aid the flow of communication and bridge the cultural divide between the two, enabling a brighter future for the industry. Construction sites have been described by Tennant, *et al. (*2011) as being ‘deeply tribal’, and the perceived performance of a project is representative of the success of the communication within it (Olanrewaju, *et al.,*

[1] eamonn.colbert@ntu.ac.uk

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2017). The nature of the industry is dependent on teamwork and group collaboration for which social interaction is key in building and developing relationships (Emmitt and Gorse, 2007). Described by the CEO of the CIOB as being a 'team sport' (Gumble, 2023), the sector should be leading the trend in teamwork, collaboration, and group dynamics. Yet the fragmented nature of the industry, internally and externally (Riazi, *et al.,* 2022), prevents this whole team approach and leads to the underlying and relatively undocumented phenomenon of 'Us' and 'Them', created through unconscious bias, stress and lacking a sense of belonging.

The main objective of this paper is to test if this phenomenon exists within the sector and generate discussion around emerging types and sets. This research is innovative in the relation to the selection of candidates for interrogation as it proposes to understand the mentality of authority divisions within the industry. Some studies (Loosemore and Lee, 2002; Hoezen, *et al.,* 2006; Tipili and Ojeba, 2014; Ogunnusi, *et al.,* 2020) focus on a management and professional-level-only selection for data collection or a specific cohort within a demographic range, yet the candidate selection for this research is from all levels and disciplines of the industry. This is to ensure that the 'us and them' phenomenon is thoroughly investigated from all perspectives to ensure an equality of data gathered.

The paper forms part of a larger research project, from which this data forms the pilot study. Its purpose was to test the initial existence of the phenomenon before the study continued. There is an abundance of published literature on the justification and adoption of pilot studies from social science research, with a large majority of it is specific to medical research or clinical trials including Morin, (2013) Thabane, *et al.* (2010) van Teijlingen and Hundley, (2002) Hassan, *et al.* (2006) and In, (2017). Construction Management researchers like Cherns and Bryant, (2006) Yang, *et al.* (2009) and Li, *et al.* (2015) among others, also favour the adoption of a pilot study to test theory and trends.

Within the construction sector and from primary research for this paper, specific sets of 'us and them' have emerged and are listed later in table 1. With Egan (1998) considering the workforce to be the most valuable commodity, more needs to be understood about why the split is so apparent among those in the industry yet remains largely undocumented. Understanding and exploring this split may aid in reducing miscommunication for the future of the construction sector.

LITERATURE REVIEW

Karl Marx's theory of "them and us" shows a disconnect between teams of social classes and within hierarchies, and this can be evidenced and reflected in the construction sector, with communication breakdowns a common occurrence between upper management and the workforce (Chartered Institute of Personnel and Development, 2020). The fracture of a sense of belonging may stem from the differences between those managing and those being managed. This is an issue beyond the realm of engineering and construction and can be seen and evidenced in wider industrial relations literature (Kelly and Kelly 1991; Coupland, *et al.,* 2005; Hyman, 1975) and social studies such as the 'Hawthorne Studies' (Mayo, 1933) and 'The Robbers Cave Study' (Sherif, *et al.,* 1961). The latter hypothesized that "when two groups have conflicting aims, their members will become hostile to each other even though the groups are composed of normal, well-adjusted individuals" (Hopper, 2019).

The ‘us and them’ phenomenon relates to differences between social groups (Cambridge Dictionary, 2023). Variances in personal construct, culture, ethnicity and even job type or position can lead to an underlying current of there being a disparity between groups in an organisation, company or even between organisations, especially when there is a perceived difference in power levels. These cultural identities extend to factors including race, gender, and class (Clarke, 2008). Group membership allows people to have a sense of belonging and fits in with Maslow’s hierarchy of needs. Once alliances are made within a group, along with the benefits, comes the likelihood of prejudice, bias, and corruption towards others outside of that group’s identity. Tajfel and Turner (1979) coined this term Social Identity Theory (SIT) and outline how individuals develop their sense of self not only from their personal identity but also from ‘association and identification’ (Lipkin, 2019) with one or more social groups. Simple instances of established ‘us and them’ sets include ‘haves and the have nots’, nation and nation, taxpayers and those on benefits, religious groups, management and workforce, sales and operations, sports teams, and many more global examples within and throughout society and industry. It could be safe to assume that most construction workers have experienced some level of this split at some stage in their career. The phenomenon in the sector can refer to a perceived division between different groups of workers in the industry, including different ethnicities, nationalities, and skill levels. This ‘notion of difference’ (Clarke, 2008) and division can lead to tension and conflict, resulting in a lack of collaboration among workers and could ultimately impact productivity.

Research such as Clarke, (2008) Fanon, (1986) and Zisek, (1993) have outlined that the phenomenon in the construction sector is a result of various factors, including unequal benefits and treatment, varying working conditions for different groups, and boils down to the fragmented nature of the industry (Proverbs, *et al.,* 2000). For example, a study by Vershinina, *et al. (*2018) found that migrant workers in the UK construction sector were often paid less than their British counterparts and were subjected to lower working conditions, which obviously led to feelings of resentment and division.

Another factor contributing to this divide could be the use of agency and casual workers in the construction sector which leads to a fragmented and divided workforce, with different groups of workers having different levels of employment security, pay, and benefits. Concern about these divisions and under-representation is highlighted by Ahmed, *et al. (*2008) and was also outlined in the Latham report (1994) about equal opportunities.

A fragmented sector, agency workers and the inclusion of a migrant workforce can all impact the flow of communication. The few studies which hint at the ‘us and them’ undercurrent all deal with migrant workforce (Krings , *et al.,* 2011), women and men in the industry (Lingard and Francis, 2004) or immigration (Ahmed, *et al.,* 2008) as being the main divide. While all these are indeed examples, these cultural separations are not the only splits which exist. Managing to bridge these divides is one of the most important aspects of site and project communication. With multiple cultures and personalities on a development, how we interact and acknowledge these differences can be crucial to communication success.

In aiding communication between ‘tribes’ or cultures, it would be useful for managers to have an awareness of the ‘chameleon effect’ (Chartrand and Bargh, 1999). This term refers to the bidirectional relationship between nonconscious mimicry speakers and understanding (Sharafaddin-zadeh and Nicoladis, 2021), and takes many forms including verbal and nonverbal, conscious, and nonconscious. Interestingly, nonconscious mimicry of accents (Giles and Powesland, 1975), rates of speech (Webb, 1972), and speech rhythms (Capella and Panalp, 1981) between partner interactions have also occurred in an effort to make the speaker 'fit in' to another group or to blend with the culture of the 'others'. This suggests that imitation of behaviours may have served socially adaptive functions, leading those who mimicked the greatest to contribute the most to the gene pool (Sharafaddin-zadeh and Nicoladis, 2021) and can serve a "social glue" function, binding people together and creating harmonious relationships (Lakin, *et al.,* 2003)

METHOD

Research in construction and construction management can be categorised as being at an intersection of social and natural science (Love, *et al.,* 2002) and as such does not have single suitable or prescribed methodological approach. Addressing research into complex phenomena and behaviours lends itself to a qualitative approach as it is exploratory and inductive. Multiple authors (Denzin and Lincoln, 2000; Flick, 2018; Silverman, 2016) promote this method as the most appropriate for investigating trends and underlying social issues research and is particularly useful when exploring complex phenomena or when little is known about a particular topic. Yet in the field of construction management, there has been lots of debate among academics as to which (generic) research methodology is most appropriate (Love, *et al.,* 2002).

Qualitative research studies are also referred to as small-N projects (Panke, 2018) as the number of observations (the 'N') is limited to a few cases. As this investigation is focusing on issues incorporating and surrounding the overall themes of communication, construction management and the split on site, an inductive approach is appropriate. Qualitative methods are usually the most appropriate in regards finding out social facts of the causes of phenomenon such as personality type, personal construct, and prosody. Investigating how these phenomena arise in the interactions of their participants suits a qualitative approach (Silverman, 2016). Previous studies around this topic have allowed for a Mixed Methods Research approach (MMR) such as the work of Olanrewaju, *et al. (*2017) and Wu, *et al. (*2017) where some elements of their studies have been based on a cross-sectional survey questionnaire. Qualitative research crosscuts disciplines, fields, and subject matters (Denzin and Lincoln, 2000) and is a situated activity that locates the researcher in the 'world' of their research topic. Immersing oneself into the field allows the research to undertake an inductive approach, using only the information directly at hand to form opinions. One of the main advantages of using qualitative methods for this research is reflexivity, the recognition and analysis of different perspectives (Flick, 2018), which can also provide detailed insights into individuals' experiences and subjective perspectives (Gibson and Brown, 2009). Qualitative semi-structured interviews (n=7) were carried out to get the opinions of those in the industry in relation to communication practices, and to investigate the existence of the phenomenon on various site types, as responses to similar situations would allow focus on the differences of views.

Data collection

Candidates from industry contractors, consultants and sites have been sourced for interviews. These candidates vary in discipline (management, engineering, civil, trades) and responsibility levels (junior, management, CEO, subcontractor, supply chain etc.) in order to get a full range of experience, opinions, and views from all perspectives. Doing this has tested the verbal communication levels experienced by each level of the construction sector and scrutinise whether 'us and them' is felt by everyone, or just one 'side' of the site or sector. Interviewees were also selected to investigate any difference in personnel on site between the large scale and infrastructure projects and those on smaller and domestic developments. The data was collected through open-ended semi-structured interviews and coded through NVivo. Open questions were chosen as they were answered based on the knowledge that the interviewee has immediately at hand (Flick, 2018).

Table 1: Candidate details for qualitative interviews

Participant Job role	Experience	Project/Site type	Company type
Site Manager	38 years	Domestic	Major UK national housebuilder
Skilled Trade	22 Years	Infrastructure	Tier 1 Contractor
Managing Director	17 years	Domestic and commercial	Housing and commercial retrofit
Assoc. Director	13 years	Project Management (client)	Tier 1 Contractor
Site Manager	8 years	Commercial	Tier 1 Contractor
Project Engineer	3 years	Commercial	Tier 2 Contractor
Eng. Surveyor	3 years	Residential Commercial	Tier 1 Contractor

In the researcher's opinion, candidates were very honest in their responses and in their expression and acknowledgement of the existence of the 'us and them' trend. The findings and data are discussed below.

DISCUSSION

The Existence of 'Us and Them'

There are multiple examples of construction sites' setup adopting a method of having stacked welfare cabins for offices, welfare areas and storage. A practical approach to sometimes small sites but also to maintain a close quarters of communication for the contractor and construction teams and compliance with CDM regulations. While this tactic is easily understood, it begins to build this split between the workers and the managers. This Marxist ideal of those 'ruling' and those 'being ruled' is emphasized by individuals having to climb the steps to the manager's or principal contractor's cabin. While one of the reasons for this setup is to be able to physically see the worksite as it develops, another is to segregate teams so that 'you're not getting drawn away into matters that might not necessarily concern you'. Other reasons would include commercially sensitive information so 'keeping that separation can have its benefits'. From this we can interpret that the phenomenon is hard to avoid in lieu of preferred and functional site setup and layout warranted by many contractors. Hierarchies, therefore, can act as significant barriers to communication (Martin, *et al.,* 2014) and many argue that it is an issue of trust between these parties which leads to any miscommunication (Polychroniou, *et al.,* 2016). However, from the interviews, candidates involved in the management side have expressed their desire for the 'management need to be separated from the workforce to set the hierarchy on the site.' The questions then arise about layout and segregation; could a separation of teams on site still be applied, but reverse the implicit hierarchy? Allowing for the management cabins to be lower in the tier, or even on the ground floor, may open the ease of communication and reduce the implied hierarchy, while maintaining the segregation desired by site managers.

Some various groups of 'us and them' also emerged during the conversations. Colloquialisms, slang, and popular expressions have been outlined in table 2 for how individuals on site refer to the ‘others’ within the project. These terms are repetitive and commonplace in other settings, and the findings of Thiel (2013) also align with the terms that emerge during the interviews. Yet as one candidate outlines, they ‘think sometimes they (workforce) can see it as a sort of them and us situation, probably because their goals are different.’ With another adding that ‘there seems to be more of a divide between the office worker and those lads on site, rather than the qualified tradesmen.’

Table 2: Terminology for the ’others’ on construction sites, from qualitative interviews

The lads in the office	The gaffer
Neanderthals on site	The office w#*?kers
‘on the tools’	Cowboys
Unskilled v skilled workers	‘hoods’

The candidates were questioned on their time spent on site and their time in the office. Unsurprisingly the managers and consultants were almost full-time office based (either on the project or in a head office) and the operatives were on site (‘boots on the ground’) for most of the time. Both sets answered the question of ‘us and them’ instantly and were able to comment on who was ‘us’ and ‘them’ with ease. Interestingly the engineers and surveyors who split their time equally between the office and the site took longer to come to a clear decision of ‘us and them’. This is more than likely because they see themselves as neither one or the other and can easily identify with both parties. The chameleon effect was understood and known about by these candidates more so than the others. In line with the findings of Chartrand and Bargh, (1999) they discussed how imitation of posture and behaviours led to an increased liking as well as a smoother interaction when dealing and conversing with those on site and the office. As White (2021) outlines, it is important to know what type of personality one has and how that personality type is impacted by this effect.

‘Us and Them’ Types

With the clear emergence of the ‘us and them’ phenomenon during the interviews, various types became evident. Depending on the job role, the location of the project and its nature, and depending on the amount of time spent on site or in the office, these themes developed. The research began by trying to highlight the existence of a split on site, predominantly between the site team and those in the office. However more types and variations surfaced during the discussions, which are highlighted in table 3.

While the initial objective of the pilot study was to investigate the presence of the phenomenon, from a site versus office viewpoint, and many more types emerged. While all candidates agreed with its presence, they also provided multiple examples beyond the site and office split. There was a clear subjective response and candidates spoke of personal experiences. This is clear in the CM v QS split which was provided by the project manager. While it can be expected to see more ‘office v site’ splits, there is also a clear split between each level of hierarchy. Client and contractor at the managerial level, and the wet and dry trades at the operational side.

Management and Operations	Working and Professional (social) classes
Site and Office	Head (project) office and site (satellite) offices
Contractor and Client	Wet and Dry trades
Construction team and contract team (CM v QS)	Women and Men
Principle contractor and supply chain	Trades v labour force

Table 3: 'Us and Them' emerging sets - from qualitative interviews

A common theme that arose from the analysis was the fact that individuals changed their ways of verbal communication. From the discussions with participants, it was queried whether they changed their strategy when speaking to people who worked at a different level from themselves. 86% agreed that they do change the way they interact with those either above and below their 'rank' or profile. While only 29% were familiar with the term dubbed 'the chameleon effect', where one party attempts to replicate or mimic the others manner of speech to communicate on their level and avoid the wrong prosodic cues in their discourse. It is the occurrence of conversational partners becoming more like each other in what they say, how they say it and other behavioural phenomena (Levitan, *et al.,* 2012). While it may not even be a conscious decision, one site manager declared that 'I actually think I do that subconsciously' to 'fit in' to the 'lads on site so that they would actually listen to you'.

One candidate spoke of the workers' sense of needing a more 'familiar ear' (accent or delivery). Another mentions how they would alter their accent, and how 'there's a few things I'd say on site that I wouldn't mention in the office'. Other phrases that emerged included 'lowering the tone' on site as opposed to the more 'professional manner' adopted in the site office. Acknowledging that everyone's personalities are different too, one candidate replied that; 'You have to pick and choose who and how you speak to people.' Another candidate speaks of their issue of dealing with the transition from site to office and vice versa as; 'I get more polite and more well-spoken when I spend time in the office'.

There exists a link here to the personality types outlined in the Myers-Briggs studies (MBTI), where it has been discovered that more empathetic individuals exhibited a greater degree of mimicry than others. One of the most predominant personality traits of those working in construction is Judging and Technical (Colbert and Aboagye-Nimo, 2021). Naturally it can be argued here that if those in the industry feel the need to change their natural approach, either in speech or body language, to talk to those in a different position, it is illustrative of an invisible split on site.

CONCLUSION

While understood, appreciated, and acknowledged by most people in the construction sector, the phenomenon of 'us and them' remains largely unpublished and documented, especially between the site and the office. This research aimed to showcase that it does exist, and not only on the construction sites themselves but in the wider industry as per table 3. It has also highlighted the evidence of individuals within the industry adapting their communication approach to sound or appear more familiar to 'others', in order to ease communication and in an effort to fit in and not be considered one of 'them'. This paper forms part of a larger research project, which is currently undertaking a quantitative study to gather larger amounts of data in which to further scrutinise this phenomenon.

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THROWN INTO A CONSTRUCTION DISPUTE: THE PERSONAL TOLL OF AGGRESSIVE CLAIMS MANAGEMENT

Henning Grosse[1]

Gloucestershire Business School, University of Gloucestershire, Oxstalls Lane, Longlevens, Gloucester, GL2 9HW, UK

This practitioner research investigates the impact of aggressive claims management on project team members. I autoethnographically explore experiences on a construction project. While I maintained a cooperative relationship with the client and design team, another contractor employed aggressive claims management. The unfolding conflict provides the material - observations and experiences for this autoethnography. In addition, I use Heidegger's thrownness as a theoretical lens to understand the unfolding processes. The investigation shows that aggressive claims management raises stress levels in the team members resulting from the need to justify and defend oneself. Tactfulness mitigates the effects but is often insufficient due to robust economic necessities and raised emotional involvement. The stress and pressure almost inevitably lead to counter-aggression and the erosion of moral standards and values for economic survival, resulting in a vicious circle of even more severe conflict. I provide no answer to how to deal with the conflict, but I show its effects by using Heidegger's thrownness to explore where it originates.

Keywords: Autoethnography; Heidegger; claims management; emotions; stress

INTRODUCTION

The economic impact of aggressive claims management has received much academic attention, however the emotional consequences on the professionals involved has gained only very limited interest in scholarship. Therefore, I explore my experiences of exceptionally aggressive claims management on one of my projects autoethnographically. I emphasise the personal and emotional effects of such activity - what it does to construction professionals. First, I give some background to autoethnography - the approach used here. Then I provide vignettes of my experiences during the ensuing conflict about filed claims. Concurrently, I connect them to the literature. To understand the events and the (re-)actions of the participants (me included) I use Heidegger's thrownness. Finally, I argue what aspects of claims management have been neglected so far.

AUTOETHNOGRAPHY

Primarily, I am writing my own story; I share my experiences to inform others. Rooted in ethnography, the approach relies on the researcher to write about their

[1] hgrosse@glos.ac.uk

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experiences and observations in the field they study (Emerson, Fretz and Shaw 2011, Hammersley and Atkinson 2007). The researcher usually takes brief notes and later develops these into longer fieldnotes. Exploring this material builds the basis for the findings and interpretations. Whereas 'conventional' ethnographers may explore any accessible setting, autoethnographers study their environment, experiences, and personal issues. Autoethnography is especially useful for explorations like mine since I can use an insider's perspective to explore a phenomenon that is otherwise difficult to access (Grosse 2019). Subsequently, I only describe how I use autoethnography.

While the conflict unfolded, I took brief notes in meetings, after phone calls and about conversations on and off-site. Later, often in the evenings, I developed them into longer fieldnotes and reconstructed the vignettes offered here. As I wrote, I simultaneously read literature, thought, and further explored, as Richardson and St. Pierre (2005) outline. Like Ellis (2019), I reviewed emails, meeting minutes and other materials to recollect the experiences. However, I do not chronicle the events to create a boring list of who did what and when (Ellis 2019). I. Instead, I present single events that reflect the situation and give an impression of what was happening. I emphasise the emotional side of aggressive claims management. The reader should feel the event rather than be given a rational explanation of consecutive events. My contribution is, therefore, not a theoretical implication in rational terms but rather an impression of the events understood as alternative theorising (Cunliffe 2022). Hence, an engaging, lively description aims to reach beyond purely rational explanations.

Therefore, I cannot describe the events from a neutrally and detached stance. Although I am trying not to cast a judgement about claims management, I cannot avoid my personal judgements influencing what I write. I have firmly vested interests and values. Therefore, my writing does not offer "accurate reporting" (Rooke, Seymour and Fellows 2004: 660). Instead, it explicitly provides an engaged and involved picture and it remains partially judgemental. Otherwise, I would not offer the lived experience needed to convey the emotional aspect of claims management practices.

UNFOLDING CONFLICT

In late 2016, we signed a contract for an urban building comprising of flats, offices, and a restaurant. We had already worked with the employer, their architects, and engineers. I would call the way we worked together 'smooth sailing'. Sometimes we argued about minor issues. But, in general, we discussed emerging problems and solved them with mutual agreement. Once we started working on the new project, smooth sailing continued as usual. Here and there, there was a site visit and a discussion about details and technical solutions.

This cooperation was not just a short "'honeymoon' period" at the start (Whaley 2020: 209) but lasted throughout the project. It shows "[r]adical integrative attitudes" which "are found among engineers" and architects "who promote engineering values above the values of claims culture." (Rooke, Seymour and Fellows 2003: 174). We brought in a structural engineer with whom we knew we could deliver high-quality and cost-efficient solutions. We had already cooperated with him successfully and produced good results for the client.

This cooperation contributed to my thrownness which Heidegger (1927) understood as already being there. Understanding myself, I cannot start from scratch; I am already there with my personal history and background. I am not innocent but already shaped by the events I have lived through. In this way, I understand my Dasein - being-there. However, this understanding inevitably departs from the inside. I am thrown into a situation with the 'backpack' comprised of my conceptions and values. From this viewpoint, I can only lift one layer after another. Still, I know I can never raise all the layers. Thrownness is "my rootedness in a culture, my already established preferences, skills, habits, and so on" (Hoffman 1993: 208).

On this project we cooperated. Of course, we had some differences, yet we managed our conflicting views productively (Loosemore and Galea 2008, Whitfield 2012) and delivered good results. Hence, my thrownness comprised of this good cooperation and prior experiences and values. But then things began to change.

In 2018, after we finished pouring concrete, our work was in essence finished. We only had to remove castings, support props and beams and complete a few minor tasks. However, the scaffolding remained under our contract and supervision. At this point, Miller, a new contractor for the cladding, windows, and doors, was brought in.

We discussed site logistics in one of the first meetings with Miller and the architect. Miller boldly demanded we remove all material and equipment from the site almost immediately. We agreed to free up most of the space for him, but we still had minor work and transports to organise. Then he made a considerable noise that we should remove our crane within a fortnight because he needed the space for his crane. Somehow my site manager arranged for it to be done on time. But then, for five weeks, nothing happened: no new crane, new material, nothing. My staff started to use the freed space for temporarily depositing material and equipment to be carried away, mainly because we could hardly move it around without a crane.

Although causing no significant problem for Miller, he claimed we had breached the agreed procedures. 'Yes, sure,' I thought, 'but what's the problem? Has (or will) any of your work or deliveries be affected? No!' There were no practical implications of us using the space temporarily.

Miller relied strongly "on strict contractual rights" (Whaley 2020: 45), which indicates toward a rather distributive approach of negotiating and managing (Rooke, Seymour and Fellows 2003). This insistence on formal procedures reminded me of the mechanism observed by Rooke, Seymour and Fellows (2004). I knew these mechanisms very well, but I did not like them. They ran counter to my thrownness, "my already established preferences, skills, habits, and so on "(Hoffman 1993: 208). I would have preferred a discussion about underlying interests but had to deal with positional bargaining. 'Well, a slight change in the way of working is not that dramatic' I thought, 'and, I will leave the project soon anyway.' But it was more than a slight change.

Not long after we had a meeting to discuss changes to the scaffolding and some minor alterations to a concrete wall. This discussion became more aggressive since the scaffolding couldn't be changed as fast as Miller wanted. He then accused me of delivering the building late to the schedule. I told him that my contract would have allowed for another three months. Miller, half a head taller than me, stood less than 30cm in front of me, much closer than was comfortable, and began shouting in my direction that my delivery was late. I gently push his torso away from me. "Don't touch me!" he yelled.

After that incident, I talked to the architect. 'It's unbearable," the architect said, and I added that I'm not willing to continue such interactions. On our way home my site *manager said, "I thought he was going to punch you". In more than 25 years in the construction sector, this has never happened to me before.*

It is a departure from what Rooke, Seymour and Fellows (2003) and others (e.g., Whaley 2020) describe. In their studies on claims management, emotions play only a subordinate role. Reviewing the research on claims management and conflicts in construction one finds advice on how to reduce conflict (Whitfield 2012), to manage conflict (Loosemore, Nguyen, and Denis 2000) and benefit from the positive effect of conflict (Loosemore and Galea 2008). But there is little notice of the emotional side of conflicts in construction. Feelings and emotions resulting from conflict and/or claims enjoy little prominence. Only some mention them at all (Kadefors 2005, Lindebaum and Fielden 2011, Nilsson Vestola and Eriksson 2023). Often conflict is just seen as a hinderance to e.g., lean construction (Albalkhy and Sweis 2021) or cost efficiency (Haaskjold, Andersen and Langlo 2023).

Therefore, I seek to highlight how the emotions within a dispute over claims unfolded, how they contributed to the conflict and how they were used to run the project almost against the wall. On this project, emotions, aggression, and even violent communication (Rosenberg 2015) were involved. Apparently, this was to generate more profit rather than to deliver a successful project.

To this end, autoethnographically researching own experiences offers unique insights. I can recount how emotions unfolded, what they do to the persons involved, how I sought to manage them and how I sometimes failed. In research on claims and resulting conflicts, interest in the economic consequences is evident but the above-mentioned aspects are underrepresented. The conflict had even more to offer.

The employer asked me whether I'm free for an urgent meeting. "We have a serious issue" the architect told me on the phone later. In the meeting, Miller explained that the front face of the house diverted by 100 mm from the axis planned. I sat there with wide-open eyes and couldn't believe what I had just heard. 'Well,", I said, "let me check that because it is completely new information, and I have to consult my foreman." I struggled to keep calm. I knew 100 mm would be massive and would cost a huge sum. I couldn't believe my men would have made such a mistake.

I felt like my back was pushed against a wall. If true, how could I come out of that? It was an extreme pressure that hit me without much warning. I could not act reflectively. I merely cruised on autopilot. Maybe there was some tact involved. Van Manen (1995: 42) explains tact as "a kind of situated practical knowledge that inheres in the act of tact itself". I haven't made the alleged mistake myself, however, I was accountable for it. I agree with Loosemore and Waters (2004: 129) that one of the "greatest sources of stress […] were […] implications of mistakes".

We left the meeting room and visited the site. I walked a dusty patch with Miller and my site manager in hearing distance behind us. "I'm sorry that I had to break the bad news to you," Miller said to me, referring to his claim that the one wall was 100mm crooked. I firmly believe that he sought to make a lot of money from this alleged mistake: from our pockets. To say that we felt this 'apology' was inauthentic is an extreme understatement. I must admit I thought, "You bloody liar!"

The impression I had in the moment was not that Miller needed to file claims for economic survival as it is often argued (Coggins, Teng and Rameezdeen 2016, Love *et al.,* 2017, Rooke, Seymour and Fellows 2004). Instead, I thought he wanted to make a profit. I thought Miller was happy having found something to base claims on rather than feeling sorry for anybody. I suspected Miller of being very claims-conscious (Chan *et al.,* 2010). It is a different way of doing business that Miller employs. I am judgmental about it; one can easily read it from my thoughts.

After the meeting and the site visit, my site manager and I took some measurements. We found approximately 100 mm. Then we called the foreman, who is not too talkative, but he immediately mentioned the walls aren't rectangular to each other by roughly 100 mm. That was it. It was designed like that. When confronted that we built it according to plan and he must have missed it, Miller merely replied with an 'Okay'.

It is an emotional rollercoaster. First, one is stressed by the fear of making a mistake and equally relieved by finding out your team's work is satisfactory. Yet the period between is stressful and exhausting. The literature talks about stressful work on construction sites but fails to explore claims management's contribution to this stress. Furthermore, as Rooke, Seymour and Fellows (2004) show, disturbance in the project delivery are necessary to file claims. Contractors actively search for mistakes to exploit them. My impression is that conflicts are deliberately managed destructively to generate even more claims from the ensuing havoc. Strong emotions add fuel to the fire by leading to even more mistakes or bad decisions. In the case presented here, I got the impression it was a deliberate tactic.

In a letter addressed to the employer, Miller claimed the heights of the different floors were, on average, 20 mm too low. This was accompanied by a verbal claim for a couple of thousand Euros for refitting already fixed windows. After a brief discussion with my site manager and the foreman, the latter went to the building site and checked using a steel belt measure and a rotating laser level. We just found around a 5 mm difference to the planned heights—nothing to be concerned about.

When we presented our results in a relatively informal makeshift protocol - a printout with some numbers scribbled on it, Miller tried to discredit us; he talked about how unreliable and inaccurate our devices were. Instead, he bragged about the reliability of his surveyor's measurements, citing his most advanced laser scan technology. However, after an external surveyor confirmed our result - Miller's surveyor miraculously found similar results. In addition, in subsequent discussions with the on-site workers, we could only account for a fraction of the costs Miller claimed.

The client, architect and I all knew, contrary to Whaley's (2020) observations, that the claim was spurious and inflated and not just weakly substantiated: there was no reason for the claim, and the sum claimed was far from realistic. It was the second time Miller had argued on the wrong grounds. We wondered whether this was systemic.

My approach could have been different. Again, I judged him according to my thrownness (Heidegger 1927). It is not how I identify as an engineer and CEO. Maybe the following vignette depicts a way of dealing with that identity struggle (Sveningsson and Alvesson 2003).

During one of the next meetings, I had to let off some steam and said to him, look you have falsely claimed that the front face is 100 mm crooked, and your measured heights were wrong too, and you didn't even apologise for causing such upheaval. How dare you?

That could be seen as a sort of revenge or a demarcation of boundaries: "Don't do that again!" like Lindebaum and Fielden's (2011) description of expressing anger. It was unnecessary and probably of little help, but the emotional involvement led me to utter it anyway. I felt I had to fight back. But this emotionality was not particular to me. Miller accused one design team member of not checking the heights properly. By their respective reaction one could feel their stress and anger. Apart from Loosemore and Galea (2008) mentioning it as cause of stress, previous research has not explored what it means to the person being held accountable for a mistake. Exploring cause and accountabilities for mistakes from a detached perspective is one thing, what that implies emotionally for the persons involve is something completely different. It is this strong subjectivity that is comprised in Heidegger's thrownness which shows its full bearing on the persons. The following underlines the emotionality:

'Henning it's better if you talk, you're so much calmer,' one of my staff members said before the meeting. Later he said, "Oh, I felt your emotionality." I thought, you don't know how hard I tried to keep calm. Another person involved in the project told me on the phone: "My wife hasn't heard me shouting like this on the phone before."

The two former vignettes show how the persons involved are drawn into the situation and realize that they did not act out their potential. It is the 'falling' that Heidegger describes. We do not act according to our potential; we are 'inauthentic' (Heidegger 1927). Yet there are the possibilities our thrownness offers us to be authentic. However, we fail to enact them and hence fall into dysfunctional conflicts.

The proneness to conflict is widely documented (Latham 1994). It often results in aggressive behaviour, which is a cultural norm expected from industry actors. Encheva was asked to "show [her]self-more aggressively on the construction site [which felt for her like she] needed to adjust in a new way" (Encheva 2022: 44-5). She further observed that "[i]Instead of supporting the peaceful way of communication, I was given an example related to how the male-dominated [and conflict-prone] industry worked" (Encheva 2022: 45). As the vignette above shows, conflict has a self-fulfilling tendency, and I can only control my emotionality to a limited degree. Suggestions like the one Encheva heard reinforce the very problem.

Notwithstanding the merits of conflicting views (Loosemore and Galea 2008), the aggressiveness and the need to 'be right' lead to personal insults (Schopenhauer 2021). The economic circumstances - costly mistakes - are an almost insurmountable obstacle to accepting and admitting one's own mistakes. It is not about learning from mistakes but about covering up for them as much as possible because being proven wrong is exceptionally costly: even more so when it comes to overpriced and spurious claims. Hence, being right becomes a vital interest. We end up in terrible blame games, and learning is inhibited. This fact was brought home by the employer:

At a later meeting, the employer argued that he would not pay anything. Therefore, either the claims were justified, and I would be held to account, or the claims were not, in which case Miller would have to cover any additional costs.

I could get my liability insurance involved, but I didn't want that because they might charge me extra the next year or, at some point, terminate the contract altogether. Hence, I had to avoid being made accountable.

Self-interest dominates, cooperation is sidelined, and opportunistic behaviour becomes the rule. It is not about creating good collaboration (Nilsson Vestola and Eriksson 2023), strengthening personal ties (Liu, Huang, and Lu 2023) or adapting a lean construction path (Albalkhy and Sweis 2021). On the contrary, it is to create more and deeper conflict to opportunistically make more profit regardless of others and the project's success. This collides with the genuine values of engineers and architects.

Miller falsely claimed my workers built a faulty structure, he also undermined my efforts to resolve conflict to hold me accountable and indirectly claim money from my company. Now with some distance, I view it more calmly but thrown into the situation it was an effort to stay so calm and not to give in to my anger.

Although it looks as if I could have rationally chosen to align with this opportunistic behaviour it is not just a rational choice. My subjectivity, my thrownness played a major role in it. My values govern how I feel about being exploited and exploiting situations opportunistically too - whether I struggle with the choice and feel stressed or not. Yet the dispute about a faulty wall had ramification beyond the building site - into my company - which I must deal with. Such conflict has potential to spill over.

I had to admit that, as a company, we made our mistakes too. For example, two windows were 25 mm too wide and there were some other minor issues. I feel anger when I see work not appropriately done, but having worked myself for three years on-site, knowing first-hand that things go wrong even when taking great care, I mediate the anger. But knowing and feeling are two different things, especially when you may have to pay heavily for a minor mistake.

Here, my feelings and conception do not align with each other. I feel strongly about the mistake of the too wide windows. I know that it is, in principle, avoidable. But I also know that it happened to me too. So, who am I to judge? And then I see the massive claims made by Miller. These claims were far from reasonable. Just minor mistakes could cost huge sums. That shows how easily my anger and frustration can result in deteriorating relations with my staff - especially if the stakes are high. At that time, I talked to my partner.

One evening my partner told me she thought I had an easy job because I had flexible hours and was often quite relaxed. However, she was surprised about the intensity of the conflict and how stressed I was now that the conflict was boiling over.

She spotted the symptoms of the pressure. Perhaps, I could have written similar fieldnotes about other participants. As if this was not enough, Miller raised another alleged defect. One large wall was said to be winded. The how and what of the alleged defect were quite complex to explore:

I read industrial standards (DIN 18202, DIN 18710), publications of professional bodies and specialist literature for a couple of evenings. I even revised my knowledge about standard deviation, mean, average and 5%-quantile. My men took measurements of the complete wall, and I analysed their data, creating a couple of Excel sheets. Yet when presenting my findings, I lost almost everybody in the room after 2 or 3 sentences - numbers are boring. Only a specialist brought in by the employer could follow my arguments. I knew in some depth what I was talking about. I wanted to do it right. But since I had lost most people in the room, I wondered if it was worth the effort. After hearing my explanations and reading my handout, the expert noted, "I haven't checked it thoroughly, but as far as I can see, there is nothing I would complain about." Finally, someone argued on a substantial level.

Yet others thought he did not contribute much because he made no significant presence. I had the opposite impression since what he said was well-argued, although very brief. In a similar vein, the architect communicated. He appears to know even the tiniest detail yet often remains silent. However, when he has a point, he knows what he's talking about in minute detail.

The complexity involved in the project makes it very difficult to follow for a non-specialist: even more so if emotionality and raised voices are involved. Hence, being unable to communicate one's point leads to misunderstandings, more conflict, and, inevitably, even more stress. This does, however, lead to even more questionable practices.

During this investigation, I realised there was no way of proving that the alleged deficiency was my fault. Since we finished the construction work, we had already come to a reversal of the burden of proof. So, the employer had to prove me wrong, which was impossible since most of the evidence (surveyor's marks) had already been removed. I could claim that it was someone else's fault but that felt unethical, and I'm not the only ethical idiot here.

I adopted the same stance - I was only willing to act according to my contractual obligations and to use questionable loopholes to avoid liability. And I felt justified. Hence, there is no point in claiming the moral high ground. I can briefly summarise my experience with similar conflicts as, "in the end, everybody fights for themselves." I abandoned most of my values and moral/ethical standards for economic survival. Although these experiences and the "learned skills" were buried under the more recent cooperative history with the team on-site, they are inevitably part of my thrownness (Heidegger 1927). I found myself acting and thinking in ways I usually despise.

In turn, I have to say, I do not know (and probably will never know) what drove Miller's actions. He will have his justification. In principle, I am not so different. Then, by some chance, Miller left the project, and all started to resolve. The project continued more amicably, and we resumed working cooperatively. At that time, I met the architect. Maybe the architect's comments are what sum it up best.

We had a coffee in their kitchen, and he expressed his frustration about the last couple of weeks, saying, "I am sorry that you had to endure all that." I replied, "It isn't your fault and I assume you had to carry an even heavier burden." He paused for a moment and then calmly said, "You know, one bad apple can spoil the bunch."

SUMMARY

I have demonstrated how demanding and exhausting conflicts resulting from aggressive claims can be. Mistakes made while planning and building are often the grounds on which claims are based. Hence the persons accountable find themselves under great stress. It goes hand in hand with the need to justify oneself or prove oneself to be correct, which, as a side note, leads to missed learning opportunities.

The resulting stress for managers, design team members and tradespersons, to name a few, leads to further aggression and a vicious spiral of aggressively negotiated conflict and stress. I provided an example of the different aspects of a conflict. I have shown through my vignettes how unreflective - inauthentic (Heidegger 1927) - acting prevailed. Acting tactfully might mitigate the worst consequence. However, to understand what impact claims related conflicts have, Heidergger's thrownness helps to see there is much more then pure rational choices (Cunliffe 2022).

I think it is particularly exhausting for professionals brought up with a tendency towards efficient problem solving. They find themselves thrown into an environment where rules contradict their values and skills, causing immense stress and frustration. This leads to exhaustion, which many of my colleagues' report, and consequently results in an exodus of professionals from the industry. However, falling (Heidegger 1927) can lead to an ever-reinforcing spiral of aggression. Yet, mobilising moral values inherent in thrownness, like moral anger (Lindebaum and Geddes 2016) can help us to challenge such practices. I am arguing from my perspective - my thrownness - my subjective, impressionist tale (Van Maanen 2011). However, it demonstrates a need which is yet unmet to investigate the personal consequences and the emotional aspect of aggressive claims management.

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THE SUITABILITY OF SENSOR-BASED DEMAND CONTROLLED VENTILATION SYSTEMS IN RETROFIT DWELLINGS: A LONGITUDINAL STUDY

Seamus Harrington[1] and Mark Mulville

School of Surveying and Construction Innovation, TU Dublin, Bolton Street, Dublin, D01 K822, Ireland

A fabric-first approach to dwelling retrofit results in increased airtightness, therefore there is an obligation to ensure that the upgrades do not lead to poor indoor air quality (IAQ) resulting from inadequate ventilation. The sensor-based demand-controlled ventilation (SBDCV) under review seeks to provide fresh air for breathing and to dilute and exhaust pollutants and odours. This system modulates the ventilation rate over time based on relative humidity levels and/or presence detection and considers that the level of ventilation provided is sufficient to control the concentration of all other indoor air pollutants, including those that are not a result of human occupancy. This research takes the form of a longitudinal study that follows a structured approach to monitor the levels of relative humidity, radon, and volatile organic compounds within participating dwellings (n=7) so that the relationship between the variables can be explored. This paper demonstrates that SBDCV systems are insufficient to ensure the removal of non-occupancy related pollutants. This could have significant health and wellbeing impacts for occupants. The findings of the paper have implications for the policy framework.

Keywords: retrofit, ventilation, relative humidity, radon, volatile organic compounds

INTRODUCTION

Ireland's Climate Action Plan (CAP) 2021 (Department of Communications, Climate Action and Environment, 2021) details a roadmap of measures that align with the European Union's ambition to achieve a net-zero target carbon emissions by 2050 (European Union, 2019). It seeks to play a key role in delivering energy efficiency in Ireland and follows a Europe wide approach to reduce energy consumption in a building sector that represents 40% of total energy usage. Accordingly, most European countries have similar retrofit strategies that focus on the reduction of regulated energy. In this context, Ireland has introduced the National Retrofitting Scheme (NRS) (Sustainable Energy Authority of Ireland, 2022a) which has set an ambitious goal of retrofitting 500,000 existing homes to a Building Energy Rating (BER) of B2 by 2030. This equates to almost 30% of all residential buildings in Ireland (Sustainable Energy Authority of Ireland, 2022c). These dwellings require fabric interventions to reduce their space heating energy demand. Such intervention

[1] seamus.harrington@tudublin.ie

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refers to the performance of the dwelling envelope (floor, external walls, roof) and requires the prioritising of insulation and airtightness prior to the addition of technology improvements, as heating demand cannot be radically reduced without a suitable designed thermal envelope (Dequaire, 2012).

The precursor to the NRS was the Deep Retrofit Pilot Programme, which was introduced in 2017 and managed by the Sustainable Energy Authority of Ireland (SEAI). A fabric first approach to dwelling retrofit was promoted, with all participating dwellings achieving a Building Energy Rating (BER) of A1-A3 and an airtightness of ≤ 5 m3/hr/m2 (Sustainable Energy Authority of Ireland, 2022b). The programme investigated the challenges and opportunities presented by deep retrofit in Ireland with the outcomes used to inform the approach to large scale retrofit, culminating in the introduction of the NRS.

83% of the mechanical ventilation systems installed as part of the 2017 Deep Retrofit Pilot Programme were Mechanical Extract Ventilation (MEV) or Demand Controlled Ventilation (DCV) systems (Sustainable Energy Authority of Ireland, 2022b). The purpose of this research study is to assess the suitability of sensor-based demand-controlled ventilation (SBDCV) systems within the dwellings under review, as little consensus exists in respect to the most important indoor pollutants that should be considered when choosing a ventilation system (Poirier et al., 2021) due to the significant list of pollutants that have been identified to date (Abadie and Wargocki, 2017; Cony Renaud Salis et al., 2017). This research follows a structured approach to monitor the levels of relative humidity, radon, and volatile organic compounds within participating dwellings (n=7). The relationship between the variables is explored so that the relative effectiveness of the ventilation strategy can be ascertained.

LITERATURE REVIEW

Ventilation

Ventilation of homes is necessary to maintain healthy and safe indoor air quality for the occupants. Following significant fabric improvements, there is an obligation to ensure that the upgrades do not lead to poor indoor air quality (IAQ), therefore ensuring the avoidance of negative effects such as inadequate ventilation (Official Journal of the European Union, 2016). Ventilation refers to the process of introducing and distributing outdoor and/or properly treated recycled air into a building or a room (Etheridge and Sandberg, 1996) and is the process by which concentrations of potentially harmful pollutants are diluted and removed from a space (CIBSE, 2006). The ventilation rate is defined as the amount of outdoor air circulated per unit time. Current Irish building regulations require that adequate and effective means of ventilation shall be provided for people in buildings. This is to be achieved by (a) limiting the moisture content of the air within the building so that it does not contribute to condensation and mould growth, and (b) limiting the concentration of harmful pollutants in the air within the building (Department of Housing, Planning and Local Government, 2019) . The presumption within such standards is that the specified minimum rate of ventilation per occupant is adequate for the control of both occupant-generated pollutants and other indoor-generated pollutants (Fisk and De Almeida, 1998). This presumption can lead to IAQ problems as pollutant emission rates from sources other than occupants vary greatly among buildings. This causes potential for building retrofit projects to result in unexpected performance outcomes and/or unintended consequences (Shrubsole et al., 2014). Unfortunately, few large-scale studies that utilise data driven methodologies to consider the impact that energy conservation measures have on the internal environment have been carried out, due to the cost prohibitive nature of data collection techniques (Carratt et al., 2020). Those that have (Majcen et al., 2016; Liang et al., 2018) relied on easily accessible data, such as energy bills, which negates the possibility of reporting on anything other than the post works performance of energy-use reduction measures.

Indoor Air Quality
Multiple studies have shown that levels of indoor pollutants can increase post energy retrofit works. IAQ depends on several factors but is primarily affected by the quality of external air that is introduced through controlled or uncontrolled ventilation channels, bioeffluents that are produced by human occupants and off-gassing from building and construction materials, equipment, furniture, domestic cleaning products and occupant's self-care products (Marć et al., 2018). These factors lead to the existence of pollutants, which can be found at high concentrations in indoor air (Tran et al., 2020), therefore directly affecting IAQ within residential dwellings.

Relative Humidity
Relative humidity (RH) is the ratio of the amount of water vapor in the air to the amount of water vapor air can hold at a specific temperature. Raising the temperature without changing the amount of moisture in the air reduces the RH. The RH goes down because warmer air can hold more moisture than colder air, the opposite occurs when the temperature falls. Pre-retrofit, this posed a significant problem as internal face of uninsulated external walls were susceptible to cooler external temperatures, which subsequently decreased the cross-sectional temperature of the wall, creating a cooler internal surface. This resulted in localised cooling of internal air causing RH levels to rise, inevitably leading to a moisture dump, resulting in condensation and subsequent mould growth. The same cause/effect was true for walls/ceilings, uninsulated floor slabs and single-glazed windows. Post retrofit in the dwellings under review, this poses a much-decreased risk due to the inclusion of a correctly insulated external envelope complete with constant higher internal temperatures.

Radon
Radon is a naturally occurring radioactive gas and has been identified as the second leading cause of lung cancer worldwide after tobacco smoking (World Health Organisation, 2009). Studies have found that energy efficiency measures that increase the airtightness of properties are observed to have an adverse association with indoor radon levels (Pampuri et al., 2018; Yang et al., 2020; Fisk et al., 2020), but that levels can be reduced with appropriate ventilation strategies (Pampuri et al., 2018; Collignan and Powaga, 2019).

Volatile Organic Compounds
VOC's are gases emitted from certain solids and liquids and include a variety of chemicals, concentrations of which are consistently higher indoors than outdoors (US EPA, 2014). VOC's have known adverse effects on human health and comfort, ranging from mild irritation to acute toxicity and carcinogenicity (Sundell, 2004). The thermal retrofit of dwellings has been associated with elevated indoor levels of VOC's (Yang et al., 2020; Kempton et al., 2022). Demand-controlled ventilation (DCV) systems that do not supply airflow continuously but are controlled by humidity sensors to save energy can pose potential problems for exposure to VOC's in rooms that are unoccupied for periods of time (De Jonge et al., 2019). Such increases can be diminished using low emitting materials (Du et al., 2019) or increased ventilation rates (Hernandez et al., 2020). Notably, it has been demonstrated that while increasing

outdoor air ventilation rates does reduce the indoor concentrations of VOCs with indoor sources, the actual reductions in concentrations can differ significantly from those calculated with the assumption of a constant indoor emission rate (Offermann and Marcham, 2016) due to the impact of environmental factors on compound specific emission rates.

Sensor Based Demand Controlled Ventilation
SBDCV systems modulate the ventilation rate (VR) the rate over time based on the signals from indoor air pollutant or occupancy sensors (Fisk and De Almeida, 1998). The VR of the SBDCV system under review is modulated by increasing/decreasing levels of RH in habitable rooms with wet rooms/bathrooms/utility and kitchens also activated by presence detection. The concept is simple. The centrally located fan extracts at a constant 8 litres per second (l/s). Humidity controlled air inlets are fitted in all habitable rooms with air extract units fitted in wet rooms/bathrooms/utility and kitchens. Increases in RH result in the expansion of a polyamide strip within the air inlet, which is used to activate one or more shutters, thereby adjusting the passage of the air according to the ambient RH. The higher the humidity in the room, the wider the shutters open, resulting in greater inflows of air. Likewise, a humidity-controlled strip and/or presence detector allow shutters within air extract units to open in wet rooms/bathrooms/utility and kitchens, resulting in the removal of stale moist air from these zones. The negative pressure that is realised by the removal of this air is equalised through inflow from the habitable room air inlets. Greater amounts of air flows into the rooms where RH is highest as the aperture created by the opened shutters (8 l/s min – 16 l/s max) within the humidity-controlled air inlets will be larger than those rooms where RH readings are lower. Internal doors are fitted with a minimum of 10mm airgap, between the bottom of the door leaf and the internal surface finish, to facilitate such air flow. No significant pollutant filters exist on the supply air side, therefore whilst outdoor air ventilation dilutes internally generated airborne pollutants, it can also introduce outdoor pollutants to the indoor environment.

The SBDCV system is identical in each dwelling under review. All systems were commissioned upon install; however, no requirement currently exists (in the Republic of Ireland) for ventilation systems to be serviced annually.

METHOD

Devices
Airthings Wave Plus loggers were utilised for data collection. New, factory calibrated devices were used for the duration of this research study. Data was collected wirelessly at 5-minute intervals, 24 hours per day in all monitored rooms (2 locations per dwelling: master bedroom and main utilised living area) for a seven-month period.

Dwelling Typology
This study was limited to dwellings that participated in the Deep Retrofit Pilot Scheme. All participant dwellings were retrofit during the lifetime of this scheme. Each dwelling was initially assessed on an individual basis so that a BER of A and an airtightness of ≤ 5 m3/hr/m2 would be achieved post retrofit works. This was facilitated by the production of a designed post-works BER during the application process (Sustainable Energy Authority of Ireland, 2022b). Table 1 details the retrofit measures that were applied to each property. It is notable that a fabric first approach (Table 2) was utilised to ensure that each dwelling met minimum required standards in respect to insulation and airtightness prior to the introduction of technologies such as

heat pump and ventilation systems. The minimisation of thermal bridging and uncontrolled ventilation channels permit the efficient operation of these systems.

Table 1: Participant Dwellings - Retrofit Measures

ID	Replacement of external doors and windows Y/N	Type of external wall insulation used IWI - Internal wall insulation FFCB - Full fill cavity bead EWI - External wall insulation N - None	Replacement of roof / attic level insulation Y/N	Floor insulation Y/N	Ventilation system	Heat Pump Y/N
1	Y	IWI	Y	Y	DCV	Y
2	Y	FFCB	Y	N	DCV	Y
3	Y	EWI	Y	Y	DCV	Y
4	Y	FFCB + IWI	Y	N	DCV	Y
5	N	N	Y	N	DCV	Y
6	N	N	Y	N	DCV	Y
7	Y	FFCB + IWI	Y	N	DCV	Y

Table 2: Participant Dwellings - Listed Improvements

ID	pre-retrofit BER	pre-retrofit energy use - kWh/m2/yr	post-retrofit BER	post-retrofit energy use - kWh/m2/yr	pre-retrofit airtightness test result - m3/hr/m2	post-retrofit airtightness test result - m3/hr/m2
1	E1	304.11	A2	33.59	16.262	4.87
2	G	470.93	A3	58.2	15.714	4.53
3	G	862.6	A2	48.13	n/a	3.38
4	G	535.59	A3	59.29	30.99	4.94
5	C3	218.48	A3	70.97	7.585	4.52
6	B3	125.95	A3	64.39	n/a	2.18
7	C2	193.12	A3	55.93	n/a	4.91

FINDINGS

The SBDCV system under review considers that the level of ventilation provided (once compliant with Part F of the building regulations) is sufficient to control the concentration of all indoor air pollutants, including those that are not produced because of human occupancy. To explore this position, the data from the monitored variables were tested for linearity, by way of bivariate correlations. The purpose of this type of statistical analysis is to find out whether changes in one variable produce changes in another, by assessing the association that exists between them. Pearson's r is used to assess the linear relationship that may exist, whilst Spearman's rho is used where the relationship may be non-linear (sometimes stronger and sometimes weaker) depending on the data.

The dataset is significant with > 65000 measurements of each variable (per room, per dwelling) over the monitored period. VOC's and radon were assessed individually in respect to RH levels, as RH is the catalyst that triggers the SBDCV system. A correlation between variables would indicate that as one variable changes in value, the other variable tends to change in a specific direction. In respect to the SBDCV system, it is expected that increases in RH would trigger greater air inflow into the habitable rooms that would lead to reductions in RH and all other indoor pollutants. Table 3 details the findings of these tests, demonstrating a weak to no correlation between the variables in each dwelling (the designation "A" refers to the main utilised living area in each dwelling, "B" refers to the main bedroom). These findings suggest that the SBDCV system as installed, is unable to adequately control indoor air pollutants that are not related to human occupancy within retrofit dwellings.

Figures 1-4 demonstrate the lack of correlation in four of the monitored rooms. Each plot incorporates a line of best fit which graphically demonstrates the lack of relationship between the variables. Figures 1 and 2 plot VOC measurements gathered during the monitoring phase.

Table 3: Correlation Coefficients

Dwelling ID	Relative Humidity v Volatile Organic Compounds				Relative Humidity v Radon			
	Pearson Correlation	P-Value	Spearman Correlation Coefficient	P-Value	Pearson Correlation	P-Value	Spearman Correlation Coefficient	P-Value
1A	0.001	0.725	0.044	<.001	0.274	0.000	0.219	0.000
2A	0.174	0.000	0.204	0.000	-0.156	0.000	-0.103	<.001
3A	0.299	0.000	0.239	0.000	-0.013	0.001	-0.120	<.001
4A	0.095	<.001	0.145	<.001	0.009	0.179	-0.023	<.001
5A	0.147	<.001	0.161	0.000	0.066	<.001	0.063	<.001
6A	0.147	<.001	0.177	0.000	-0.300	0.000	-0.296	0.000
7A	0.133	<.001	0.190	0.000	0.205	0.000	0.202	0.000
1B	0.016	<.001	0.008	0.043	-0.298	0.000	-0.329	0.000
2B	0.008	0.034	0.050	<.001	0.030	<.001	0.010	0.010
3B	0.172	0.000	0.138	<.001	0.128	<.001	0.202	0.000
4B	0.169	<.001	0.231	<.001	-0.369	0.000	-0.420	0.000
5B	0.101	<.001	0.095	<.001	-0.045	<.001	-0.013	0.002
6B	0.177	0.000	0.254	0.000	0.004	0.332	-0.032	<.001
7B	0.111	<.001	0.149	<.001	-0.214	0.000	-0.151	<.001

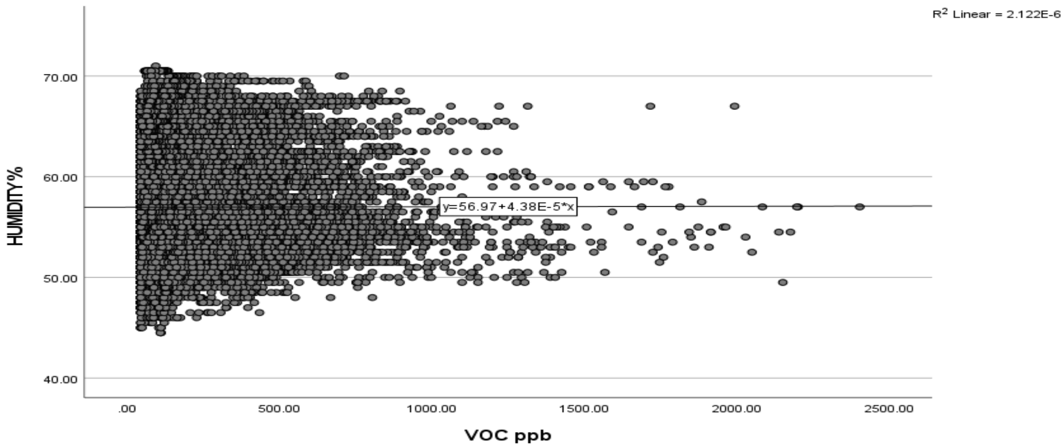

Figure 1: Relative Humidity and VOC Scatter Plot – Dwelling 1A

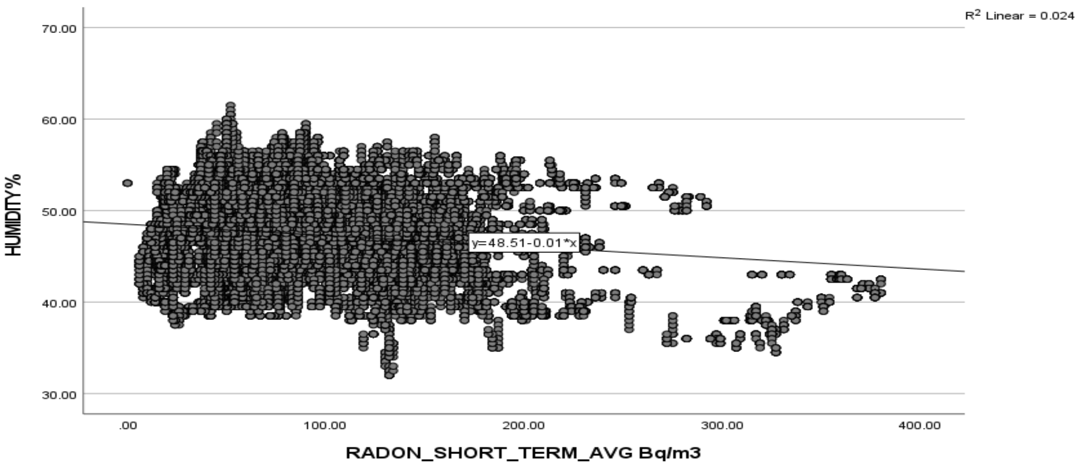

Figure 2: Relative Humidity and Radon Scatter Plot – Dwelling 2A

The Airthings Wave Plus loggers use a metal-oxide based sensor with a sensitive layer that reacts to chemicals by adsorption. This type of sensor reacts to most volatile organic compounds but is not able to differentiate between them. Therefore, it is not possible to consider specific adverse health effects from the measurement data, as each type of VOC has its own specific threshold limit value (TLV). This is defined as the limit a person can be exposed to a certain VOC without experiencing adverse effects. The lack of correlation is a cause for concern, should the levels exceed a compound specific TLV within the indoor environment. Figures 2 and 4 detail radon measurements that are more than the national reference level of 200 becquerels per cubic metre (Bq/m3). It is accepted that this level of activity may not exist within all retrofit dwellings but rather is a potential unintended consequence of dwelling retrofit in high radon areas.

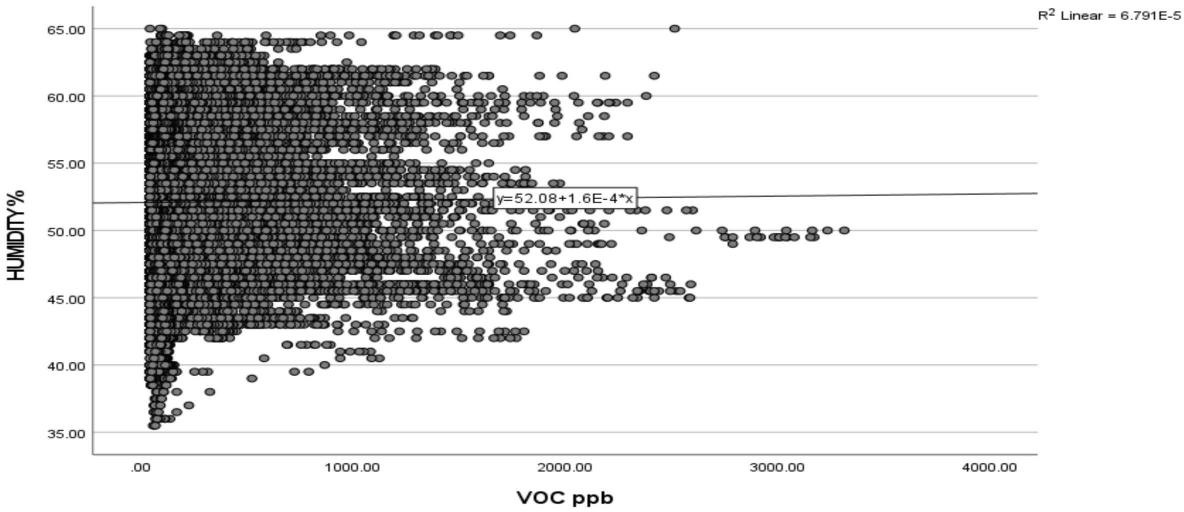

Figure 3: Relative Humidity and VOC Scatter Plot – Dwelling 2B

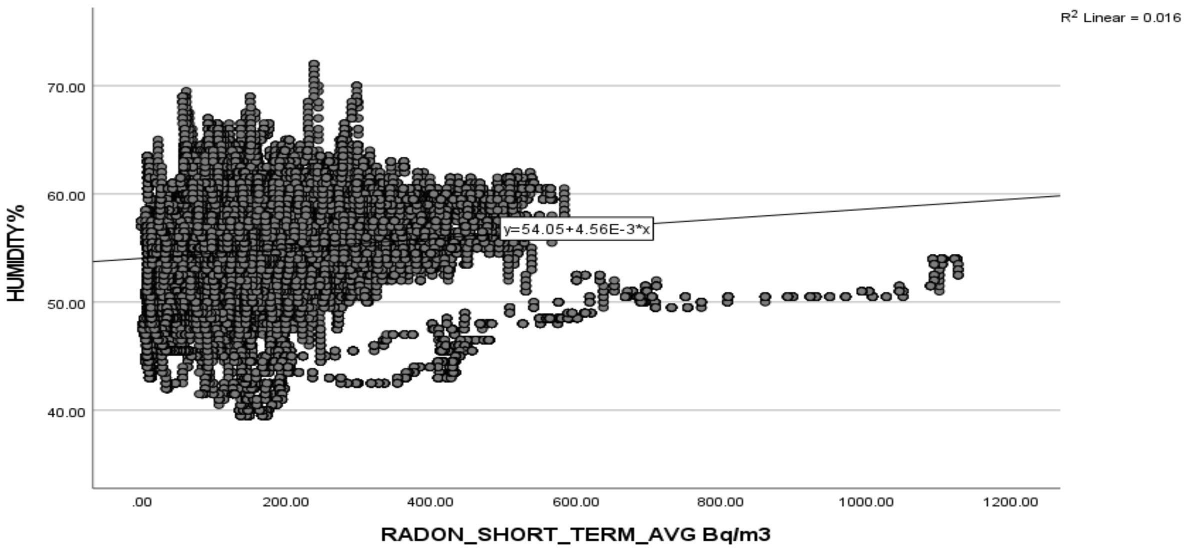

Figure 4: Relative Humidity and Radon Scatter Plot – Dwelling 3B

These results question the suitability of deploying a SBDCV strategy when undertaking large scale dwelling retrofit, due to the significant impact that indoor air pollutants can have on dwelling inhabitants (Borsboom et al., 2016; Logue et al., 2012). It is accepted that the sample size (n=7) is small but countered that the near identical fabric first approach to each retrofit suggest these findings can be extrapolated to apply to all dwellings (including those in other jurisdictions) that fit criteria similar to those listed and achieved in Tables 1 and 2.

CONCLUSIONS

This research has demonstrated that SBDCV systems that are activated by RH and presence detection are not sufficient to control the levels of specific indoor pollutants that are not produced as a direct result of human occupancy patterns, as these pollutants have varying emission rates and do not correlate to the number of occupants in a space. The financial cost associated with dwelling retrofit ensures that retrofit measures become locked-in for a significant period, therefore the ventilation strategy adopted within the dwellings under review has the potential to cause significant health and wellbeing impacts for occupants. It is suggested that balanced mechanical ventilation systems, that incorporate multi-pollutant sensors and an automatic modulating boost capacity, are considered for install within retrofit dwellings. Such systems should also incorporate suitably sized filters for incoming air, to limit the introduction of external pollutants to the internal environment.

We are constructing the future, therefore our approach to indoor air quality is critically important as we seek to retrofit 500,000 existing homes to a BER of B2 by 2030.

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LEARNING BETWEEN PROJECTS: AN ACCOMPLISHMENT OF SOCIAL-MATERIAL PRACTICES IN PROJECTS

Andreas Hartmann [1]

Department of Civil Engineering and Management, University of Twente, PO Box 217, Enschede, 7500AE, The Netherlands

The one-off nature of projects represents both a source for creating new knowledge and a barrier to continuously improving organisational routines. The temporary configuration of task-dependent resources appears to stimulate learning within projects but limits the dissemination of this learning between projects and the broader organisation. This paradoxical learning potential of projects has attracted much attention in the literature. However, learning from and between projects is still predominantly seen as the inflow and outflow of knowledge possessed by individuals or stored in databases or documents. Such a narrow view of project-based learning neglects the social-material complexity of project practices. In this paper, the argument is put forward that learning between projects is foremost an accomplishment of social-material practices in the context of projects. By adopting a practice theory lens and based on an illustrative case of railway viaduct construction, we will show how cross-project learning trajectories emerge from the social-material practices in projects.

Keywords: project-based learning; socio-materiality

INTRODUCTION

The construction industry is witnessing a far-reaching transformation from transitioning towards a sustainable, circular, and digitalised economy. As a result, more than ever, construction organisations need to be able to adapt, change and innovate their business practices; or, put differently, they need to learn.

Since the construction industry has been blamed for its low productivity and innovativeness, its learning capability has gained much interest in the industry itself but also in academia. Here, structuring construction activities around projects is seen as the primary learning challenge (Hartmann and Doree, 2015). Although the idiosyncratic nature of projects with their demand-specific activation and configuration of resources creates a fertile ground for generating new knowledge, the intrinsic temporality of projects appears to discontinue learning processes beyond project fences. Compared to other industries where projects are organisational vehicles for separating explorative activities from main business processes, in construction, the main business processes are realised through projects. Project-based learning in the context of construction then does not primarily mean to convert new

[1] a.hartmann@utwente.nl

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practices developed in projects into repetitive organisational routines but rather to develop and establish reproducible practices through a series of projects. Learning is something that spans projects rather than occurring from projects.

The learning challenge of project-based organisations has attracted much research over the years. For instance, the ARCOM conference 2022 included several contributions on the topic. All contributions implicitly or explicitly understand learning as a process of knowledge acquisition, creation, storage, and utilisation. On the epistemological ground of such understanding, knowledge is codifiable and transferable from projects to the organisation or other projects. The main locus of learning becomes the intersection of projects. The following expressions are paradigmatic for this: "[…] interdisciplinary teams make it possible to work closely together with one another and use the knowledge from others for the sake of the project" (Kamphuis *et al.,* 2022, p.137); "[…] social housing associations need to effectively coordinate the flow of knowledge in and about the inter-organizational collaboration with long-term partners" (Kamphuis *et al.,* 2022, p.92); "[…] the temporal nature of construction projects inherently results in newly acquired knowledge not being captured, transferred, and retained" (Boerkoel *et al.,* 2022, p.422).

The notion of knowledge as a commodity existing independent from the knowing subject is very prominent in the literature on learning in project-based organisations. However, such unilateral understanding reduces project-based learning to a context-independent knowledge transfer problem and the widely shared perception that the construction sector insufficiently learns from previous projects. Moving away from such an ontological view of knowledge to one that considers knowledge as a process of knowing and collective competence realised through the situated interplay of human and non-human actors (e.g., tools, technologies) in project work (Kokkonen and Alin, 2015) can shed a different light on the learning capability of the construction sector. Learning then does not hinge on knowledge as a transferable commodity between projects but emerges from and is embedded in the social-material context of project practices. It becomes a practical and collective accomplishment in projects with the aim "to discover what to do; when and how to do it, using specific routines and artefacts; and how to give, finally, a reasonable account of why it was done" (Gherardi *et al.,* 1998, p.274). Such a practice perspective does not deny the potential of translating practical knowing through reflexive activities into explicit knowledge that can be made accessible to others through documents, models, and other forms of transmittal artefacts. Reflexivity is even recognised as a mechanism for opening practical knowing to discourse and negotiation and enabling its change and institutionalisation (Gherardi and Nicolini, 2001). The practice perspective stresses, however, that any form of knowledge and knowing is enacted in a process of doing and the result of collective participation in project practice. Project-based learning then emerges in projects as social sites where knowing and doing are inseparable in the engagement of the social and the material, and knowledge of the social-material relationship constituting the project practice is constantly (re)produced. This knowledge gets inscribed in material characteristics and unconsciously internalised by individuals.

In this paper, we argue that project-based learning emerges from socio-material practices within projects that (re)produce the knowledge and knowing of the relationship between the social and the material of these practices across projects through which the practices endure, change, or are institutionalised. In the following, we further elaborate on the understanding of learning as a socio-material practice of projects, followed by an illustrative case and some discussion and conclusions.

Project-Based Learning as Socio-Material Practice

From a practice theoretical perspective, project-based learning is not a mere cognitive exercise of individuals but occurs through the participation of individuals in the collective processes of a project. Learning is always situated in the context of projects and the communities of these practices (e.g., project team) establishing them. Projects are the social sites where project team members interact with each other based on specific institutional rules, professional norms and language, assigned roles, and power relations. Knowing these rules, norms, language, roles, and relations is through enacting them in daily work. Project team members constantly (re)produce them and rather non-deliberately internalise their meanings and recognisable patterns in the long run, leading to habitual acting (Figueiredo *et al.,* 2021). Particularly in the project context, this emerging process of knowing is often challenged by virtue of the temporary nature of projects and their changing social constellations cutting through routine and habitual behaviour.

At the same time, project team members also engage with material artefacts in project work, including tangible objects such as construction machinery, tools, and building elements, and intangible entities such as digital models, software, and designs. By using these artefacts in their work, project team members experience the artefacts' features, working principles, and constraints. What can be done in project work by whom, and how the work should be structured is not least constituted by material resources. In project work, the social and the material are interwoven or imbricated, as Leonardi (2011) puts it. The imbrication metaphor implies that both entities can exist independently from each other and only come into relationships in the practice work of projects. Such an ontological view deviates from the understanding of socio-materiality formulated by Orlikowski (2007), who, based on the work of Barad (2003), argues that the social cannot be ontologically separated from the material. Both are entangled in the sense that there is "no social that is not material and no material that is not social" (Orlikowski, 2007, p.1437). Practices are constantly evolving and becoming, and so is learning. Knowledge is embedded in socio-material relations, and knowing is bound to the social and material and cannot be separated from practising (Gherardi and Miele, 2018).

We agree with the understanding of knowledge and knowing embedded in the socio-materiality of practices. However, we follow Leonardi's ontological understanding of the social and the material as independent entities. Material artefacts used in projects carry in their structural properties the knowledge and knowing of previous practices that enable or constrain project teams to do their current work in a particular manner. The structural properties of artefacts remain unchanged across contexts, but what artefacts do and which properties are activated depends on how they are used and how people perceive the possibilities of what they can do for them (Leonardi, 2013). This can also mean that they are used differently than intended, and their structural properties are modified. Learning occurs through this mutual constitution of the social and the material; the structural properties of artefacts afford or constrain the way they are used, while the way they are used can reconfigure or change their structural properties. With the notion that the social and the material are separate and come into a relationship in project practices, the temporal dimension of learning is put forward (Kringelum and Brix, 2020). The social and material imbrication in current project work is preceded by socio-material relationships of previous practices, which endure in the structural properties of artefacts and the habitual acting of people.

With the previous, we have localised project-based learning in the social-material context of projects. However, the learning cannot be limited to the temporal boundaries of a project. Social and material structures precede and affect the becoming of social-material relationships in projects, and the practices in the projects elaborating these structures (Leonardi, 2011). Project-based learning, then, is a trajectory of socio-material practices of projects where the (re)production of the knowledge and knowing of the socio-materiality in one project predates and affects the (re)production in another project. Therefore, understanding the learning in a project needs to consider the social and material historicity of the project practice and how the structural elaborations in previous projects ripple through and affect the current practice.

Illustration

In the following, we present a illustrative case to underpin our argumentation that the learning between projects is an accomplishment of social-material practices in projects constituting a learning trajectory.

Our case comprises the practice of designing and constructing a railway viaduct with a focus on two activities. Both activities are one of the most reoccurring in construction practices: pouring concrete and providing auxiliary construction. Although these activities appear very routine and repetitive, their social and material imbrication can differ between project contexts and lead to the emergence of learning.

In our case, the context is the design and construction of railway viaducts by a contractor for the railway agency in the Netherlands. Based on the availability requirement of the agency, the contractor first renewed the deck of the viaduct temporarily supported by an auxiliary construction called the sand pot (Figure 1). The sand pot consists of two steel plates, two steel strips, and two steel cams filled with sand. The size is 290 cm wide, and the length depends on the width of the rail deck, which rests on the sand pot. After the walls and floor of the underpass have been created, the sandbox can be removed. This is achieved by high-pressure jetting of the sand under the steel plate; the steel support plate falls on the steel cams. Then the permanent viaduct walls were constructed under the deck by placing a formwork that was filled with concrete (Figure 2). Here, we adopt a broader understanding of the two activities than only their actual realisation. We consider the preparation and design as part of the activities.

Our retrospective analysis covers four projects stretching over five years. Data was collected through interviews with staff members of the contractor involved in the four projects. These included two design managers, two design engineers, two project managers, and one construction manager. It should be noted that the original aim of the research was to gain a deeper understanding of technology development processes. However, while analysing our data, we recognised the role of technologies or materials in the development process and the interaction with project actors. We, thus, revisited our data from a learning perspective focusing on the socio-material relationship in the learning process. We were specifically interested in how different material artefacts were used in the projects, how they constrain or afford activities, how actors relate to each other while using or modifying artefacts, and how activities in previous projects affect socio-material configuration in current projects.

Project 1

Project 1 was not the first construction of a railway viaduct with similar requirements. In a previous project, both activities were already applied.

In Project 1, the calculation and implementation methods for the sand pot were further developed based on the previous project. Design engineer B and construction manager A discussed the points for improvement together with design engineer A who was responsible for the engineering in the previous project. This link was made by design manager A, who had confidence in the principle of the sand pot. The development focused on the settlements, tolerances, and construction method. Design engineer B continued with the calculations of design engineer A and elaborated on these more clearly. This resulted in a more detailed description of how the geometry of the sand pot needed to be determined. This calculation was internally checked by design engineer A. The assembly method was also further developed by exploiting the experiences of the previous project. Construction manager A was responsible for the assembly during the possession. Via design manager A, construction manager A contacted the previous construction manager. His predecessor indicated that the performed assembly method was much work due to the multiple small elements. Therefore, construction manager A prepared a method to simplify the construction during the hectic period of possession. As a result, the sand pot was assembled with just one underlay plate (around 18 meters) instead of single elements of 3 meters. Eventually, this method performed well.

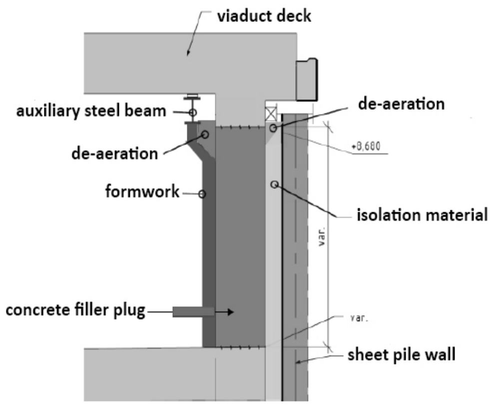

Figure 1: Principle of sand pot concrete

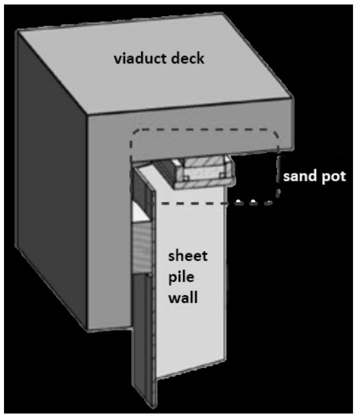

Figure 2: Principle of pouring under a viaduct deck

Construction manager A was also responsible for emptying the sand pot after completing the walls and floor. The sand pot is filled with sand, which needs to be removed to take the sand pot out of operation. To catch the cover plate during the removal of the sand, studs were welded in the corner of the construction in the previous project. Construction manager A tried to reduce the costs for this construction and replaced the welded studs with wooden laths. Eventually, the wooden laths did not work correctly. They started to float while removing the sand with water, obstructing the water flow.

For pouring the entire wall under the railway deck, self-compacting concrete (SCC) was used since SCC was regarded as an appropriate mixture to guarantee a completely filled and compacted concrete wall. However, the final wall showed many cracks and was not watertight as required. The construction manager responsible for Project 1 was aware of the outcomes of the previous project. While preparing for the new project, he contacted the previous construction manager to exchange details of the work method and experiences. As a result, the work method was modified. Only a small part around the joint between the deck and wall was filled with SCC, and extra reinforcement was applied to mitigate the risk of cracks around this critical part. Because the work method needed to be assessed by the client, an engineering report was drafted by design engineer B. Eventually, this work method resulted again in cracks and leaks in the wall and a laborious rework through injections.

Project 2

In Project 2, design manager A continued with the engineering method. Design engineer C was responsible for the engineering, and design engineer B shared the engineering report of Project 1. The developed engineering method, explained in the previous engineering report, was followed by using project-specific inputs (e.g., the forces). Design engineer A conducted an internal control of the final engineering report. Construction manager A was again responsible for the assembly of the sand pot. The assembly method was prepared and implemented with inexperienced project coordinator B. The method consisted of a fully preinstalled construction (i.e., installation of the underlay plate filled with sand and cover plates) and the placement of the construction during the possession. The pre-installation required the integration of a crane company during preparation and construction. A work plan for the possession was developed that includes the 'lifting plan'. Construction manager A was again responsible for emptying the sand pot and returning to the welded studs.

In Project 2, project coordinator A was responsible for preparing the work method for constructing the walls underneath the railway deck. He was aware of the previous problems: "If we start doing it the same way, then you can inject for 30,000 euros. Thus, you can invest quite a bit in a more expensive mixture, expensive facilities." Therefore, together with the subcontractors, he worked on a method to prevent any cracks and leaks in the walls. This included the material engineer of the concrete plant and the formwork supplier. In cooperation with the material engineer of the concrete plant, a low-vibration mixture was developed. This mixture had the same flow features as SCC but with fewer fine additives and plasticisers. These adjustments mitigated the heat development, which reduced the risk of cracks and leaks. Furthermore, together with the formwork supplier, the formwork was adapted to allow the pouring the concrete mixture from the bottom. Eventually, this resulted in a crack-free wall.

Project 3

Design manager A based the engineering of the sand pot again on the experiences from the previous projects. The previous engineering reports were transferred to the new design engineer, and the engineering was wholly adopted. This complete adoption was justified by the smaller forces on the sand pot compared to the previous projects. However, the geometry of the sand pot was adjusted due to different soil characteristics. The responsible construction manager in Project 3 could not build upon earlier experiences for the construction assembly. The experiences from the previous projects were provided by a presentation given by design manager A and through collaboration with the crane company. This method was again retained in the integral work plan, and the construction was executed within the possession.

In Project 3, the concrete walls were poured approximately two months after the construction of the walls in Project 2. A different work method was developed, although some aspects were adopted from Project 2. The construction manager from Project 1 could bring in his experiences, and with project coordinator B the work method was developed. Project coordinator A was shortly involved during the design phase to share the work method of Project 2 with the project team. However, for Project 3, a pouring method from above was chosen since the main requirement was fair-faced concrete. This requirement was not present in Project 2. In collaboration with a concrete plant different from the one in Project 2, a concrete mixture like the one used in Project 2 was developed. Similar to Project 2, the design team was not involved because the design of the railway was already in a detailed stadium. Eventually, the developed mixture performed as an SCC, resulting in cracks and leaks in the wall. Furthermore, during the filling of the walls, the hose got stuck, resulting in a not completely filled wall.

Project 4

Project 4 will be the subsequent application of the sand pot. Although not yet prepared, it was indicated that the same approach would be followed as in the previous projects. Experiences from these projects were already integrated into the project through the involvement of design manager B and project coordinator B.

For Project 4, the work method for the walls was still under development during data collection. Through the continuation of project coordinator A, the experiences of Project 2 contributed to this project. This included the early involvement of project coordinator A in the design phase. Together with design manager A, the work method was further developed. As the design manager pointed out: "If I had not had project coordinator A, I wouldn't have thought of it [the facilities in the deck]”. The work method contains two adjustments to the overall design: (1) the wall attachment is inclined outwards by two degrees so that air can escape to the backside; (2) these wall attachments are equipped with ventilation facilities. These facilities enable pouring the concrete with a surplus height and allow air movement during pouring. A similar concrete mixture used in Project 2 was developed with a new concrete plant.

CONCLUSIONS

By changing the ontological perspective on project-based learning and mobilising a practice theoretical conceptualisation of learning, we developed our central argument that learning between projects is a socio-material accomplishment in projects constituting learning trajectories. The practice of constructing a railway viaduct served us as a case to support our argumentation. Of course, the case has only exemplary character since its methodological approach does not conform to the epistemological standards of practice studies. Notably, the cross-sectional data collection based on interviews cannot fully grasp the emergence of practices as a multifaceted and multidimensional phenomenon (Nicolini, 2012). In this regard, the purpose of this paper is rather modest. Its aim is, first and foremost, to endorse an alternative theoretical avenue for understanding project-based learning. Although practice theory has already found its way into construction management research in general and learning in and from projects in particular (Kokkonen and Alin, 2015), the cognitive approach to learning still dominates. One may argue that this dominance rests on the explanatory power of the approach. We cannot compare the knowledge gain from different theoretical schools and traditions here. What we can do is show that the practice theory lens can offer unique contributions to our understanding of project-based learning. While the cognitive approach boils down the learning between projects to the transfer of knowledge from one project to another, practice theory shifts the learning focus to the enactment of knowledge in the context of ongoing projects. The presented case indicates that project-based learning is not just happening through knowledge transfer at the intersection of projects but instead emerges as an inherent part of socio-material practices in projects. From a cognitive learning perspective, one may argue that the contractor could not transfer lessons learned between the projects since similar deficits reoccurred (e.g., cracked wall). Given the multiple transfer mechanisms in place, this argument becomes weak. Project members participated in several projects bringing in their experiences gained in previous projects. Technical reports documented the engineering and implementation of work methods and were consulted on subsequent projects. Our argument here is that the reoccurrence of deficits is not signalling the inability of a contractor to learn but expresses the situated constitution or emergence of learning from socio-material practices in projects.

The emergence of project-based learning includes both synchronic and diachronic emergence (Elder-Vass, 2010). Synchronic emergence refers to the relationship between a whole (here, the practice of designing and constructing a viaduct) and its parts (here, the social and the material in pouring concrete and providing auxiliary construction) at a specific point in time. Through the interaction of different project actors, their individual experiences with the sand pot and the pouring of concrete were enacted to construct the viaduct walls and understand the construction's performance outcomes. The modified working methods express the developed collective understanding that is more than individual experiences. The situated interaction in the projects was based on the different actors' assigned roles that shaped how they built relationships with each other—for example, driven by his belief in the sand pot design manager A brought construction manager A and design engineer B in contact with design engineer A who initially develop the method. This position of design engineer A was even institutionalised through his responsibility for absolute control in subsequent projects and created social agency in the sense that there was a collective belief in the technology.

In the same manner, the interaction of the material elements of the sand pot and the concrete formwork constituted the structural properties of the overall construction, including load-bearing capacity, flushing capacity, form stability, and tightness. Changing these reconfiguration of material elements resulted in altered properties. For example, combining a concrete mixture with fewer fine additives and plasticisers with an adjusted formwork construction led to a crack-free wall. Here, the structural properties of the material used remained essentially the same across projects; mainly, the usage and structural configuration of the material changed. In Project 1, the SCC was only used for a small part of the construction compared to the complete filling of the formwork in the previous project. The concrete properties were then modified in Project 2, resulting from the unsatisfactory outcome of Project 1. However, the deviation of the concrete behaviour from the expectations also signals a limited control of what material can afford. The affordance of materials became manifest in unexpected performance outcomes. Replacing the welded sluts in the sand pot with wooden laths resulted in water blockage while removing the sand. Learning in the projects also emerges from materials that responded differently than expected. The affordance of materials operates in a particular range through which materials can possess agency and elude their control in specific contexts and applications (Leonardi, 2013). For the sand pot this meant that construction manager A returned to the welded sluts to ensure the flushing capacity of the sand pot.

These examples also indicate the imbrication of the social and material in the learning. The aim of reducing costs was the reason for replacing the welded sluts with wooden laths. Developing the method for pouring concrete required modifications to the concrete mixture, the formwork, and the deck design realised through the collaboration between the construction manager, design engineer, material engineer, and formwork supplier. The interactive process brought up collective competence embedded in the socio-material relationships. The switch to another concrete plant shows how unique and critical this socio-material constellation is for the practice. Likewise, the engineering reports drafted in each project were used in subsequent projects and, as such, formed the interaction between design engineers and construction managers while situationally adapting the engineering. They inscribed the project-based interactions and relationships of actors stretching across projects. The socio-material imbrication within projects (re)produce the knowledge and knowing of the relationship between the social and the material of these practices across projects

The latter points to the diachronic emergence of learning which emphasises the historicity of the practice and its development over time. Both activities, the sand pot and the pouring of concrete, developed over a series of projects as the result of engaging with the outcomes of previous projects. The learning in one project was predated and affected by the socio-material relationships in another project. The learning in the projects constituted a learning trajectory across projects. This trajectory is characterised by the continued reconfiguration of the social and the material in projects through which learning emerges from the tension between what project actors intend to achieve and what material artefacts can do in the specific context of a project. This emergence of project-based learning through the situational imbrication of the social and the material in projects has a main implication for our understanding of learning in and between projects. Learning is inherent to project practices since their socio-material complexity will always require social and material reconfigurations while project actors engage with each other and their numerous artefacts. Or put differently, something like best practices are illusive. This does not mean that project activities are not repetitive. It only stresses the dynamic nature of project practices, constantly balancing social and material requirements. The reproducibility of activities then becomes a matter of the extent to which the situated socio-material imbrication in a project practice resembles previous socio-material relationships.

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DRIVERS AND CHALLENGES OF VERTICAL INTEGRATION IN THE TANZANIAN CONSTRUCTION INDUSTRY

Catherine Luambano[1], Neema Kavishe[2], Sam Zulu[3] and Nicholas Chileshe[4]

[1] *School of Construction Economics and Management, Ardhi University, Dar es Salaam, Tanzania*

[2,3] *School of Built Environment, Engineering and Computing, Leeds Beckett University, Leeds, UK*

[4] *UniSA STEM, Sustainable Infrastructure and Resource Management (SIRM), University of South Australia, Adelaide, South Australia, SA 5001, Australia*

Vertical integration is originally from the manufacturing industry. It is considered as a diversification strategy adopted in the construction industry as means of solving some of the existing problems associated with construction industry such as supply chain problems, fragmented process and absence of integration to mention a few. Based on existing literature, there is paucity of studies in this area. therefore, to bridge the knowledge gap the aim of this study is to identify driving factors and challenges encountered in the application of vertical integration in the Tanzanian construction industry. A qualitative research approach was adopted through a case study method whereby a total of 15 semi-structured interviews were conducted. Data were analysed through content analysis. The findings showed that the top three driving factors were increase in competition, quality improvement and client satisfaction. Whereas, nature of contracts, high investment cost, decreased strategic flexibility and increased business risk were the most mentioned challenges. The results of this study will foster better understanding of the drivers and challenges encountered and suggest solutions to enhance the application of Vertical Integration in the Tanzanian Construction Industry.

Keywords: challenges; diversification; driving factors; Tanzania

INTRODUCTION

Vertical Integration (VI) is a strategy where a company owns or controls other stages of the production chain. The client, consultant, contractor, manufactures and suppliers of materials are some of the key players in a construction production chain. When one player takes control of several of the production steps involved in construction that is what's called VI. It involves entrance into construction related markets such as preconstruction activities like production of construction materials, post construction activities such as operation of power plants or complimentary activities such as manufacturing of furniture.

VI originated from the manufacturing industry as a means of reducing per unit cost of products. It happened during the time of very great volatility, which was later named

[1] n.w.kavishe@leedsbeckett.ac.uk

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the second industrial revolution (Casson and Godley 2007). It started in the last quarter of the nineteenth century in the United States of America. According to Chandler (1977), It came in three phases, the period of market expansion, then necessary developments in transportation to permit mass markets to begin and lastly the phase which saw the integration between mass production and mass distribution among a few pioneer firms who could only sell in volume if they created a way in which they could distribute in volume. Companies would supply their own raw materials, process, then transport and distribute the products by themselves.

VI was later adopted by the construction industry as means of solving some of the problems associated with construction. The construction industry is associated with a couple of problems which can be summarized into three groups; the product development process, e.g., fragmented process, problems related to the stakeholders, e.g., absence of integration and the contracting process, e.g., supply chain problems Latham (1994) and Egan (1998). But, the adoption of BIM technologies has enhanced VI in the construction industry, particularly in the developed countries because it demands inter-professional collaborations in project delivery (Jia, *et al.,* 2017). In developing countries like Tanzania, construction industry has continued to grow gradually over the years because of the country's investments in building and infrastructure projects (Kikwasi and Escalante, 2018). This growth has influenced a dramatic increase in competition within the industry to a point where some firms have decided to undergo VI. However, VI is fairly a new concept in the Tanzanian Construction Industry as compared to other industries such as the manufacturing industry. Examples of companies that have seen great success through VI in other industries in Tanzania include Mohamed Enterprises Ltd (MELT) and Bakhresa group of companies (Absanto and Nnko, 2013).

Despite the adoption of VI in Tanzanian construction firms, there is barely any literature on VI, moreover, there is little experience and knowledge shared regarding the adoption of VI. Therefore, to bridge the knowledge gap the purpose of this study is to identify the driving factors and challenges encountered in the application of VI in the Tanzanian construction industry.

LITERATURE REVIEW

VI is one of the diversification strategies (Al-Sayegh, 2010). This type of diversification within the construction industry involves divergence into markets that relate to construction such as material supply, buildings maintenance and/or interior designing. According to Dikmen and Birgonul (2003) the reasons for related diversification include controlling quality, quantity and price of suppliers. In a vertically integrated system, the roles of developer, supplier, designer and builder are all done by one organization. A classic example is the design and build system (Oyegoke *et al.,* 2010). VI strategy increases a company's involvement in the production chain within which it operates (Barney 2007). Basically, according to Eldamnhoury and Hanna (2020), vertically integrated firms bring in-house expertise to do the activities that were previously outsourced. One could simply say, vertically integrated companies extend boundaries of their operations by keeping them under one firm. VI could either be forward or backwards (Adeleke, *et al.,* 2019).

Forward integration happens when a company progresses towards the end user in the production chain (Adeleke, *et al.,* 2019). It is when a company involves itself in activities that succeed them in the production chain. For example, in construction when a contractor diversifies into real estate where they can sell buildings. Forward integration allows a company to have more dominance on the demand side (Lin *et al.,* 2013). Conversely, backward VI happens when a firm involves itself with activities preceding it in the production chain. It is when a firm moves towards the input of the subject product or service (Adeleke, *et al.,* 2019). For instance, Thomas, (2010) explained that backwards integration involves diversification towards the start of the production chain like the sources of raw materials gaining more control over quality and proportions of such materials.

Driving Factors to Vertical Integration

A driving factor is something that has the power to cause something else to happen. In other words, it's something that strongly influences people and makes them do something. Cook and Garver (2002) explained that VI can be motivated by the aspiration to tend to customer needs without going overboard with cost. As the construction industry grows, customers are becoming more and more demanding of better and uncommon designs of buildings and structures. VI eliminates the problem of double profiting which allows companies to maintain lower prices while meeting diverse customer needs.

Guan and Rehme (2011) mentioned intensified competition as another driving factor to VI. Increased competition comes with the growth of any industry and construction is not any different. In any industry with intense competition, one will need to provide services of a high quality while maintaining relatively lower prices to stand out, and VI can support that. Similarly, Al Sayegh (2010), stressed that, the desire to improve quality could also lead to VI. The issue of quality is very sensitive in the construction industry, Davis and Pitts (2004) argue that when a firm has the ability to manage input into the process can decrease defect rates and hence gain competitive advantage. When we talk about the concept of quality in construction it goes together with the concept of time, in the sense that if that product or service can be available on time.

On the other side Green, (2020) reported that clients desire to achieve better value for money, hence the drive towards VI. Likewise, variability in input and output markets is another driving factor to VI (Desai and Murkheji 2001). Examples of construction inputs are building materials, time and money. Sometimes there's a massive volume of building materials in the market with no construction projects around, which forces the price of building materials to go down. Other times there is too many projects but not enough building materials, this gives the supplying firms leverage over the contractor and can choose to sell building materials at a very high price. A seminal study by Nayyar (1993) highlighted that this variation within the construction industry could drive a firm to vertically integrate as it realizes a market that is yet to be utilized by their counter parts. With VI firms can utilize this market for lower costs to gain quick profits through synergy creation. This also gives a firm total control on production because the firm is aware of the number of projects they have and can estimate the volume of inputs needed and make sure it is available when needed.

Attractiveness of the market can motivate a firm to vertically integrate (Al-Sayegh 2010). Market attractiveness include the extent to which a market offers opportunities to firms, considering the profitability, market size, growth rate and the level of competition. Whether a firm should or should not integrate and to what extent, it is all dictated by the attractiveness of the market in which that firm operates in. The best time to integrate is when the industry is in the growth phase and getting profits is relatively easy. Intangible resources, unique resources and core competence could make a firm want to vertically integrate (Khalil, 2010). It is well known that branding and reputation that precedes the company are vital in building a business. When a company has these, it can be motivated to vertically integrate because of its good image/brand. Example, Persimmon, one of the UK's largest house builders, chose to vertically integrate parts of its supply chain, including tiles, bricks and timber frames and it managed to achieve leading margins of around 27% (Collinson Grant, 2023).

Additionally, a firm can be encouraged to integrate when there are idle tangible resources such as capital, machinery, or labor. Al Sayegh (2010) supports that, surplus of tangible resources is a motivation to vertical integration.

Challenges of Vertical Integration Strategy

Like any other strategy, vertical integration is associated with few challenges considering that the firm is doing more work. Difficulties and complexities in coordinating activities was identified as a challenge by Al Sayegh, (2010). Coordinating the activities of one line of business on its own can be difficult, adding other lines of business just goes on to add on that. The firm might need extra or completely new set of human resource with additional skill sets to help with the coordination otherwise it could result to poor production due to poor coordination.

Another challenge is the need for high costs/investments (Desai, Mukherji 2001). Any business cost money, so when a firm chooses to either extend its operations or buy a new business, they will need extra capital to buy the new business and keep it running or to reinvest in the new technologies to avoid obsolescence and stay competitive. Additionally, vertical integration can include the problem of unclear scopes and design changes that is associated with design and build procurement system Oyegoke *et al.,* (2010). On the other side it is said that difference in economic and technological circumstances that exist in the various stages of a value chain, requires distinct management styles and cultures. Trying to manage the challenges that exist across successive businesses can be difficult to the management (Osegowitsch and Madhok, 2003). Vertical integration reduces flexibility by forcing the firm to follow trends in the segments they integrated. If technology or market changes making the production methods or products of one line of business outdated, the firm may find it difficult to respond quickly. Therefore, increase in business risk (Khalil, 2010) is another reported challenge in vertical integration.

METHOD

A qualitative approach was adopted in this study because there is limited studies and knowledge of vertical integration in the construction context, therefore this study is exploratory in nature to facilitate the discovery of information in this area/topic (Amaratunga *et al.,* 2002). Similarly, Yin (2016) supports that qualitative approach is suitable for new and emergent topics. Through a case study research design data was collected using Semi-structured interviews because the semi-structured interviews allow the flexibility to explore questions into areas which could provide new perspectives of issues not previously perceived (Axinn and Pearce, 2006). A total of 15 interviews were undertaken with respondents from 3 case companies in Tanzania. The sample size is considered sufficient, because the range between 5-50 interviews is enough to attaining saturation (Patton, 2002). The interview transcripts were analysed using the summative content analysis method because it is an unobtrusive and nonreactive way to study an aspect of interest and it can give basic insights of how words are used (Hsieh and Shannon, 2005). Additionally, summative content analysis enumerates the contextual use of phrases or words in the collected data (Squires *et al.,* 2022).

A two-stage sampling technique was used whereby the first sampling stage involved the selection of case studies through snowball sampling. This sampling technique was considered appropriate because vertical integration is not common in Tanzania, only a few firms are vertically integrated. The second stage involved the selection of respondents within the case studies, whereby purposive sampling was used. This was because of the nature of research subject and research questions. The case study selection criteria included: the firm must be a construction related firm and must be vertically integrated. Whereas the selection criteria of respondents from the cases included only members involved in decision making within the firm. The selected firms were identified as information rich cases. Likewise, Yin (2018) emphasized on using two or multiple cases as it is more substantial compared to when you use one case also it allows for examination of how a phenomenon behaves in different settings.

FINDINGS

A total of three case studies were selected including Group Six International Limited, Dar es Salaam Glass Works and Advent Construction Limited. Based on the criteria explained above. The interviews revealed that Group Six International (Case 1) dealing with supply of construction equipment, building materials, real estate development, maintenance, and technical consulting among other things, has been vertically integrated both ways, forward and backward for around 7 years. Dar es Salaam Glass works Limited (Case 2) is also integrated both ways for over 20 years into supply of materials, real estate, logistics and transportation of materials and machinery, to mention a few. For the third Case findings revealed that Advent Construction Limited (Case 3) is only integrated backwards mainly into supply of ready mixed concrete and construction blocks for almost ten years. Below is Table 1 showing the profile of case studies.

Table 1: Profile of Case Studies

Case	Type of vertical Integration	Experience
Case 1	Forward and backwards	7 years
Case 2	Forward and backwards	20 years
Case 3	Backwards	10 years

Table 2 below illustrate the profile of interviewees. A total of 15 respondents were purposely selected and interviewed from the three case studies. Generally, 8 out of 15 people who were interviewed, had more than 10 years of working experience in the construction industry. Furthermore, examination of Table 2 indicates that 5 out of 15 had the top-level position within their organization and the majority were in the decision/managerial position in different departments hence a justification that information was solicited from reliable and well experienced personnel.

Driving factors for vertical integration

In order to identify the driving factors of vertical integration in Tanzania, interviewees were asked, "what were the driving factors that motivated their company to diversify into other construction related activities?". Table 3 summarizes and reports on the driving factors for vertical integration to Tanzanian construction firms as explained by the interviewees. It is noted that, the most mentioned driving factors of vertical integration in the Tanzanian construction industry are: 'the need for quality.

Table 2: Profile of Interviewees

Case	Interviewees	Designation	Experience in construction industry (Years)
Case 1	A	Deputy general Manager	6-10
	B	Engineering Department Manager.	11-15
	C	Project Manager	6-10
	D	General Manager	16-20
	E	Finance department manager	11-15
Case 2	F	Financial Manager	11-15
	G	Chief Executive officer	6-10
	H	Project coordinator.	>20
	I	Managing Director	0-5
	J	Chairperson board of directors	>20
	K	Senior quantity Surveyor	6-10
Case 3	L	Manager Tendering and Estimation	6-10
	M	Senior project manager	16-20
	N	Managing Director	16-20
	O	Financial advisor	6-10

Improvements' (n=11), 'Increased competition'(n=11), 'Clients demands (n=9)', and 'Core competence'(n=9). These responses were tallied based on how many interviewees out of all 15 respondents mentioned that factor. The factors that were mentioned by less than 5 interviewees among fifteen were less significant. In this study only the top four mentioned drivers will be discussed.

Based on Table 3, 'desire for quality improvement' was mentioned by the majority (f=11). For instance, Interviewee A from case 1 was quoted saying:

> Quality is the main factor in the construction Industry, if you construct a good quality building you can use it for many years without the need for renovation. So as a firm, we realized we could provide quality concrete with better strength if we produce it ourselves, that's how the idea of making ready mixed concrete with a batching plant came about. In the batching plant everything is computerized which makes it precise and with guaranteed quality. We supply concrete to our projects and other projects.

Likewise, Interviewee E explained that:

> In order to maintain quality, we decided to do a number of things in house, so we can have more control of quality, and this became our competitive advantage through better pricing.

This finding is like existing studies (Al Sayegh, 2010; Davis and Pitts, 2004; Singh *et al.,* 2004). Example Singh *et al. (*2004) emphasized that 74% of quality related problems can be solved by adopting vertical integration. Davis and Pitts (2004) also stated that the ability to control inputs in the production chain can decrease defects and hence gain the firm a huge competitive advantage.

Another driver mentioned by most interviewees was 'increased competition' within the industry. Recently Tanzania has witnessed growth in the construction industry as the result of the country's investments in building and infrastructure projects (Kikwasi and Escalante, 2018). For instance, Interviewee J from Case 1 acknowledged that:

> For our company, we have been in business for over 40 years, we have seen the Tanzanian construction industry grow and change to be what it is today. It is almost like vertical integration was a natural strategy for our firm as a result of changes that happened in the industry, with time the industry kept on being more competitive, it became harder to win tenders so we had to find a way that could reduce cost in order to give us a competitive advantage.

Guan and Rehme, (2012) agrees with this fact as they claimed that increase in competition forces firms to integrate.

Table 3: Summary of Interview responses on the driving factors for vertical integration

No.	Driving Factors for vertical integration	Interviewees															Total
		Case 1					Case 2						Case 3				
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	
1	Need for quality improvements	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓		✓		11
2	Clients demands	✓	✓	✓	✓	✓				✓	✓			✓	✓		9
3	Competition	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓		11
4	Familiarity and Core competence	✓	✓	✓		✓	✓			✓	✓			✓		✓	9
5	Market availability			✓			✓	✓		✓						✓	5
6	Business expansion	✓		✓				✓							✓		4
7	Financial pressures	✓															1
8	Improved profitability	✓											✓			✓	3
9	Need to protect core business secrets	✓															1
10	Unavailability of materials		✓										✓	✓			3
11	Idle labour and equipment		✓			✓					✓	✓					4
12	Company's good reputation							✓		✓		✓					3
13	Buildability challenges									✓							1
14	Company's vision to grow										✓	✓			✓		3
15	Availability of capital											✓					1
16	Cost advantages												✓			✓	2
17	Contractual conflicts													✓			1
18	Technological interdependencies														✓		1

The need to satisfy several clients was another significant driver which led the companies to undergo vertical integration. Interviewee B revealed that:

> Material suppliers can be a headache, depending on them and yet you commit yourself to deliver a project on time, automatically gets you in trouble with clients. We had to ask ourselves why do we have problems with our clients all the time over something that we can do ourselves in a timely manner? Basically, the need to satisfy our clients motivated us to start supplying glass to our own construction projects as well as other projects

Equally, Cook and Garver (2002) also supported that integration can be sparked by the desire to satisfy diverse customer needs while maintaining lower costs. The fourth most mentioned driver is the Core competence. This was also mentioned by 9 respondents across the three case studies. Many interviewees pointed out that vertical integration was a result of them being familiar with the construction industry and having that core competence that allowed them to navigate easily through other construction related lines of business. Interviewee O contended that;

> We are quite competent in the construction industry, our reputation as contractors precedes us. So, for us it was easier to expand our business in the same industry that we are familiar with and because of the core competence, we did not need a lot of new employees, mostly we just had to train the employees we already had which made it a lot easier.

Therefore, based on the identified drivers the reported findings demonstrate clearly what compelled/motivated these firms to adopt VI which is essential information for promoting VI in Tanzanian construction industry as well as in other similar countries.

Challenges Associated with Vertical Integration in Construction

In trying to assess the challenges of VI strategy in relation to the construction industry, the respondents were asked about the challenges that their companies face as a result of adopting VI. The following were identified as major challenges; 'nature of contracts', 'need for high investments', 'lack of support from the government', 'increase in business risk' and 'reduced strategic flexibility' as summarized in Table 4 below. Nature of contract was mentioned by 9 respondents from all the three cases. The major argument was that firms which have integrated to do both designing and constructing under design and build contracts.

Table 4: Summary of Interview responses on the challenges of vertical integration

	Challenges of vertical integration	Interviewees															Total
		CASE 1					CASE 2						CASE 3				
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	
1	Nature of contracts	✓		✓	✓	✓	✓						✓	✓	✓	✓	9
2	Need for high investments	✓			✓	✓		✓	✓	✓		✓					7
3	Lack of support from the government	✓		✓	✓		✓					✓			✓	✓	7
4	Increased business risk	✓			✓				✓			✓	✓			✓	6
5	Decrease strategic flexibility	✓	✓		✓	✓			✓		✓	✓					7
6	Failure of the main business	✓							✓			✓			✓		4
7	Design changes	✓									✓						2
8	Surplus of materials	✓								✓	✓		✓				4
9	Abrupt technological changes		✓						✓			✓			✓	✓	5
10	Need for high supervision to ensure quality		✓														1
11	Decrease flow of knowledge from outside the firm					✓							✓				2
12	Management bureaucracy						✓		✓			✓	✓				4
13	Lack of specialization							✓				✓		✓	✓		4
14	High exit barriers							✓									1

when there are a few designs and build contracts in the market its loss for them since they have invested a lot of capital to make the system work. Example Interviewee M highlighted that:

> There is no point of having the designing department within the company if most contracts are following traditional approach., it was discouraging to integrate into designing back in the days' because of inadequate projects of that nature.

Need for high investment was also mentioned by 7 respondents. The majority claimed that although in a long run vertical integration reduce production cost and enjoy economies of scale as a result of producing in large quantities the challenge behind this is high cost of capital to run the business. Interviewee G highlighted that

> Our firm bought a batching plant about 8 years ago although we wanted to make our own concrete way before that, but we had to wait until we had enough capital.

This finding is consistent with Desai and Mukherji (2001) implying that the need for high capital is not the challenge only in Tanzania but also in developed economies. Therefore, concluding that adoption of VI requires high capital.

Lack of support from the government appeared to be a unique challenge identified in Tanzania as there wasn't any study with a similar challenge. Interviewee N, highly emphasized on the need for government support to construction firms in developing countries. He further explained that in few years ago most public infrastructure and building projects in Tanzania were only contracted to public construction firms living private firms struggling and some collapsing due to lack of works. Increased business risk was also another challenge Interviewee C explained that:

> Construction is a very spontaneous industry, to be a competitive player you need to have the ability to change rapidly with the industry, a high degree of vertical integration could reduce the ability of a firm to change rapidly and hence increase risk of failure.

Al Sayegh (2010) supported this result inferring that VI comes with additional risks. Thus, the identified challenges create awareness and serve as a reference point for enhancing the knowledge of industry stakeholders on the possible challenges which could lead to failure when adopting VI in the construction industry despite its significance.

CONCLUSIONS

This study aimed to identify driving factors and challenges encountered in the application of vertical integration in the Tanzanian construction industry. The findings showed that Tanzanian construction firms are vertically integrated in both ways, forward and backwards. The top three driving factors were increase in competition, quality improvement and client satisfaction. Whereas, nature of contracts, high investment cost, decrease strategic flexibility and increased business risk were the most mentioned challenges. The results of this study will contribute to the body of knowledge and will enhance the application of Vertical Integration in the Tanzanian Construction Industry. Additionally, the identified findings can assist industry practitioners and stakeholders interested in growing/expanding their business or adopting VI as a strategy to tackle some of the existing challenges (such as quality issues and delays) they have been facing. Likewise, these findings have created the need to address the challenges in order to support the growth of firms and the industry within Tanzania and other similar countries in Sub-Saharan Africa. On the other hand, the study recommends that, firms need to undertake strength weakness, opportunity and threat analysis before adopting vertical integration in order to be prepared and avoid the emergent challenges to realize the company objectives.

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CONSTRUCTING THE TEAM: A PERSONALITY-BASED PERSPECTIVE TO TEAM ABSORPTIVE CAPACITY

Bello Mahmud Zailani[1], Yahaya Makarfi Ibrahim[2], Muhammad Abdullahi[3], Afolabi Dania[4] and Mu'awiya Abubakar[5]

[1,2,3&5] *Department of Quantity Surveying, Ahmadu Bello University, Kaduna, Nigeria*

[4] *School of Applied Management, University of Westminster, London, UK*

Recent research has shown that personality traits can impact a team member's contribution to the team, which can in turn affect the team's absorptive capacity and performance. This paper provides theoretical foundations for the formulation of a model to explore how individual personality traits interact with relational learning activities to improve team absorptive capacity and performance based on the Myer's Briggs Type Indicator (MBTI) personality framework. It is argued that potential absorptive capacity which constitutes acquisition and assimilation capacities is influenced by the extroversion-introversion (E-I) and sensing-intuition (S-N) personality traits taxonomies of individual team members. Similarly, the individual thinking-feeling (T-F) and judging-perception (J-P) personality traits taxonomies were argued to influence realized absorptive capacity of the project team which constitutes transformation and exploitation capacities. The proposed interactions presented in this paper are based on a literature review, therefore empirical investigations are needed to validate the proposed arguments and relationships. Nonetheless, this paper can serve as a starting point for future academic efforts.

Keywords: Absorptive capacity; MBTI; personality traits; project; team performance

INTRODUCTION

Studies such as Vecchio *et al.,* (2016) in organizational behaviour have highlighted the significant effect of individual characteristics and perceptions towards team building and performance. Evidently, there has been an array of constructs in the modern management literature that have been argued to mediate the effect such characteristics and perceptions on team performance (Bjorvatn and Wald, 2018; Um and Kim, 2018; Eisenberg *et al.,* 2019). One of these constructs is absorptive capacity, which reflects a set of dynamic organizational routines and processes by which organizations acquire, assimilate, transform, and exploit work related knowledge. Such knowledge has significant bearing on the built environment as this is mostly delivered using project teams of diverse compositions. Previous studies such as Zailani *et al. (*2021) have explored the effect of project team absorptive capacity on improving the overall project team performance and project management

[1] bellomahmud34@gmail.com

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success. Bjorvatn and Wald (2018) established a positive effect of absorptive capacity on mitigating project constraints and improving performance. Leal-rodríguez *et al.,* (2014) in a study to model the distinct dimensions of absorptive capacity and effect on project team performance argued that the construct is characterised by two main components. The potential absorptive capacity, which include the ability to acquire and assimilate new information or knowledge, and realized absorptive capacity, which include the ability to transform and exploit new information or knowledge The study indicated that potential absorptive capacity has an important influence on realized absorptive capacity, positively moderated by relational learning activities such as sharing work experiences, and peer training amongst others that ultimately affect performance.

Although there is no contention that studying personality traits in relation to team performance is not a novel academic venture, the Big-Five framework of personality has been excessively used to assess the relationship between personality and team performance (Nowak 2018; Soomro *et al.,* 2016; Mammadov, 2022). However, noting the limitations of the Big Five personality studies, Carl Jung's theory of personality types (Jung, 1923) which serves as the foundation for the Myer's Briggs Type Indicator (MBTI) personality framework presents a differing approach to assessing team member's personality with regards to relational learning. The cognitive style MBTI psychological framework defines an individual's personality trait based on four psychological functioning typologies: sensing vs. intuition, thinking vs. feeling extraversion vs. introversion, judging vs. Perceiving. While personality traits such as extroversion, agreeableness, conscientiousness, emotional stability, and openness to experience have been argued to remain constant, and have a direct relationship with overall team performance (Roberts and Woodman, 2017), it is argued in this paper that the distinction of the Jung's theory (1923) makes the MBTI framework most suitable to study dynamic relational learning interactions between team members, with a view to assessing the individual cognitive characteristics of the team members and how it affects the team performance through mediating factors (Roberts and Woodman, 2017).

It is argued that relational learning activities that builds on team level absorptive capacity mediate the relationship between dynamic personality traits and team performance. Although Studies on absorptive capacity have been largely concerned with the construct as an aggregated, organizational or team level phenomenon, recent studies have called for the adoption of a micro-foundations approach by uncovering the actions and agency of individuals in absorptive capacity studies (Scuotto *et al.,* 2022; Knudsen *et al.,* 2022). This paper focuses on this perspective to build up its arguments.

LITERATURE REVIEW

Personality Traits and Performance

The nexus between personality traits and performance has been widely studied in the past, with many studies positing the influence of personality traits on the thoughts and decision-making processes of an individual, thereby dictating their behaviour and performance (Nowak, 2018; Judge and Zapata 2015). Nonetheless, (He *et al.,* 2019) noted that the construct of team or individual performance is broad and multidimensional, just as the indicators of personality traits are also multifaceted. Therefore, assessing the interaction between personality traits and performance may involve a certain level of variability, as certain dimensions of a specific personality trait could have more influence to specific performance metrics than others. For instance, dimensions of personality traits that promote dutifulness and self-discipline have been found to have stronger associations with the performance dimension that facilitates interpersonal relations and task dedication (Dundley *et al.,* 2016).

The premise of the Big-Five framework is that factors that include extraversion, agreeableness, conscientiousness, emotional stability, and openness to experience are poised to remain stable and consistent over time, which collectively predisposes an individual to behave in a certain way in all situations (Roberts and Woodman, 2017). Although (Furnham, 1996) highlighted the overlapping similarities between the Big-Five and the MBTI frameworks, Celli and Lepri (2018) found that the MBTI framework having 4 binary classes and 16 possible personality type combinations (Figure 1) is best suited for modelling performance dynamics that involves complex deep learning processes. According to McCrae and Costa (1989), the MBTI is distinct from other personality assessment frameworks, because of it being formulated from a classical theory, and it set out to measure personality type combinations, rather than continuous personality trait variables.

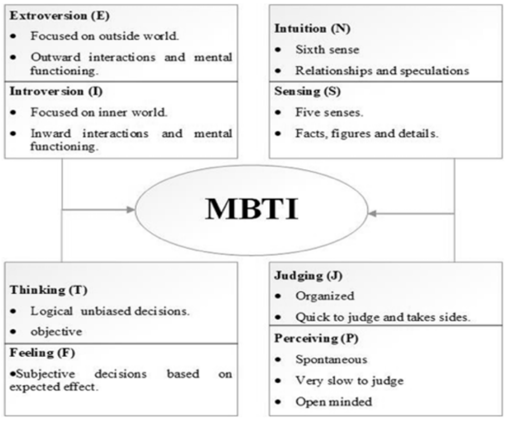

Figure 1: The MBTI Taxonomy

Relatedly, recent advances in technology, has prompted the adoption of machine learning approaches to modelling team dynamics such as personality traits towards optimizing performance (Ahmad and Saddique, 2017). Celli and Lepri (2018) argued that the MBTI framework performs better with the machine learning algorithms, yielding positive outcomes, and enabling data-driven performance optimizations. Similarly, Ahmad and Siddique (2017) studied the performance of gradient boosting algorithm trained with Kaggle MBTI dataset, reporting significant performance improvement.

Absorptive Capacity and Performance

Zahra and George (2002) conceptualized the construct of absorptive capacity as a set of dynamic organizational routines and processes by which organizations acquire, assimilate, transform, and exploit knowledge. Absorptive capacities are path-dependent and develop cumulatively, facilitated by communication between individuals and subunits (Cohen and Levinthal, 1990). Killen *et al.,* (2012) noted a sparing application of the absorptive capacity construct in the project management literature as opposed to organization-focused business literature. However, an established stream of literature views projects as temporary organizations (Burke and Morley, 2016). Also, Hobday *et al.,* (2000) opined that most or all business activities of an organization are undertaken in the form of projects. Thus, it is argued that the development of absorptive capacity in teams presupposes smooth knowledge exchange between individuals or project team members.

Table 1 depicts the four dimensions of absorptive capacity as conceptualized by Zahra and George (2002), which according to Sun and Anderson (2008) is a multi-level learning process directly related to the individual or organisation. In recent literature, these dimensions have been grossly classified into Potential Absorptive capacity and Realised absorptive capacity by Leal-rodríguez *et al.,* (2014). Potential absorptive capacity enables the organizations or project team to be receptive to both internal and external innovative knowledge. That is, to acquire, analyse, interpret, and understand this new knowledge. It involves the dimensions of knowledge acquisition and assimilation. Whereas, realized absorptive capacity reflects the organization's ability to transform and exploit the new knowledge, incorporating it, with existing knowledge, into its operations. This capacity is thus determined by the dimensions of knowledge transformation and exploitation.

Nowak (2017) observed the interactions between the two broad classifications of absorptive capacity, establishing a link between the ability to access and recognize the value of new knowledge or idea, and the ability to leverage on new knowledge or idea towards performance optimization. Volberda *et al. (*2010) argued that realized absorptive capacity enables the individual or team to be more responsive to novel knowledge, thereby further strengthening the dimensions of potential absorptive capacity. While Zahra and George (2002) posited that the creation and exploitation of novel knowledge or idea is the core of absorptive capacity formulation, it is argued that having weak internal mechanism of integration and learning could significantly hinder this process (Volberda *et al.,* 2010), ultimately leading to poor performance. The extent of such hindrance according to Chang and Shih (2019) remains relatively unclear, providing appropriate context to interpreting how the manifestation of novel knowledge is regarded as either an opportunity or a threat.

Nexus Between Personality Traits, Absorptive Capacity and Performance

Despite the popularity of absorptive capacity in the wider organizational management literature, there is an emerging interest among project management and team scholars to apply the construct (Bjorvatn and Wald, 2018). This is noting the similarities perceived between organizational and project team settings, with an established stream of literature perceiving projects as temporary organizations (Sydow, 2017; Burke and Morley, 2016). As noted by Zwikael and Unger-Aviram, (2010), the professional and organizational diversity frequently encountered in construction project teams represents a palette of original and novel perspectives that need to be assessed, assimilated, and applied by the project team collectively. Knippenberg and Schippers, (2007) noted the tendencies of diversity within teams to result in conflict of opinions and interests which diminishes ultimate performance. On the other hand, diversity has been reported to promote relational learning activities as it broadens the scope of knowledge and expertise within the team enabling innovative processes that yield improved outputs (Mitchell *et al.,* 2017).

Nowak (2020) argued that cognitive diversity, constituting the dimensions of personality traits significantly influences the ability of the team to assess, assimilate, transform, and exploit new knowledge towards performance improvement. Acquisition capacity emphasizes not only evaluation of the use of the knowledge, but also its transfer.

Table 1: Dimensions of Absorptive Capacity

	Dimensions	Components	Role/ Importance
Potential Absorptive Capacity	Acquisition	• Prior investments • Prior knowledge • Intensity • Speed • Direction	• Scope of search • Perceptual schema • New connections • Speed of learning • Quality of learning
	Assimilation	Understanding	• Interpretation • Comprehension • Learning
Realized Absorptive Capacity	Transformation	• Internalization • Conversion	• Synergy • Recodification
	Exploitation	• Use • Implementation	• Core competencies • Harvesting resources

This entails close personal interaction and mutual trust and respect between team members. However, considering the diversity often experienced in teams, the importance of being able to communicate in the language of others within a team to ensure knowledge assimilation has been highlighted (Pedrosa and Välling, 2013). The extroversion-introversion (E-I) and sensing-intuition (S-N) taxonomies of the Jung (1926) model collectively define individual perceptions and orientation towards generating and processing data. Thus, depending on the inclination of the team member towards extroversion or introversion for instance, the individual's capacity for perspective taking could serve as a means of overcoming interpretive barriers to successful knowledge integration, caused by the existence of different thought worlds inside the team (Distel, 2019).

Similarly, assimilation capacity is characterized by the team's ability to work together across professional and structural divisions (Zahra and George, 2002). Complementary skill sets and a common professional language aid the team in analysing and interpreting the new knowledge, thus ensuring timely and economical knowledge processing. To assimilate the acquired knowledge and obtain advantages from it, team members must interpret and comprehend the knowledge to finally learn it (Hussain *et al.,* 2022). In this regard, the cognitive characteristics and capabilities of individual team members could play a vital role in determining the collective absorptive capacity of the team (Knudsen *et al.,* 2022). This has a direct link to the team's ability to acquire new knowledge or ideas, as well as assimilate information which reflects the overall potential absorptive capacity of the team.

Also, potential absorptive capacity which constitutes acquisition and assimilation capacities of team members serves as the catalyst for exchanging and externalizing the tacit knowledge possessed by individual team members in the form of past experiences and lessons learned (Duffield and Whitty, 2016). This knowledge contributes to the project team's explicit and articulated knowledge and forms the bedrock for a mutual understanding between team members. As Leal-rodríguez *et al.,* (2014) found that potential absorptive capacity complements the formulation of realized absorptive capacity, the thinking-feeling (T-F) and judging-perception (J-P) personality taxonomies of the Jung (1926) model presents the opportunity for transformation and exploitation of new innovative knowledge within project teams (Rezaei-Zadeh *et al.,* 2022). Potential absorptive capacity grants individuals within the team with mutual access to pertinent information from their internal and external knowledge networks (Duffield and Whitty, 2016). This builds the team's absorptive capacity by enabling project team members to identify and acquire relevant external information through active networking (Biedenbach and Müller, 2012).

Ultimately, it could be argued that potential absorptive capacity increases the propensity to promote and implement new ideas for both the recipient and the sharer, which therefore enables the team to exploit relevant knowledge and information towards the achievement of team objectives (Yuan *et al.,* 2022). Both subsets of absorptive capacity could be seen to coexist and participate in the improvement of team performance. Teams cannot possibly exploit innovative knowledge without first acquiring it (Nowak, 2021). Also, transforming and exploiting acquired knowledge for performance improvement might be elusive when the team lacks the necessary cognitive traits to do so (Yuan *et al.,* 2022).

Test and Validation

Proposed Testing and Validation of Theorised Interactions

Evidently, there exist a variety of approaches and techniques adopted in literature to test and validate theoretical relationships as presented in this paper (Ye and Liu, 2021; Sharma *et al.,* 2019). Notably, Structural Equation Modelling (SEM) being a multivariate statistical method is often used to test and validate hypothetical relationships between different variables (Kaplan and Depaoli, 2012). It allows the assessment of both direct and indirect paths of influence between different variables, providing a weighted magnitude of the relationships which can provide insights into complex systems of relationships (Hair, *et al.,* 2010). Standardized measurement scales for MBTI personality traits (Myers, 1962), absorptive capacity (Jiménez-Barrionuevo *et al.,* 2011) and team performance (Rezvani *et al.,* 2019) could be used to measure the respective major constructs. Alternatively, abbreviated scales of personality have been used in organisational studies and validated in different empirical settings. As stated by Gosling *et al.,* (2003), short instruments of personality demonstrate respectable psychometric characteristics, suggesting that their use in research is justified. For absorptive capacity, the multi-item proposed by Jansen *et al.,* (2005) designed to capture various system's capabilities embedded in organisational structure, processes, and knowledge sharing routines could be used to accurately measure the construct and provide low explanatory power. Alternative measures for team performance include manager ratings, or peer ratings of team performance could be adopted although Conway (2001) highlighted that different perspectives may reflect somewhat different aspects of the criterion which could affect the reliability of the assessments.

Overall, adopting a SEM approach to testing and validating the hypothesised relationship between personality traits, absorptive capacity and team performance will provide empirical insights into the strength and magnitude of the relationships. Furthermore, deep learning techniques such as association rule mining could be used to uncover meaningful associations and patterns between dynamic personality traits and transient relational learning activities that define team absorptive capacity and performance.

CONCLUSIONS

This paper examined the distinct taxonomies of the MBTI personality types based on the Jung's theory, and how they relate to the dimensions of absorptive capacity. It is argued that potential absorptive capacity which constitutes acquisition and assimilation capacities is influenced by the extroversion-introversion (E-I) and sensing-intuition (S-N) personality traits taxonomies of individual team members. Similarly, the individual thinking-feeling (T-F) and judging-perception (J-P) personality traits taxonomies were argued to influence realized absorptive capacity of the project team. The theoretical interactions highlighted in this paper aims to trigger a discourse on the abstract relationship between individual's personality trait, and their ability to contribute to relational learning activities which builds team absorptive capacity and influences team performance. Moderating constructs such as team absorptive capacity, having expansive factors are argued to provide deeper insights into the relationship between personality and team performance. Overall, it is duly acknowledged that the arguments presented in this paper are limited by the theoretical foundations established, and the lack of empirical data to test their validity and reliability. Nonetheless, it is believed that the paper could serve as a foundation for future academic efforts to ascertain the empirical dynamics of the relationships.

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SIMILARITIES, INTENT, AND EMPHASIS: ALIGNMENT OF INTERNATIONAL ETHICS PRINCIPLES WITH BUILT ENVIRONMENT PROFESSIONAL STANDARDS IN GHANA

Samuel Mamphey[1], Andrew Knight and Emmanuel Manu

School of Architecture, Design and Built Environment, Nottingham Trent University, 50 Shakespeare Street, Nottingham, NG1 4FQ, UK

Professional codes of conduct establish the ethical rules and parameters within which built environment professionals operate. In 2021, the IESC published the first-ever global ethical standards for the built environment sector. The ability of global ethics standards to promote parity and greater ethical practice has been a subject of extensive debate. A year on since its adoption, there is little understanding of the global acceptance and uptake of the standards. Focusing on sub-Saharan Africa, the extent to which the existing built environment standards in Ghana are aligned with the global standards has been examined in this paper using a qualitative research approach based on content analysis of ethics standards. The study identified similarities and differences between the global standards and the codes of ethics for the following Ghanaian professions (engineers, architects, and surveyors). Some common elements were also identified, indicating that some rules are indeed universal and culture free. Yet, ethical principles in all the standards examined were also sometimes explained differently in terms of intent and emphasis of the rules.

Keywords: ethical standards; professional bodies; code of conduct; Ghana

INTRODUCTION

The primary aim of the International Ethics Standards Coalition (IESC) is to promote and maintain universal ethical standards for the built environment sector, across different geographical locations (IESC, 2021a). Globally, there are approximately 120 professional bodies, associations and standards setting organisations, who are full members of the IESC (IESC, 2021b). Around 155 others have also openly declared support for these International Ethics Standards (IES) including governmental organisations, academic institutions, and several other businesses (IESC, 2021c). In an increasingly globalised and interconnected world, these universal ethics principles aim to provide consistency across markets and encourage professional organisations to follow the same set of ethical standards wherever in the world they operate. Without guidance from a unified set of ethical principles, professionals who operate on a globalised scale must adapt to different ethical environments in the different jurisdictions within which they conduct business, presenting a dilemma where moral

[1] sam.mamphey@ntu.ac.uk

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clarity is often blurred (Peperkamp, 2019). To attain this goal, professional bodies in the built environment sector must adopt and integrate the IESC principles into their existing codes of ethics or conduct. The modified codes would then have to reflect the high-level principles in the IESC standards, such that the globalised ethical environment would not differ materially from country to country. Although the standards are developed for the global built environment sector, it is unclear if the IESC standards mainly reflects the norms and values associated with the western societies from which it was initiated or even which unified set of ethical standards are most pronounced. Past research that investigated the adoption of global ethics standards in professions such as engineering (Alzahir and Kombo, 2014) and accounting (Espinosa-Pike and Barrainkua-Aroztegi, 2014; Barrainkua and Espinosa-Pike, 2015) suggests that adoption of some principles in a global code of ethics can be constrained by the sociocultural factors in the host country. A key research question that was raised, and which is pursued in this study is on the universality of the IESC ethics principles in terms of how it aligns to codes of ethics in Ghana's built environment sector.

The aim of the study was therefore to investigate the IESC principles in terms of their alignment or non-alignment to the codes of ethic used in the Ghanaian built environment sector. The rest of this paper is structured as follows. The next section presents a discussion on efforts to standardise ethical practices in the built environment sector, followed by the methodology adopted for the study. The findings are presented based on which conclusions have been drawn.

Global Ethics Principles in the Built Environment.

Built environment professionals must make ethical choices in their practice daily. Globally, these choices are regulated and judged by the professional bodies to which these practitioners belong. The regimes of regulation are usually contained within a code of ethics which guides professional behaviour. Irrespective of their common heritage as built environment professions, the various disciplines within the sector operate separate codes of ethics reflecting the ethical conditions of the countries within which they operate. Indeed, noticeable disparities can also be seen in the codes of professional bodies operating even within the same country. The result of this is that there are broad inconsistencies in the spirit, letter, and application of the codes of ethics for built environment professionals from one location to the other. This imposes some difficulty on professionals who operate across different geographical boundaries (Ast, 2018). Differences can also be discerned in the degree to which the codes are enforced especially when comparing developed economies with developing economies (Rossouw, 1994). Rachels and Rachels (2012) explained that human values are inextricably tied to the cultural background within which they are forged.

In practice, this means that communities that are similar socio-culturally are likely to share ethical views, while those from diverse cultures are less likely to agree on ethical perspectives. Ethical relativism is a belief that morality varies from one culture to another and that what is deemed ethical in one culture may be considered unethical in another (Airoboman and Thomas, 2021). Proponents of this concept argue that there can be no single framework within which to judge ethical conduct. This view is contested by moral realists (FitzPatrick, 2022) who espouse the notion of ethical objectivism, a belief that the ethical domain is to be understood on a realist model. Thus, moral judgements are absolute and not dependent on extraneous factors. Some argue that taken to the extreme, ethical relativism can become ‘convenient relativism' whereby all sorts of behaviours can be justified under the banner of ethical relativism (Parboteeah and Cullen, 2017). Notwithstanding this debate, some professions such as accounting (IESBA, 2015), auditing (IIA, no date), legal (IBA, 1988) and medical (WMA, 2022) operate a universal code of ethics for their practitioners around the world. The IESC seeks to replicate this practice for the global built environment sector. The challenges associated with the implementation and enforcement of global standards are well documented (see Vanasco, 1994) and highlights the significance of cultural alignment as a key factor in the implementation these standards. Thus, the effort required to smoothly adopt and implement the IESC standards in Ghana depends on how well the existing Ghanaian professional ethics codes already align with the IESC principles.

METHOD

A qualitative content analysis of the code of ethics for built environment professional bodies in Ghana, UK and the USA was undertaken. The choice of the USA and the UK for analysis was influenced by the significant similarities between the operational structures, practices, and procedures of Ghana's construction industry and that of those countries (Osei, 2013). From the UK and the USA, the codes examined comprised those that existed before, as well as those issued after the adoption of the IESC standards. The Ghanaian codes examined were from before the adoption of the IESC standards since no updates have yet been issued following the adoption the IESC standards. The codes of conduct selected for examination represented those from three key professional groups in the built environment industry, Architects, Engineers, and Quantity surveyors.

The decision to utilise the code of ethics from these three professional groups was primarily driven by a need to ensure that the professions selected from Ghana had their direct comparable opposites in the selected Western countries. This alignment was done to limit or minimise any potential inconsistencies and ensure that the subject of this comparison (the code of ethics) is guided by the same or similar professional practices in both countries. The codes were directly obtained from the professional bodies themselves or from their websites.

Employing a content analysis methodology, a key objective of the researchers was to elicit or decipher meaning from collected data to draw realistic conclusions from it (Kleinheksel *et al.,* 2020). The methodological approach considered the context in which the occurrences of words, phrases, and sentences were recorded for analysis, discussion, and to provide an in-depth understanding (Boettger and Palmer, 2010). Using a deductive approach, the researchers adopted the 12 principles within the IESC standards to create thematic categories which formed the basis for analysing the rules and provisions found in the selected codes of ethics. The following steps were followed:

1. Constructing a coding frame using the 12 categories based on the IESC principles.
2. Line by line coding of the pre-existing UK/USA professional codes using the coding frame.
3. Line by line coding of the updated UK/USA professional codes using the coding frame.
4. Line by line coding of the Ghanaian professional codes using the coding frame.

The analysis began with the exploration of similarities and differences. Where similarities were identified, further analysis was undertaken to assess the intent and emphasis placed on these principles within the different codes of ethics in Ghana. This is also reflected in the frequency of citation analysis undertaken for the codes of ethics in the Ghanaian built environment sector, as the main unit of analysis.

FINDINGS

This section presents the content analysis results showing comparisons of the IESC standards against the existing codes of practice in the UK, USA, and Ghana.

Comparison of the IESC Standards and Pre-Existing Codes in the UK and USA

A comparative analysis of the code of ethics for the Royal Institute of British Architects and the American Institute of Architects shows that their codes pre-existing to the adoption of the IESC standards were already in consonance with the global principles as they would come to be established.

Table 1: Comparing IESC global standards with codes of ethics of RIBA (UK) and AIA (USA)

IESC Global Standards	Architects (AIA) - USA	Architects (RIBA) - UK
Version	2020	2019
Accountability	✓	✓
Confidentiality	✓	✓
Conflict of Interest	✓	✓
Diversity	✓	✓
Financial Responsibility	✓	✓
Integrity	✓	✓
Lawfulness	✓	✓
Reflection	✓	✓
Respect	✓	✓
Standard of Service	✓	✓
Transparency	✓	✓
Trust	✓	✓

As shown in Table 1, prior to the adoption of the IESC standards, all twelve (12) of the IESC principles were fully represented and adequately catered for, in the existing codes of ethics for the two professional bodies. This shows that the IESC standards closely mirrors the ethical framework that exists in those societies.

Comparison of the IESC Standards to the Updated Codes in the UK

Within the UK, at least three professional bodies, including the Royal Institute of British Architects (RIBA), Royal Institution of Chartered Surveyors (RICS), and the Institution of Civil Engineers (ICE), have modified and published updated versions of their codes, following the ratification and adoption of the IESC principles in 2021. The UK experience demonstrates that adaptation has been easier for UK professional bodies. This is mainly because these organisations already possessed baseline ethical ideals and aspirations that closely resembled the standards within the IES. As shown in Table 2, the three UK professional bodies have modified their standards and now have codes that are compliant with the ethical principles within the global standards.

Table 2: IESC compliance comparison of old and new versions of UK codes

IESC Global Standards	Surveyors (RICS)		Engineers (ICE)		Architect (RIBA)	
	Version 2012	Version 2022	Version 2017	Version 2022	Version 2019	Version 2021
Accountability	✓	✓	✓	✓	✓	✓
Confidentiality	✓	✓	✓	✓	✓	✓
Conflict of Interest	✓	✓	✓	✓	✓	✓
Diversity	✓	✓	✓	✓	✓	✓
Financial Responsibility	✓	✓	✓	✓	✓	✓
Integrity	✓	✓	✓	✓	✓	✓
Lawfulness	✓	✓	✓	✓	✓	✓
Reflection	✓	✓	✓	✓	✓	✓
Respect	✓	✓	✓	✓	✓	✓
Standard of Service	✓	✓	✓	✓	✓	✓
Transparency	✓	✓	✓	✓	✓	✓
Trust	✓	✓	✓	✓	✓	✓

A closer examination of their modified codes revealed that not only are they compliant with the IESC standards, but that they also reflect the spirit and focus of the IESC principles. Notwithstanding efforts by the IESC to promote the widespread adoption and implementation of these standards, the evidence suggests that the push to adopt and implement the standards will be considerably much smoother in regions of the world where existing standards are already comparable to the IESC principles.

Comparison of the IESC Standards and the Ghanaian Codes

An evaluation of the Ghanaian codes predating the adoption of the IESC standards reveals that they do not reflect certain key principles within the IESC standards. This is in sharp contrast to the findings obtained from comparing the codes in the UK and the USA with the IESC standards. Even though the IESC standards were ratified and adopted in 2021, professional bodies in Ghana have not yet taken any steps to update their professional codes of ethics to incorporate the new global standards. A key question that arises is whether the Ghanaian professional bodies also view the issue of global standards with the same urgency and importance as their western counterparts. Indeed, a significant portion of the drive and ambition to create and implement a unified set of global ethics standards in the built environment sector has arisen from western societies (ISURV, 2017) prompting some such as Chattopadhyay and De Vries (2008), to question their underlying reasons and motivations for undertaking such initiatives. Table 3 highlights the areas of differences and similarities between the IESC standards and the existing standards originating from the Ghanaian built environment professional bodies.

Data in the table suggests that there are many topical areas where the professional codes of ethics of the Ghana built environment bodies broadly reflect the IESC standards. Indeed, on principles such as conflict of interest, financial responsibility and integrity, all three Ghanaian codes seem to largely follow the IESC standards in their scope. However, even where the rules seem similar, some contextual misalignment can sometimes be discerned. For example, regarding respect, both the IESC and the Ghanaian professional bodies demand consideration for others. However, the IESC standards go further to include discrimination and prejudice in its scope of expectations. The Ghanaian codes on the other hand are silent and do not address these two concepts in any way.

Table 3: Comparison between the IESC standards and the three Ghanaian standards

IESC Global Standards	Surveyors (2007) (Frequency of Citations)	Engineers (2012) (Frequency of Citations)	Architects (2016) (Frequency of Citations)
Accountability	✓	✓	✗
Confidentiality	✓✓	✓	✗
Conflict of Interest	✓✓✓✓	✓✓✓	✓✓✓
Diversity	✗	✗	✗
Financial Responsibility	✓✓✓	✓✓✓	✓✓
Integrity	✓✓✓✓✓✓	✓✓✓✓✓✓	✓
Lawfulness	✗	✓✓	✗
Reflection	✗	✗	✗
Respect	✓	✓	✗
Standard of Service	✓✓✓✓✓✓✓✓	✓✓✓✓	✗
Transparency	✓✓	✗	✗
Trust	✓✓✓✓✓	✓✓✓	✗

Other features of the IESC standards such as rules relating to accountability, confidentiality, lawfulness, respect, standard of service, transparency and trust appear in at least one of the codes of ethics, although they are not present in all three of the Ghanaian codes examined. This points to a lack of uniformity in the ethical codes of ethics guiding built environment professionals within the Ghanaian context. This is unsurprising and rather consistent with the findings of Langlois and Shlegemilch, (1990) who indicated that there can be significant differences in the approach to ethics even amongst people who share similar cultural orientations. Out of all three codes, that of the GIA was identified as having the least alignment with the IESC standards. The GIA code only aligned with the IESC standards in the areas of conflict of interest, financial responsibility and integrity.

Two of the IESC's guiding principles were missing from all three Ghanaian codes. These are related to the principles of diversity and reflection. In addition to requiring practitioners to complete CPD to maintain and advance their professional skills, the IESC standards included a second concept on reflection. This obligated practitioners to reflect on their work to ensure that it is consistent with the evolving nature of ethical principles and professional standards. It is possible to argue that the point that one's practice must be consistent with evolving ethical principles and professional standards is captured in the obligation to complete CPD as stipulated in the Ghanaian codes. For the purposes of comparison, however, it is worthy to note that reflection as an IESC concept is accurately and separately captured in the codes emanating from both UK and USA professional bodies. This variation can be corrected by the Ghanaian codes of ethics stating an explicit requirement for the CPD undertaken by practitioners to include content on the evolving nature of their ethical responsibilities. The exclusion of diversity from the Ghanaian codes could be traced to the cultural environment in the country, which is like the situation that pertains in other parts of the African continent. Although Africa is the continent with the most diverse populations and has over 1000 different ethnic groups (Awedoba, 2005) the amount of research on diversity and inclusion management is relatively low (Appiah and Adeyeye, 2021). As a society, Ghana is multi-ethnic, multi-religious and multicultural and is estimated to have over 90 ethnic groups (Asante and Gyimah-

Boadi, 2004). Yet, corporate Ghana has a low appreciation and understanding of the subject of diversity and inclusion management (Appiah and Adeyeye, 2021). The broad commonalities between the different ethnic groups in the country obscure the differences between them making it harder to identify discrimination. Owing to this and other factors, Ghanaian society at large has failed to grapple with the issues of discrimination and marginalisation to the same degree that western societies have and continue to do. The same can be said of discrimination against sexual minorities (Akinwotu, 2021), gender discrimination (Akotia and Anum, 2015) and people living with disabilities (Ocran, 2019). The absence of these issues from the cultural conversation and as matters of vigorous debate may account for the inability of the professional bodies to include it in their codes. However, discrimination against minorities in Ghana exists and the built environment sector will not be immune from its effects. Provisions for diversity will need to be included in the Ghanaian codes if they are to be brought into conformity with the spirit and letter of the IESC principles.

Specificity

Provisions found in the Ghanaian codes but are missing from the IESC standards are outlined in Table 4. For example, items 2, 4 and 12 in the table do not directly relate to any of the IESC standards. On the other hand, items 6, 7, and 10 are examples of Ghanaian provisions that go even further but could be related with the IESC's broad ideals on giving due attention to social and environmental considerations (accountability) and treating others with consideration, avoiding acts that will damage the wellbeing of others (respect). Item 9 which is a provision in the Ghana Institution of Engineers' code enjoins members to recommend specialised professionals to undertake roles where needed. This can be said to be an expansion of the IESC standards that requires professionals to only take on assignments for which they are adequately qualified and trained. Similarly, item 11 also from the Ghana Institution of Engineers stipulates that members are not to get involved with payments on projects. This is an even more explicit provision than the IESC standard on financial responsibility which merely calls on practitioners to be truthful, transparent, and trustworthy in financial matters. The specific and granular provisions of the Ghanaian codes suggests that they were written with the intention of resolving context-dependent ethical concerns that are prevalent in Ghana. Those issues while relevant in the Ghanaian context may not necessarily be applicable to other jurisdictions to merit their inclusion in a globalised set of ethical standards.

Al-Aidaros *et al.,* (2015) and Allen (2010) presented and discussed a two-pronged approach to ethical code building. The first approach, known as the conceptual framework approach, establishes high-level overarching principles that may be applied to evaluate ethical behaviour and to determine compliance with the fundamental principles of a code. In contrast, the second component known as the rules-based approach, stipulates de facto rules that must be followed in an absolute manner. Utilising the conceptual framework approach, (also sometimes referred to as a 'principles-based' code (Allen, 2010), the IESC standards provides a set of shared high-level ethical principles. It will be inconceivable then for the IESC to anticipate and accommodate all matters of ethical concern, especially those that have peculiar country or culture-specific implications. Consequently, comparisons and efforts to evaluate whether the Ghanaian codes are in conformance with the IESC standards should be based on whether the Ghanaian codes incorporate all the guiding principles that are included in the IESC standards. Ultimately, the responsibility lies with professional bodies who are members of the IESC to ensure that the specific details within their codes adhere to the core concepts of the IESC standards.

Table 4: Standards found in only Ghanaian codes

	Standards in Only Ghanaian Codes	Surveyors	Engineers	Architects
1	Contribution to charitable objectives	✓	✓	
2	Guidance on solicitation for work	✓	✓	
3	Guidance on taking over work started by a fellow professional	✓	✓	✓
4	Guidance on promotion of services offered	✓	✓	✓
5	Not to collaborate with members who are not in good standing	✓		✓
6	Not to supplant fellow professionals	✓		✓
7	Exercise restraint in criticising fellow professionals in public		✓	
8	Adhere to laid down whistleblowing procedures		✓	
9	Recommend client engages specialist skills where required		✓	
10	Respect for cultural heritage		✓	
11	Not to get involved with payments on projects		✓	
12	Advise client of consequences of overruling professional judgement		✓	

A comparison of the IESC standards with the Ghanaian codes revealed some elements of the IESC standards were already in the Ghanaian codes. For some of these however, some variation could be discerned in the context and focus. Some elements, such as diversity and reflection, were completely absent from the Ghanaian codes, while some aspects from the Ghanaian codes did not make it into the IESC standards. This can be traced to the fact that there are unique cultural and ethical considerations within the Ghanaian context which were unaccounted for in the IESC standards.

CONCLUSIONS

A successful implementation of a universal set of ethics standards for the built environment profession would result in several clear advantages and benefits. Notwithstanding the considerable global engagement prior to the establishment of the standards, this study shows that the global standards are more aligned with western codes than they are with the Ghanaian codes. More work would be required to adapt and implement the standards in Ghana than in regions where the IESC requirements are already comparable to existing standards. The professional bodies will need to update their professional codes of ethics to accommodate and integrate the elements of the IESC standards that are not present in their codes. They will also need to re-orient their members, through targeted CPD activities, on the revisions and the implications for their practice. The primary shortcoming of this study is that its emphasis is based entirely on the examination of secondary data. It is therefore limited by the lack of input from experts and professionals within the Ghanaian built environment sector. There is a need for further research that involves the collection and analysis of primary data. This could provide a deeper understanding of contextual issues and allow better insight into the possible challenges and how they can be addressed for the successful adoption and integration of the IESC standards. This work is currently being undertaken as part of a larger research effort.

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IMPACT OF PROJECT QUALITY CULTURE ON DEFECTS IN INFRASTRUCTURE PROJECTS

Darren Edson Mukwanason[1], Apollo Tutesigensi[2], Muzafalu Kayondo[3] and Harrison E Mutikanga[4]

[1&2] *School of Civil Engineering, University of Leeds, Woodhouse Lane, Leeds, LS2 9JT, UK*

[1,3&4] *Uganda Electricity Generation Company Limited (UEGCL), Okot Kiwanuka close, Kampala, PO Box 75831, Uganda*

A Quality Management System (QMS) compliant with the ISO 9001 requirements is a necessity for the bidders of most Engineering Procurement and Construction (EPC) type contracts in developing countries - to ensure quality assurance and quality control during project implementation. However, construction defects and rework continue to torment infrastructure projects despite the ISO 9001 certification of the key project players (client, consultant, and contractor). This research investigates the mismatch between an ISO-9001-certified QMS and quality-related poor performance in infrastructure projects. A single case study approach was adopted, and project documentation was scrutinised using thematic analysis. Frequency analysis was then used to identify project cultural factors contributing to poor-quality performance, which were later analysed against the ISO 9001:2015 principles of quality management using qualitative software. Recalcitrant Project Quality Culture (PQC) was found to be a key cause of the defective work. Hence, we argue that honest and cooperative implementation of a tripartite PQC would reduce the severity of defects and rework in EPC construction projects.

Keywords: defects; infrastructure; ISO 900; project performance; quality culture

INTRODUCTION

The ISO 9001 quality management guidelines are one of the most internationally accepted quality management standards in the manufacturing and construction industries (Okudan and Budayan, 2021; Chini and Valdez, 2003). Among others, some of the benefits of ISO certification are improved quality performance, which translates into customer satisfaction (Psomas and Kafetzopoulos, 2012) and better company reputation (ISO, 2015). Nonetheless, some studies have shown that some contractors attain ISO certification as a marketing tool to increase their competitiveness and win over contracts (Hadidi *et al.,* 2017) and not for the sake of the perceived improvement of organisational quality performance. The certification process involves a third-party agency which audits a company's existing quality management processes to assess whether the company qualifies for the certificate. Certificates are only issued for ISO 9001, which outlines the requirements of a quality

[1] mukwanasond@gmail.com

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management system. These certificates are periodically renewed and are subject to change (Hadidi *et al.,* 2017): they may be renewed, suspended, or even withdrawn.

An ISO 9001-certified quality management plan (QMP) is often a prerequisite for most bidders for EPC-type infrastructure projects as mitigation against poor-quality performance. Despite these efforts, defects and rework continue to plague infrastructure projects (Wu, 2014) resulting in poor quality performance (Mutikanga *et al.,* 2023) and adversarial relationships between clients and contractors (Kanji and Wong, 1998; Love and Edwards, 2004). In this paper, we investigate the cause of the disconnect between an ISO-9001-certified QMP and poor-quality performance on an infrastructure megaproject.

Quality Management in Projects.

Defects and Quality Performance

In the 6th Edition of '*A guide to the project management body of knowledge'*, a defect is defined as *an imperfection or deficiency in a project component where that component does not meet its requirements or specifications and needs to be either repaired or replaced*. Chong and Low (2006) categorises defects into patent and latent defects. Patent defects are those that can be easily identified by mere visual observation, such as surface cracks in concrete, whereas latent defects are those that can only be identified through specialised tests. Latent defects typically manifest after some time of occupancy (Chong and Low, 2006) such as insufficient reinforcement which may lead to structural failure after a given period. A defect is not usually an outcome of a single cause but rather occurs when multiple interrelated causes combine forming a defect's pathway (Aljassmi *et al.,* 2015; Love and Edwards, 2004). It is therefore prudent to establish the underlying causality of the defect (Love and Edwards, 2004) through proper investigation of the multiple causal factors (Chong and Low, 2006). In infrastructure projects, a QMP defines the procedures and measures required to prevent, correct, and control the recurrence of defects. A QMP outlines the quality assurance and quality control measures as proposed by a contractor. Therefore, quality is achieved through the implementation of quality management standards such as ISO 9001:2015 and total quality management, which outline the processes to achieve quality performance (Egwunatum *et al.,* 2022). The implementation of these quality guidelines involves interactions between people and processes and can therefore be seen as a social culture (Ankrah, *et al.,* 2009).

Project Quality Culture

Different researchers have studied the influence of organisational culture on quality performance (Cronemyr *et al.,* 2017; Okudan and Budayan, 2021), however, there is still a paucity of information on project quality culture due to the inherent uniqueness of projects. To contribute towards closing this gap, this study also seeks to investigate the impact of PQC on defects in a single case study. In general literature, culture refers to the shared values, group behaviours, and norms (Kotter and Heskett, 1992) or the values, rituals, heroes, and symbols (Hofstede, 1997) which bind a group. From the ISO perspective, culture is seen as the beliefs, history, ethics, observed behaviour, and attitudes that are interrelated with the identity of an organisation (ISO 9004: 2015). However, Schein argues that *culture is a pattern of basic assumptions learned by a group as it solved its problems of external adaptation and internal integration, which has worked well enough to be considered valid and, therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to those problems* (Schein 2010). These varying definitions portray the vast dimensions, elements and complexity of the subject of culture (Ankrah *et al.,* 2009). Generally, culture may be studied at four distinct levels; macrocultures (nations, global occupations, ethnic and religious groups); organisational cultures (private, non-profit, and government organisations), subcultures (occupational groups within organisations); and microcultures which are the microsystems within organisations (Schein, 2010). At all these levels, culture is manifested through the three dimensions of artefacts, espoused beliefs and values, and underlying basic assumptions (Schein, 2010). Artefacts consist of the phenomena that can be seen, felt or heard when one encounters an unfamiliar culture (*ibid*). The visible artefacts may include; *language*; artistic creations (*tangible artefacts*); *group norms*; observable rituals and ceremonies; *observed behaviours* which are made routine through organisational processes, structural elements such as charters, and organisation charts (Schein, 2010). For example, at a national level, group norms may comprise the government policies such as national development plans, whereas, at a microculture level (project level) these comprise things like construction quality management plans. Some macroculture aspects such as language, may still manifest at the organisational and microculture level. For example, the national languages of most countries are often adopted as administrative languages on most projects. On the other hand, espoused values are the publicly communicated principles and values that the organisation claims to be trying to achieve (Schein, 2010), such as "equality for all" at the national level or "product quality" at the project level. Finally, the underlying assumptions are those things that are usually known, but are not discussed, nor are they written and so cannot be easily found (*ibid*). These include unconscious thoughts, perceptions, and feelings and are therefore more difficult and complex to study. Simply put, culture at the macroculture level is what a foreign tourist would encounter when they visit a new country such as the architecture, and political climate. On the contrary, culture at the organisational and microculture level are the things an external consultant would encounter whilst visiting a new organisation, like quality management practices, leadership styles, and communication methods. Ankrah *et al.,* (2009) argue that organisational cultural dimensions can be contextualised based on their relevance to a particular setting. Considering a project as a temporary organisation (Müller *et al.,* 2016) we treat construction quality management as a microculture within a project by relying on the cultural dimensions of *language, tangible artefacts, group norms*, and *group behaviour*, already described above, to establish the impact of PQC on defects. Microcultures are variable and dynamic, and thus present special opportunities to study culture formation and evolution (Schein, 2010).

METHOD

Case Study Selection

A single case study approach is used through purposive sampling, a non-probability method, to carefully select a case study with the requisite characteristics to address the research question (Saunders, 2018). The case study is a complex infrastructure project in a developing country, herein anonymised as Project E. The project cost is over $500M, with a construction period of 40 months. Project E has a contractual defects liability period (DLP) of 2 years for notification of observed defects. The DLP is extendable by another 2 years subject to contract interpretation. The project is implemented under a modified EPC-type contract where the Contractor is charged with engineering, procurement, and construction. Therefore, the final quality of the delivered project is significantly dependent on the Contractor's quality performance. The project presented numerous defects during its construction and post-handover period which makes it suitable for the study. Additionally, all the major players—the Contractor, Consultant(s) and the Implementing Agency (the Agency)—involved in the project implementation possess ISO 9001-certified quality management systems. This case study is found appropriate and is tailored to the context of the research question (Saunders, 2018; Yin, 2018) to capture the complexity and dynamism of the organisational set-up in projects (Love and Edwards, 2004). The failure of a concrete hydraulic structure in Project E is used for an in-depth investigation of poor-quality performance through the assessment of defect causality. The notation of "t(0)" is used to represent the project commencement date, and "t(x)" is used to indicate the elapsed project duration, where "x" is the number of months elapsed from "t(0)". This notation is used to show a cause-effect relationship.

Roles of the Different Project Players.

The Client is the government of Country A. The Client delegated contract administration powers to an implementation agency (the Agency). Despite the Agency being ISO 9001 certified, this was not a contractual requirement. The Consultant's role is to supervise the Contractor's works in accordance with the ISO 9001 quality standard. It is a contractual requirement for the Contractor to implement an ISO 9001-certified Quality Management Plan (QMP). However, it is the Consultant's duty to review and approve all the Contractor's submissions before the execution of works, including the review and approval of the QMP. The Agency is responsible for the overall supervision of the project and contracted a Panel of Experts (Experts) and a Project Management Consultant (PMC) for additional technical support. The Experts typically advise the Client on quality-related and project implementation challenges based on the construction industry's best practices.

Data Collection

Uncompiled secondary data were systematically collected (Saunders, 2018) from Project E. This included multiple documentary information to ensure that the data were stable, unobtrusive and specific (Yin, 2018). The collected data comprised of; project QA/QC reports; quality-related correspondences from the Agency, Contractor, and Consultant; non-compliance reports; DLP reports; root-cause analysis reports; contract documents, Client's Requirements; Contractor's QMP; minutes of meetings, and relevant newspaper articles. This is congruent with the ISO recommended potential sources of nonconformities; (1) internal or external audit findings (2) monitoring and measuring results e.g., inspections (3) nonconformity outputs (4) customer complaints (5) noncompliance with statutory and regulatory requirements (6) problems with external providers (7) employee identified problems (8) observations from a superior or responsible person or process patrols, and (9) warranty claims. Yin (2018) argues that documentary evidence sometimes leads to biased selectivity culminating in biased reporting. To circumvent this, we studied the secondary project data holistically in its entirety and substantiated it through Expert reports and independent audit reports.

Data Analysis

The Contractor's QMP outlined the processes and controls to deliver Project E in accordance with the Client's Requirements. In this case, secondary data were used to undertake a retrospective analysis of the Contractor's compliance with its QMP. An interpretivist philosophy was used to inductively identify evidence of non-compliance and to draw inferences. The data were coded using Nvivo, a computer-aided qualitative data analysis software (CAQDAS), to facilitate data analysis and identification of relationships and patterns (Saunders, 2018). Further fragmentation of the data was done using thematic analysis for a systematic and flexible examination (Braun and Clarke, 2006) based on the constructs of quality culture. An abductive approach was employed to generate topics (Saunders, 2018) in relation to the ISO quality management principles. Frequency analysis was then undertaken, qualitatively, to group the findings into themes based on the dominant constructs of project culture. These are; (1) *group behaviours* (2) *quality norms* (3) *tangible artefacts,* and (4) *language* (Schein, 2010). The tangible artefacts include the standard project documentation as stipulated in the contract. The project norms and behaviours were identified through the documented quality practices and challenges in the project reports. The amalgamation of the ISO quality management practices and the identified constructs of culture was used to inductively establish the project quality culture (PQC) in Project E. Such a metaphorical approach provides an in-depth understanding of the underlying culture of the project (Cameron and Quinn, 2011).

FINDINGS

The manifestation of the cultural dimensions of group behaviours, quality norms, tangible artefacts and language are detailed in Tables 1, 2, 3, and 4 respectively. The PQC that manifested in Project E is compared against the expected ISO quality management practices to illustrate the causality of the failure of the concrete hydraulic structure.

Table 1: Implication of the group behaviours on defects and rework on the concrete hydraulic structure

ISO recommended practice	Identified practices in Project E	Implication of behaviours on defects/rework
Evidence-based decision making by carrying out preventive action to eliminate potential nonconformities	Widespread execution of rework without root-cause analysis reports	This resulted in defect recurrence and rework
	It was noted in one of the Expert reports that "many of the concrete defects have been repaired without an approved plan using unacceptable procedures and methods" [noted at t17]	This resulted in latent defects as noted in Audit Report 3 stating, "The repairs have already been completed incorrectly… cavitation could occur and cause additional damage to the concrete." [noted at t17]
Training of workers to uphold competence	Extensive deployment of incompetent workers was evident in the poor concrete works performed across the site	The extensive poor workmanship accelerated defect development
Adequate process control to meet project requirements	Understaffed QA/QC team which was inadequate to enforce compliance to the Requirements	This led to development of latent defects due to compromised defect identification capacity
	This was echoed in Expert Report 4 stating, "neither the Contractor nor the Consultant have sufficient mechanisms in place to provide the required level of quality assurance and quality control for this project. Processes appear lax, lack the required independency from construction/production, and are understaffed" [noted at t17]	One audit report captures the implications as follows, "the Consultant has failed to properly supervise the concrete placements and curing allowing the Contractor to continue the unacceptable practices without correction." [noted at t29]. This bred more concrete defects.
Continual improvement	Poor attitude toward quality improvement recommendations	This resulted in accelerated structural deterioration of the concrete works.
	According to the PMC, there were no reports documenting the crack repairs undertaken on the concrete hydraulic structure on the project. [noted at t17]	One Audit Report noted that there was a poor record of repair activities performed which made it harder to port-examine the causes of the defects and thus their recurrence. [noted at t29]

Table 2: Implication of the quality norms on defects on the concrete hydraulic structure

ISO recommended practice	Identified norms in Project E	Implication of norms on defects/rework
Conformity to method statements to implement what was planned - PDCA	Works were being executed without approved method statements	Resulted in the cracking of the concrete surfaces due to the application of subpar methods
	One audit report stated, "concrete repairs being performed by the Contractor for removal of form ties do not follow the procedures indicated in the Contractor's own Concrete Defect Treatment Plan." [noted at t17]	This resulted in rework as was predicted in one of the Expert reports stating, "the repairs will fail in a short period of time due to the edges being too thin and the width to depth ratio too large." [noted at t22]
Due consideration of standards and codes	Widespread ignorance and misinterpretation of standards and codes by the Contractor's workers	This resulted in the sealing off of the concrete-slab expansion joints and hence rework
	For example, it was identified that concrete was being placed in lifts of 3 metres without any temperature control mechanisms in place contrary to the Client's requirement to place concrete in 1.5m lifts. [noted at t10]	To quote "The results are significant thermal cracking in many of the placements. Significant cracks have been observed…," [referring to the concrete works], as observed during a follow-up inspection by the auditors. [noted at t15]
Design reviews conducted to meet the Client's requirements	Inadequate design by the Contractor as noted by the Experts stating, "The buffer blocks are designed to C25 concrete strength which does not provide sufficient abrasion resistance for the design life of the civil elements." [noted at t29]	This resulted in "… accelerated deterioration of the blocks due to abrasion and delamination as a result of reinforcement corrosion" according to one of the Expert reports [noted at t29]
Perform Internal audits to evaluate conformity to the QMS	No evidence of internal audits by the Contractor, as captured in Expert Report No. 3 stating, "the Project Quality Plan as specified in the Client's requirements is not implemented as evidenced by numerous quality issues and no audit has been instructed or organized by the Consultant to challenge this plan." [noted at t29]	This led to a deficient QA/QC organisation and procedures which fostered defect emergence.
Conformity to Client's requirements [For project E, the quality requirement for civil works is to have a design life of 100 years without any major structural rehabilitation within the first 40 years]	Following all the above-mentioned quality deficiencies, the concrete works failed to meet the specified Client's requirements	This resulted in the premature failure of the concrete hydraulic structure and the subsequent unsatisfactory performance of Project E
	Due to the extensive poor-quality practices performed on Project E, one of the audit reports cautioned that "Abrasion/cavitation may occur during the service life in areas at the floor/wall interfaces..." [referring to concrete works] [noted at t17]	This resulted in cavitation as reported by an independent expert stating, "Probable Causes for observed hydraulic performance observed is likely correlated with cavitation and subsequent erosion and loss of some buffer blocks, changing the flow pattern of the stilling basin." [noted at t72]

Table 3: Implication of artefacts on the defects and rework on the concrete hydraulic structure

ISO requirement	Manifestation of tangible artefacts in Project E	Implication of tangible artefacts on defects/rework
Maintain documented evidence of the nonconformities that are rectified	One of the audit reports noted that there were no reports documenting some of the crack repairs that were undertaken on the concrete hydraulic structure on Project E	This hindered the development of standard defect prevention methods as noted in one of the Expert reports; "Poor record on activities which were actually performed; thus, it becomes harder to post-examine cause of defects"

Table 4: Implication of language on defects and rework on the concrete hydraulic structure

ISO recommended practice	Manifestation of language in Project E	Implication of language on defects/rework
Communication should be done in a format and structure compatible with the project language and needs	Most of the Contractor's supervisors were not competent in the project administrative language 'A'. This is best portrayed by one of the audit reports stating, "Whilst on site, it was apparent that key personnel lacked the fluency in language 'A'"	The Contractor's supervisors' inability to speak the project language 'A' resulted in less transparency and miscommunication. This eventually led to document-related rework.
	According to another expert report, "…some of the concrete repair methodologies were in the Contractor's native language 'B', moreover, the translations from language 'B' to language 'A' were not correct."	This introduced nonconformities in method statements leading to misunderstanding of information resulting in the incorrect application of procedures. This always led to resubmission of the method statements and rework

Causality and Evolution of the Defects in the Concrete Works of Project E

The findings reveal that Contractor's inadequate design, subpar working methods, and inadequate quality assurance and control harboured poor quality practices and procedures. The Contractor's inability to follow its own method statements was further exacerbated by the Consultant's laxed supervision of the works as manifested in the practices in table 1. The result was numerous patent defects in the form of cracking, abrasion, delamination, corrosion of reinforcement, cavitation, and concrete erosion among others. Moreover, there was no improvement in these methods as can be seen that the same observations were being made from t(0) till t(29). Poor documentation and profiling of the corrected defects meant that it was hard to undertake post-examination of defects. Eventually, this led to the rectification of only visible defects whereas others remained concealed. The concealed defects eventually manifested at t(72), as latent defects, since the quality of the concrete hydraulic structure could not meet the client's design requirements to withstand the imposed dynamic loads thus its structural failure. Ultimately, the project's overall performance as at t(72) was rated as, "*Unsatisfactory*" by one of the infrastructure performance review Experts. We adopt the term, "*recalcitrant*" from Cameron and Quinn (2011) to describe the PQC on Project E. Therefore, the above narrative addresses the impact of PQC on defects in an infrastructure project.

Analysis and Implications of the Defects

On project E, the recalcitrant PQC is established as a key cause of defects as discussed above. The PQC comprised behaviours, norms, and tangible artefacts which manifested through the poor-quality practices resulting in the emergence of defects, acceleration of defect development and deterioration, rework, and additional work, as depicted in tables 1, 2, 3, and 4. The defects ranged from conventional cracking, abrasion, delamination, corrosion of reinforcement, cavitation, and concrete erosion among others, which resulted in the premature failure of the concrete hydraulic structure. The lack of quality in construction is manifested in poor non-sustainable workmanship and unsafe structures, and in delays, cost overruns and disputes in construction contracts (FIDIC, 2019).

In Project E, the failure of the concrete hydraulic structure led to time extensions, disputes, additional costs, claims and counterclaims. On EPC-type projects, the contractor is responsible for scheduling works, managing subcontractors, and developing the means and methods of construction, therefore, any shortcomings in the quality of works could lead to non-excusable delays (Thomas *et al.,* 2002) which attract liquidated damages. Typically, defects are symptoms of an inadequate or deficient QMS and we, therefore, argue that procurement agencies should consider quality performance as a key selection criterion at the tendering stage. This would reinforce the requirement for ISO certification and circumvent the prevalent use of ISO 9001 certification as only a marketing tool by some incompetent contractors. Direct measures such as allowing for adequate independent quality reviews and checks are recommended to manage defects. The failure of the concrete hydraulic structure on Project E attracted a lot of public attention through the media which could lead to the besmirch of the Client's reputation. Therefore, we propose that quality-related liquidated damages could be built into contracts to compensate clients for any reputation damage suffered because of a contractor's failure to adhere to its QMP. This could be likened to defamation and appropriate compensation computed for the client. These recommendations would foster a cultural change through improved quality practices which in turn reduce defect occurrence and severity. Senior management commitment from all project players is crucial for implementing cultural change initiatives (Schein, 2010).

An organisation focused on quality *promotes a culture that results in behaviour, attitudes, activities, and processes that deliver value through fulfilling the needs and expectations of customers and other relevant interested parties* (ISO 9000: 2015). From the findings, it is evident that Project E was dominated by the recalcitrant PQC of the Contractor. This resulted in a deviation from the expected ISO 9001 quality management practices which could in turn foster the normalisation of deceptive practices (Brooks and Spillane, 2017). Basic quality practices such as follow-up on review comments (Woo and O'Connor, 2021) were inexistent. Consciously, one would not expect any organisation striving for continuous improvement to condone nonconformities. The implication is that clients and tendering agencies should not overly rely on the perceived competence of contractors certified under different quality management bodies. This is because it is always too late and often costly to make any meaningful organisational changes after the commencement of the project works. As highlighted in the analysis section, it is crucial for the client to exercise due diligence in the selection of contractors and consultants at the bidding stage to verify the maturity level of the contractor's QMS. Implementation of quality can therefore be achieved when the Client, Consultant, Contractor, and subcontractors play their roles (Kanji and Wong, 1998) in accordance with the quality management principles and best practices (Love and Edwards, 2004).

CONCLUSIONS

The contributions of this study are twofold: firstly, we establish recalcitrant PQC as a key cause of defects and rework in the case study project; Secondly, the study reveals that recalcitrant PQC is also a key factor for the mismatch between an ISO 9001-certified QMS and the actual poor-quality related project performance in EPC-type projects. This manifested in the form of a violation of the Client's requirements and disregard for quality management guidelines. As we seek to "construct for the future," we argue that the honest and cooperative implementation of a tripartite project quality culture is a key factor in reducing defects and rework in EPC infrastructure projects in developing countries. This involves the contractors, clients and consultants having to work with a shared project quality vision as discussed in the analysis section. That way, quality in infrastructure projects would be thought of as meeting the Client's needs and expectations. The findings from this research provide some lessons to be learnt by stakeholders in projects with similar characteristics to mitigate poor-quality project performance. We acknowledge that the findings of this study were based on secondary data from a single case study and therefore recommend further research into a framework to ameliorate the recalcitrant PQC.

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MEASURING SOCIAL VALUE IN RAIL INFRASTRUCTURE PROJECTS: A SYSTEM DYNAMIC APPROACH

Yingshuang Shi[1] and William Collinge

Department of Engineering Management, School of Engineering, The University of Manchester, MECD Campus, Manchester, M13 9PL, UK

Social value refers to the social impact that a development makes to society for improving the economic, social and environmental wellbeing. The creation of social value is particularly relevant in the built environment for realising sustainable development goals. The built environment has a major impact on the local economy development, the wellbeing of individuals and communities, and environment regeneration through construction and management of infrastructure projects. Measuring social value in infrastructure projects encourages sustainable buildings through considering social contribution beyond economic returns. Although attention has been given to social value measurement, one of the main limitations of existing tools is that they do not take systems thinking that explicitly illustrates social value creation as an interaction process between a project and its environment over time. This paper addresses this issue by describing a system dynamics approach that can measure social value of rail infrastructure projects through the application of systems thinking. The application of this approach is illustrated through a case study, the Crossrail project in the UK.

Keywords: social value; rail infrastructure; system dynamics; system thinking

INTRODUCTION

The built environment has an important role to play in realising the sustainable development goals through construction and infrastructure projects (Raiden and King, 2021). Sustainable development requires that projects should not only deliver economic benefits but also have positive impacts on environment and society. While much attention has been given to effective use of resources and reduction of carbon emission, social dimensions of sustainability become increasingly important in construction and infrastructure project delivery (Loosemore, 2016). One of the most important terms related to this is social value, which refers to the social impacts that a development makes to society for improving the economic, social and environmental wellbeing.

In the UK, policies have been initiated to use public procurement to create social value (Public Service (Social Value) Act 2012). The Procurement Policy Note issued from September 2020 states new themes and outcomes of social value that should be considered in all central government procurements. These themes and outcomes

[1] yingshuang.shi@postgrad.manchester.ac.uk

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include helping local communities to recover from the impact of COVID-19, tackling economic inequality by creating new opportunities and increasing supply chain capability, fighting climate change including working towards net zero greenhouse gas emissions, tackling employment inequality, and improving wellbeing and community cohesion. Recent development in the rail sector shows that much effort has been given to social value creation in rail infrastructure projects.

However, measuring social value of rail infrastructure projects is challenging as there are various impacts on different areas such as the economy, society, and environment while these impacts are ambiguous and difficult to be evaluated quantitatively. Cost-benefit analysis is a preferred tool that is often used in the public sector to measure the performance of infrastructure projects. It supports decision making of investment options in terms of costs and benefits. Existing practice shows that it has been applied successfully to social value measurement by broadening its scope, focusing not only on financial costs and benefits, but also on non-financial costs and benefits (Freelove and Gramatki, 2022; Fujiwara *et al.,* 2022). Although various methods of non-financial valuation are incorporated into the cost-benefit analysis to improve its capability in social value measurement, it is still limited in analysing dynamic interactions between system components. System dynamics is particularly suitable here for dealing with such dynamic and non-linear interactions. System dynamics can identify components, links and feedback loops and present them in causal loop diagrams, which provide insights into the system structure and improve understanding. Causal loop diagrams can be transformed to stock flow diagrams which are computer-based simulations. It can be used to predict the project performance overtime and provide explicit suggestions on possible interventions (Leon *et al.,* 2018).

This paper aims to contribute to current research on social value measurement by proposing a system dynamics approach. Specifically, it presents the first step of system dynamics application to social value measurement by presenting a causal loop diagram to illustrate how positive and negative impacts and interactions between them can be identified, selecting the Crossrail as a case study.

LITERATURE REVIEW

Social value in rail infrastructure projects

Rail infrastructure projects are one common type of linear infrastructure that delivers hundreds of miles of railway that cross large areas. Rail infrastructure projects play an important role in creating social value (Freelove and Gramatki, 2022). One the one hand, rail infrastructure projects have an obligation to deliver social value as such type of projects are usually initiated by the government - such projects being forced to consider social value in the procurement process (Loosemore, 2016). On the other hand, rail infrastructure projects, such as the UK’s High-speed 2 railway, are key instruments to tackle worldwide challenges given their characteristics of widely economic, social and environmental impacts. Thus, social value is at the heart of rail infrastructure projects in delivering outcomes and benefits.

A range of studies have been conducted to examine the social, environmental and economic impacts of large rail projects. There are many impacts in the context of rail, ranging from employment and training, supply chain, health and safety, rail accessibility to economic development, climate, and COVID-19 recovery. However, not all of these impacts can be quantified and captured in market prices, which poses great challenges for social value measurement.

Social value measurement approaches

Social value measurement is the practice of evaluating social, economic, and environmental impacts. Various approaches have been developed to measure the social value, with social cost-benefit analysis being a preferred approach frequently used in the public sector (Nickel *et al.,* 2009). With a broader scope than traditional cost-benefit analysis, social cost-benefit analysis focuses not only on financial impacts, but also on non-financial impacts such as people's health, culture, and community cohesion. Identifying these impacts depend on taking the perspective from all group of stakeholders. The value of financial and non-financial impacts is captured in market price either as costs or benefits. Social return on investment is another approach used for social value measurement (Ryan and Lyne, 2008). It is based on the use of market prices, accounting profits and the calculation of rates of return, deriving from traditional cost-benefit analysis. This method is similar to social cost-benefit analysis while it emphasises stakeholder engagement with less rigour on quantification of non-financial impacts (Freelove and Gramatki, 2022). In addition to these two approaches, there are many other methods for measuring social value, including cost-effectiveness analysis, cost-utility analysis, and multi-criteria analysis (see Fujiwara *et al.,* 2022). Although these approaches, especially cost-benefit analysis, are increasingly used in social value measurement, conducting these approaches is still challenging in infrastructure megaprojects. This is particularly because infrastructure megaprojects have long-term and different impacts, which are often understated or even unrecognised at present while their effects would be amplified in the future. However, the conventional approaches are restricted to impacts that are more observable and easier to measure, as they are tools used for capturing non-financial impacts in market prices. Thus, more rigorous and academic studies over the application of specific tools have been called by many scholars to address these issues and advance social value measurement (Beer *et al.,* 2018).

System thinking to deal with social value measurement

System thinking is defined as a discipline for seeing wholes, interconnections, and dynamics rather than isolated and static parts (Senge, 1990). System thinking acknowledges that a system is made up of interrelated elements and its behaviours emerge because of interactions between these elements. In other words, system thinking believes that the behaviour of a system cannot be predicted by analysing its parts in isolation as a system is more than the sum of its parts. System thinking has been identified as a useful way to better assess the effect of impacts caused by a project (Ehrlich, 2022). The delivery of a construction project has different social, environmental, and economic impacts. The value of these impacts is determined by various socially, environmentally, and economically dynamic factors, as well as interactions between each other (Yao *et al.,* 2011). However, such dynamic interactions are often ignored in the social value measurement area. Existing methods, such as cost-benefit analysis, assess project impacts in isolation and are unable to capture the value from a system thinking perspective.

System dynamics is a system thinking approach than can help to study the behaviour of complex systems by capturing complicated interactions between different elements in the system. The strength of system dynamics in dealing with complex problems has inspired its application to sustainability development. Zhang *et al.,* (2014) used system dynamics method to construct a model for assessing the sustainable development ability of construction projects. Their model integrated social, economic, and environmental factors and identified dynamic interactions between these variables. Similarly, Zhou and Liu (2015) examined the interrelations between project, social, economic, and environmental systems and developed a complex system model to assess the sustainability of infrastructure projects. Nguyen *et al.,* (2017) suggested system dynamics as a tool that complements cost-benefit analysis and developed a model to evaluate the social and economic benefits of infrastructure projects.

In summary, system dynamics is valuable method to measure the sustainability and social benefits of infrastructure projects. The literature highlighted the value of system dynamics in dealing with dynamic factors and their non-linear interactions, which can't be achieved by conventional analysis methods such as cost-benefit analysis. Thus, the goal of this paper is to explore how social value assessment can benefit from system thinking, through the application of system dynamics to provide a practical example.

The research approach adopted in this paper combines system dynamics with the case study method. While system dynamics generally uses quantitative data and mathematical equations to represent the real complex world, a shared perception is that the most information available for the modelling process is qualitative in nature (Luna-Reyes and Andersen, 2003). Qualitative data is the major information source for modelling because ignoring qualitative variables would result in narrow model boundaries and biased results (Sterman, 2002). Case study is part of qualitative social research approach that "investigates a contemporary phenomenon within a real-life context" (Yin, 2003, p13). Kapmeier (2006) suggested that system dynamics can benefit from the empirical information provided by case study. This paper focuses on social value in infrastructure megaprojects. In comparison with economic impacts, social and environmental impacts are often understated and unrecognised as they are difficult to be quantified and captured in market price. Thus, combining system dynamics and case study is suitable for exploring less quantitative factors and non-linear relationships in a more comprehensive and holistic way.

This paper adopted a single case study approach (Yin, 2003), based on the analysis of secondary data (Akcam *et al.,* 2019). Crossrail is a UK major infrastructure project that aims to deliver a new railway, known as Elizabeth line, running through the central London. Crossrail was initiated for the growth of London. The construction began in 2009 and it was opened in May 2022, followed by full route opening one year later as scheduled. It represents a typical case of infrastructure megaprojects for social value delivery. This paper focused on the value creation in both construction and operation phases because the project is completed, and the operation begins. The modelling process would benefit from the secondary data for two reasons. First, collecting primary data such as interview is difficult because the project is finished, and the delivery team has been dissolved. Second, there is a lot of secondary data available because this project was under constant supervision and scrutiny from politicians, professional bodies and the media. One important information source is the Crossrail Learning Legacy, which provides abundant information such as original reports, documentations, and expert insights.

In this paper, casual loop diagrams were applied to describe the dynamic and non-linear relationships between social, environmental, and economic impacts. As a system dynamics tool to qualitatively model the cause-effect relationships between system elements, the casual loop diagram is an appropriate tool to explore the causalities and feedback effects in order to understand the structure and dynamic behaviour of a complex system. As shown in Figure 1, a casual loop diagram consists of variables described in words or phrases and curved arrows representing casual relationships linking these variables. An arrow with the '+' symbol indicates that the effect is positively related to the cause. For example, an increase/decrease in variable A leads to an increase/decrease in variable B. An arrow with the '-' symbol indicates that the effect is negatively related to the cause. For example, an increase/decrease in variable C leads to a decrease/increase in variable B. The arrows can compose loops, showing either reinforcing (R) and balancing (B) feedbacks. These feedback loops, as a consequence of positive or negative casual relationships, determine the dynamic behaviour of the system.

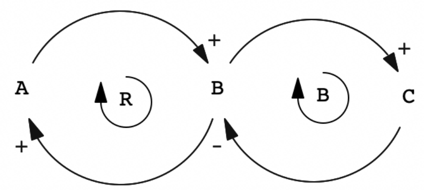

Figure 1: Casual loop diagram notation

Model Description

A casual loop diagram was constructed (see Figure 2), that illustrates the relationship between rail investment and transport benefits. Rail projects generally improve transport capacity, accessibility, and connectivity, as well as reducing travelling time. In the case of Crossrail project, it is estimated that a fully operational Crossrail will increase the central London's rail capacity by ten per cent. As the new line runs alongside London Underground lines with many connections to the existing rail network, it can relieve the congestion of the rail transportation in the central London. This new line runs through the central London with two branches, to Reading and Heathrow Central in the west, and to Abbey Wood and to Shenfield in the east. It can improve surrounding residents' accessibility to the central London. It is estimated that an additional 1.5 million people would benefit from the improved journey time, with access to central London within 45 minutes.

The casual loop diagram presented in Figure 2 involves one balancing feedback loop and one reinforcing feedback loop, showing the dynamic interactions between social-economic impacts related to transport benefits. In the balancing feedback loop, the improved traveling experience caused by reducing congestion and traveling time can potentially attract new rail passengers. However, the increasing number of rail passengers would increase the congestion of the existing rail network, which in return reduces traveling experience. The reinforcing feedback loop illustrates how the traveling experience can be improved during the operation phase. The increasing number of rail passengers increase the revenue, which could increase the investment to improve operation service, resulting in improving safety and traveling experience. The analysis of dynamic relations and feedback loops can provide some insights on the investment and operation. For example, predicting the increased number of rail passengers is important as it can lead to estimate appropriate capacity increased by the investment, thus reducing congestion in the future. Also, innovative design and use of renewable energy system could decrease the operation cost, increasing investment in improving traveling experience, making the rail operation more sustainable.

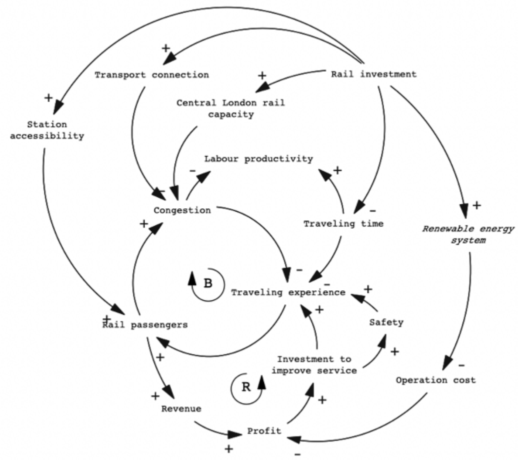

Figure 2: The relationships between rail investment and transport benefits

In Figure 3, the casual loop diagram illustrates the relationship between rail investment, employment, and local economic development. The case demonstrated a lot of social-economic benefits achieved by the Crossrail. During the construction, Crossrail is estimated to support 55,000 jobs across the country, indicating the contribution of rail investment to job creation. Also, Crossrail helps to develop surrounding areas and facilitate regeneration. The broader development schemes of designing stations and surrounding areas deliver over three million square feet of office, retail, and residential space, creating the capacity and conditions for people to work and live. For example, it has attracted business such as Facebook and Deutsche bank and would create more than 300,000 new jobs in central London.

As shown in Figure 3, the diagram involves two reinforcing feedback loops illustrating the local economic growth behaviour.

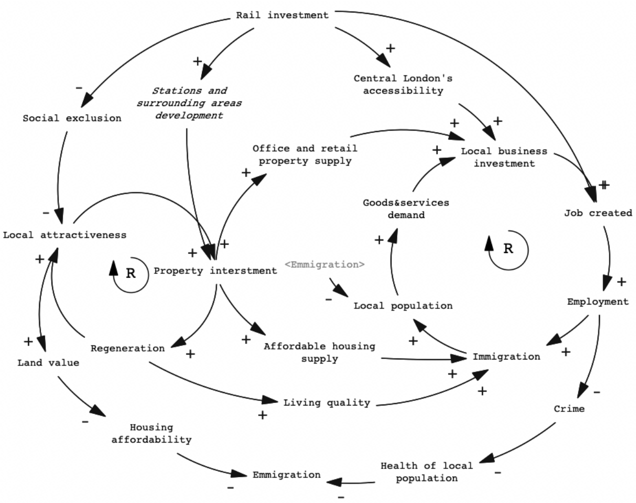

Figure 3: The relationships between rail investment, employment, and local economic development

In the left loop, reduction of social exclusion and local regeneration make local areas surrounding the rail stations and rail line more attractive to property investment, which would facilitate local regeneration in return. The loop on the right illustrates the dynamic interactions between local economic development, employment, and local population growth. The new job opportunities, supply of affordable housing as well as improved living conditions would attract more people to move into London. The growing population require more goods and services, motivating local business investment, which would in return create more job opportunities. The relationship between two loops is connected by property development and regeneration. For example, the construction of new homes and offices increases the supply of office and retail property and affordable housing, providing attractive conditions for local business investment and immigration. Also, the diagram shows other social and economic impacts. For example, the improved local attractiveness would increase the land value, resulting in less affordable housing and thus increasing in emigration. In addition, the increase of employment rate can reduce local crime, thus improving health of local population and reducing emigration.

Figure 4 illustrates the environmental impacts by the construction and operation activities. Although the activities involved in these two phases are different, this model combined them in one variable because they share similar environmental impacts. The construction of new rail can lead to the destruction of natural habitats, resulting in a reduction of biodiversity. In the case of Crossrail, for example, over eight million tonnes of excavated material were created as a part of construction. Also, the construction activities produced a lot of waste material to landfill, which could lead to soil and water pollution and impact biodiversity. In addition, the construction and operation activities require the consumption of significant energy, which would lead to the emission of carbon dioxide and pollutions into the air, contributing to climate change. Thus, the rail investment should focus on mitigation actions to minimise these impacts. The Crossrail committed to wildlife and habitat protection. The reuse and recycle of waste and excavated material benefited the physical environment and biodiversity through restoring landfills and creating new habitats. Air pollution was mitigated during construction by controlling the emission of construction machinery.

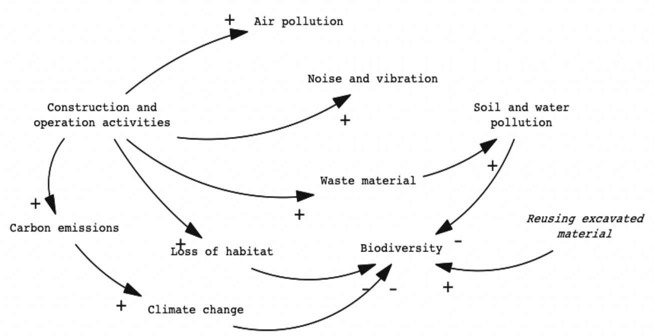

Figure 4: The environmental impacts by construction and operation activities

Figure 5 provides a holistic picture of the casual relationships between the Crossrail projects and its social, environmental, and economic impacts. More casual relationships were added. These includes the positive effect of local population on rail passenger number, and the negative effect of rail passenger number on car users leading to indirect impact on carbon emission and air quality. The operation of Crossrail is estimated to save 70,000 to 225,000 tonnes of $CO2$, mainly due to the displacement of car journeys. In addition, negative environmental impacts, such as air pollution and noise, by construction and operation activities on the health of local population might increase the emission rate.

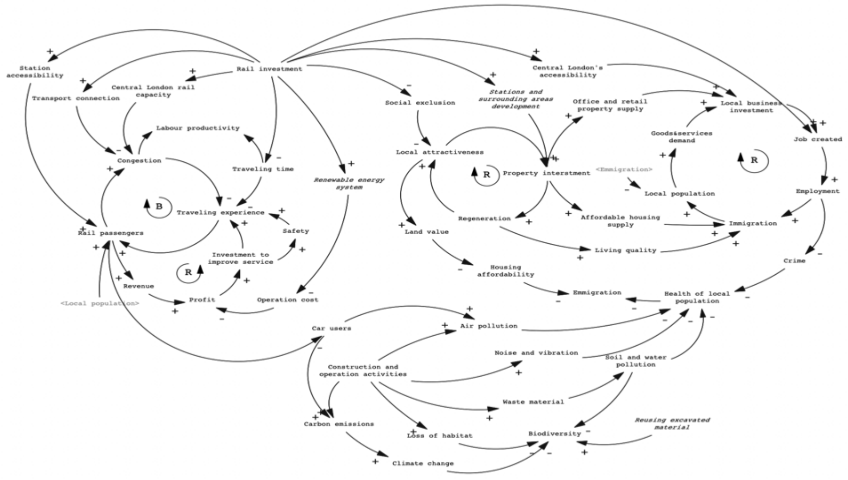

Figure 5: The casual loop diagram of the Crossrail

DISCUSSION

This paper illustrated the application of the system dynamics approach to social value measurement through a case study, Crossrail. The developed model suggests social value of large infrastructure projects is generated through interactions within and between four subsystems, the project, economy, society, and environment. It provides better understanding of the dynamics of social value in the context of rail infrastructure projects by identifying short- and long-term impacts and explicating their interrelations through the construction and operation phases. Thus, the social value measurement in rail infrastructure projects can benefit from system thinking. It should be noted that the system dynamics is not an alternative approach to conventional assessment method such as Cost-Benefit Analysis. Rather it should be complementary by adopting system thinking, with particular emphasis on dynamic interactions between the system components. The value of the contribution of this paper comes particularly from proposing system dynamics as an appropriate approach to social value measurement for rail infrastructure projects.

The grand challenges such as climate change, loss of biodiversity, income inequality, housing shortage, loss of social mobility, and the need to recover from the COVID-19 pandemic are increasing the complexity of our work. System thinking is a way of seeing a whole that is composed of a set of interrelated elements, leading to systematic behaviour over time. It is advocated that system thinking is a powerful approach to deliver good policy making and services (Government Office for Science, 2022). Applying system thinking to sustainability enables better understanding of the impacts of decisions on the surrounding environment and exploring opportunities for dealing with challenges (Yao *et al.,* 2011). The findings of this paper imply that the causal loop diagram can explain how social value can be delivered by strategies and opportunities explored and designed in early phases. Thus, this paper confirms the value of system dynamics thinking for social value measurement in supporting good decision making and policy design. A qualitative system dynamics model can be used to support managers and decision makers by searching more sustainable solutions and analysing the impact of different solutions on relevant social, environmental, and economic dimensions and ultimately the social value delivered by the project.

System dynamics models to study sustainable issues are subject to studying macro-level system behaviour because of interactions between social, environmental, and economic systems. The model scope and boundary are determined by the definition of problem that system dynamics is used to solve. This means that the model boundary of social value depends on social impacts on different sub-systems. The developed model identified many social impacts of a rail infrastructure project that define the model scope and boundary.

CONCLUSIONS

This paper focused on dealing with challenges in social value measurement by exploring positive and negative social, environmental, and economic impacts to improve the comprehensive understanding of social value in rail megaprojects. The casual loop diagram tool was applied to the Crossrail project to identify direct and indirect impacts, as well as map casual relationships and feedback loops. Consequently, the resulting model is capable of explicitly revealing the dynamic creation of social value by illustrating the interactions between the project, society, environment, and economy. The main contribution of this model is that it helps decision makers to recognise the relationships between different impacts and determine key factors in the system to inform appropriate actions for achieving social value, in both investment and execution phases.

There are several limitations and directions for feature work. Firstly, the system dynamics approach used in this paper primarily relies on a specific case which is Crossrail to set up the conditions for modelling. Although many impacts and relationships between them are general in the rail and transport sector, careful consideration should be given to the model application as each project has its distinct features. Future studies could benefit from identifying social, environmental, and economic impacts in a general system dynamics model that is flexible and adaptable to a wide range to situations. Given the project features, extending the proposed model by considering project factors such as scope, scale and location should be further explored. In addition, the resulting model can be only applied for qualitative analysis and has limitation in quantitative social value measurement. This paper suggests that the proposed model can be used as a basis for developing a stock-flow diagram, as computer-based simulation and quantitative analysis are fruitful areas for exploring model application. For example, quantitative system dynamics models can be used to measure and predict social value by combining the proposed model with current social value measurement approaches, like cost-benefit analysis. Also, a computer-based system dynamics model can be used to simulate policy scenarios and to support decision makers for adoption of further improvement actions. This requires further analysis of project strategies and actions, as well as their related social impacts.

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STRATEGIC MANAGEMENT PRACTICES AND OPPORTUNITIES FOR ADAPTING SMES TO CONSTRUCTION INDUSTRY CONDITIONS: TOWARDS A QUALITATIVE GROUNDED CONCEPTUAL FRAMEWORK

Diane Thompson[1], Nicholas Chileshe[2], Jeremy Coggins[3] and Albert Stevels[4]

[1,2&3] STEM, University of South Australia, GPO Box 2471, Adelaide, South Australia, 5001, Australia

[3] STEM, Delft University, PO Box 5, Delft, 2600 the Netherlands

Small and medium-sized enterprises (SMEs) make up most of the construction industry in Australia. The recent COVID-19 crisis emphasized the challenges of strategically managing labour; materials; interdependencies; customers; and financial solvency/viability. While existing studies have provided insights into strategic responses taken by construction firms generally; there is a lack of research regarding how and why construction SMEs implement such responses. This paper introduces a novel conceptual framework for analysing strategic management practices and identifying opportunities for adapting to industry conditions. The framework incorporates 10 key strategic response measures identified from extant literature and has been qualitatively tested through 30 semi-structured interviews of employees in the South Australian construction industry. Responses were thematically analysed following general theories of resource allocation and stakeholder management. All 10 measures were verified as pertinent. Four additional strategies were identified as being especially important to SMEs during times of crisis: collaborative culture; promoting corporate values/objectives; succession planning and human resource management. This framework will assist practitioners and policymakers in ensuring a more robust future for construction SMEs.

Keywords: conceptual framework; resource-based theory; SMEs; stakeholder theory

INTRODUCTION

The construction industry is accustomed to experiencing disruption (Armstrong *et al.,* Aug 2021), whether due to cyclical economic or financial trends, disasters (man-made or natural), extreme and unpredictable weather conditions, or "normal" change management. Operational challenges regarding supply chain, labour relations, asset management and workplace health and safety are all "run of the mill" issues for construction management. However, since the onset of the COVID-19 crisis in 2020, the Australian construction industry has been experiencing a 'perfect storm' of adverse conditions in the form of an unprecedented combination of high levels of demand,

[1] diane.thompson@mymail.unisa.edu.au

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fixed price procurement, and extreme shortages of materials and labour. This 'perfect storm' has led to a 'profitless boom' with contractors commonly experiencing significant delays, spiralling costs, and financial losses on construction projects. Consequently, in the 2022/23 financial year, construction insolvencies reached a 10-year high with 1,872 Australian construction companies entering administration or having a controller appointed (ASIC, 2023).

In Australia, construction is the fourth largest industry in terms of employment (ABS, Dec 2021) and share of GDP (RBA, Dec 2021) and most businesses are small and medium-sized enterprises (SME). This industry generates total income more than $499 billion (ABS, 2023). To stabilise construction and ensure a more resilient foundation, it is critical that a strategic management framework be developed to assist constructing for the future.

Previous studies have examined strategic responses by the construction industry to adverse conditions, particularly in the turbulence of recession (Tansey *et al.,* 2013); however, the industry conditions being experienced in Australia and, indeed globally, have not been explored in depth nor from the viewpoints of all stakeholders. This paper outlines applied research that has been undertaken to explore "how" and "why" certain strategies have been implemented to tackle the impacts of these industry conditions in one small-medium enterprise in the South Australian construction industry. This research introduces a conceptual framework that brings together the context of the industry and the factors currently being faced, linking these to the relevant underlying theories and strategic management principles.

LITERATURE REVIEW

This study examined extant literature that researched the impacts of COVID-19 on the global construction industry. Two databases (Scopus and ProQuest Central) were utilised due to their nexus with management, as well as engineering and the built environment. Key terms for the search were "COVID-19 impacts" and "Global Construction Industry" to be found in the Title, Key Words and Abstract. A global search was conducted due to the dearth of Australian-specific studies in this area.

The search included journal articles, conference papers and books written in English in the areas of business, management, accounting, and engineering. Focus was given to literature published in 2021 and 2022 as those published in 2020 were deemed to concern the initial reactionary strategies implemented due to COVID-19. The search returned 129 results. Of these, 13 publications were selected for analysis of industry conditions and strategic responses based on a combination of three main criteria: firstly, highest number of citations; secondly, extent of global coverage; and, finally, with the breadth of scope to which strategies were considered across operational aspects. Six industry conditions were identified across the selected studies. These were: skills shortages, changed working conditions, shortages of materials, project delays, rising cost of materials and cashflow pressures.

Strategic responses identified from the literature were largely focussed on tangible aspects of business. Employee well-being processes that directly responded to regulatory requirements such as mask wearing, hand sanitising and social distancing represented early responses (Alsharef *et al.,* 2021; Jones *et al.,* 2022; Leontie *et al.,* 2022). As part of changes in working arrangements, there was greater adoption of technology for meetings that moved online which, whilst difficult in the initial stages for some SMEs, did result in greater collaboration (Nnaji *et al.,* 2022; Ogunnusi *et al.,* 2020; Sami Ur Rehman *et al.,* 2022).

Relationship management with both subcontractors and suppliers became critical as the industry experienced greater shortages in both labour and materials (Husien *et al.,* 2021; Leontie *et al.,* 2022; Ling *et al.,* 2022). Australia was particularly impacted by the closure policies implemented in China (Husien *et al.,* 2021; Leontie *et al.,* 2022; Ling *et al.,* 2022). Project management and the need to adopt more advanced scheduling and planning processes, such as Building Information Modelling, were areas of strategic response necessary not only due to the shortages but also significant project time delays (Jones *et al.,* 2022; Ling *et al.,* 2022; Orzeł and Wolniak, 2022).

From a legal and financial view, significant strategic responses were required to navigate contractual implications and pricing mechanisms, deal with liquidity/solvency issues, and to maintain viability/profitability. Studies looked at the inclusion of contingencies in standard building contracts and whether contractual "force majeure" clauses sufficiently covered the impacts of COVID-19 (Alsharef *et al.,* 2021; Ogunnusi *et al.,* 2020; Sierra, 2022). Innovation in pricing mechanisms was required to handle these new industry conditions (Husien *et al.,* 2021; Mercy *et al.,* 2021; Sami Ur Rehman *et al.,* 2022). Seeking new avenues of credit and changing cash reserves were amongst strategies utilised to deal with cashflow difficulties (Alsharef *et al.,* 2021; Sami Ur Rehman *et al.,* 2022). In many countries, government support was received to aid liquidity (Leontie *et al.,* 2022; Ogunnusi *et al.,* 2020).

This literature suggests that the multitude of strategic responses to current industry conditions are transient in as much as they are reactive to the conditions without appearing to establish longer-term structural change. The following section outlines the theories that were analysed to create the theoretical foundation for this study.

METHOD

The methodology for this study follows the phases proposed by Jabareen (2009) for developing a conceptual framework to ensure relevance and validity. This approach is illustrated in Figure 1.

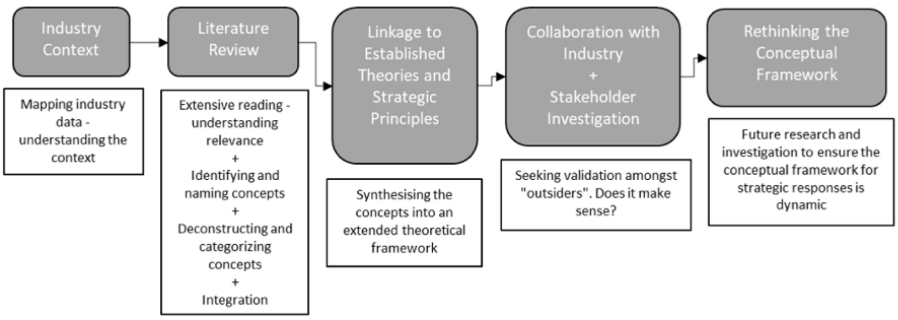

Figure 1: Research Approach

The predominantly qualitative research design for this thesis was undertaken as a pragmatic, explanatory single case study with four embedded areas of analysis. These embedded areas are Innovation and Learning, Internal Processes, Customer and Financial. Identified as pragmatic because the study incorporates a variety of methods (both quantitative and qualitative), techniques and procedures to collect and analyse data (Creswell and Creswell, 2018). Explanatory in nature because it comprises data based on cause-effect relationships which explain how and why certain decisions occurred (Yin, 2014).

Regarding the use of a single case study, given that there are multiple embedded units of analysis which seek to answer questions of "how" and "why" certain strategic responses were implemented, Yin (2014) argues that construct validity and analytic generalisation is possible. Being that the lead author is able to conduct the research as an intern within the case study organisation, provides an exceptional opportunity to access information which is usually not given to third parties, further supporting the use of a single case study in this instance.

The research is being conducted by the lead author over a period of approximately one year as an internship with G-Force Building and Consulting Pty Ltd (G-Force), a family-owned company with 39 employees established in 2006 and based in Adelaide, South Australia. Industry internships are encouraged by the Australian Government to promote applied research that will be valuable to the industry (DESE, 2021). This approach enabled the co-design of the research methodology which is important in making the research more valued and interesting for the industry (Freytag and Young, 2018). Planned methodologies were developed in consultation with G-Force management to ensure they were relevant and would add value to the study and initial findings from the literature review were formally presented to the executive management to ensure they made sense and aligned with the context of industry strategy.

Qualitative data were predominantly collected via semi-structured interviews with identified stakeholders, namely the employees of the organisation (internal stakeholders) as well clients, suppliers, and contractors (external stakeholders). The semi-structured interview technique permits the stakeholder to elaborate on subjects which are directly relevant to them, thereby assisting them to articulate their thoughts (Freytag and Young, 2018). Ethnographic observations are utilised for the purpose of triangulating the interview results and for the purpose of realism and relativism (Freytag and Young, 2018). Documentation and archival records were also analysed to offer evidence of strategic responses and implementation, including communication to stakeholders. Analysis of official documentation and records together with triangulation from external stakeholder interviews and ensuring no business involvement in the analytical stage and write-up of conclusions mitigated the risk of bias and supported the building of objective knowledge (Freytag and Young, 2018).

Extended Theoretical Framework

As the first step towards developing a novel conceptual framework to assist SMEs in making strategic responses to construction industry conditions, a framework was constructed based upon the following two established theories: resource-based theory and stakeholder theory. These theories were deemed the most suitable as the basis for the framework as the six industry conditions identified from the literature review concerned limited resources management and relationship management of internal and external stakeholders.

Resource-Based Theory

Resource-based theory (Penrose, 1959), while initially referred to as a theory of the growth of firms, can also be used to examine sustainability and the outperforming of rivals (Rugman and Verbeke, 2002). As stated in the fourth edition of The Theory of the Growth of the Firm, "the firm… is a collection of productive resources (human and non-human) under administrative coordination and authoritative communication that produces goods and services for sale in the market for a profit" (Penrose and Pitelis, 2009). The terms "administrative coordination" and "authoritative communication" indicate the sphere in which control of the organisation exists. The single entity case study approach adopted by this research enables in-depth research of the strategic management of the resources within the bounds of the firm.

Stakeholder Theory

Stakeholder theory was first developed in the 1980s to provide support to managers facing difficulties strategically managing their organisations during unstable times (Freeman and McVea, 2001). Stakeholders have been defined as a "wide range of groups who can affect or are affected by the corporation" (Freeman, 1984). Stakeholder theory provides a framework for managing stakeholders in three separate areas: rational, process and transactional. This approach provides techniques for mapping the stakeholders of the organisation, understanding the internal processes of the organisation and provides an explanation of how to analyse the interactions between the organisation and its stakeholders (Freeman, 1984). Stakeholders have been further defined as primary or secondary (Gibson, 2000) where primary stakeholders have an official or contractual relationship with the organisation and secondary stakeholders are others that can influence the organisation, such as environmental groups, industry bodies, and other societal participants.

Stakeholder Investigation: Findings from the Semi-Structured Interviews

Verbatim transcripts of the interviews were reviewed and sorted into areas of strategic response using Braun's (2006) Thematic Analysis to identify themes and sub-themes that arose during the interviews. Determination of what constituted a theme or sub-theme depended on the prevalence of strategic ideas that arose across all interviews. Prevalence here does not only refer to the number or extent of occurrences across the interviews but also the emphasis or importance placed on the ideas by the participants.

In the first instance, the lead researcher noted key words at the conclusion of every interview. These key words facilitated the development of patterns across all interviews. These then formed the basis for the codes and subsequently inductive reasoning gave rise to the themes and sub-themes. Field notes from observations and minutes of meetings are intended to be coded using the same inductive thematic analysis. By using thematic analysis inductively rather than theoretically, there is a closer link to the data itself which has a close correlation with grounded theory (Patton and Patton, 1990).

The responses from the executive management team validated the framework derived from the 13 global studies discussed above. Responses from employees in the broader organisation (administration, project management, site supervision and tradespeople) demonstrated a clear indication that other deeper, more intangible strategies were of equal importance in "riding the storm" of challenging industry conditions.

Additional strategies consisted of building a more collaborative culture, accessing more extensive human resource (HR) facilities, succession planning and a very strong overarching strategy for reiterating, communicating, and upholding corporate objectives and values. While the executive management team said these were strategies that had always been in place, it was clear that other employees felt there needed to be greater focus and emphasis on these strategies in times of crisis.

Employees felt that in times of crisis it was more important than ever to implement strategies to continually improve effective and innovative means of collaboration between team members working at different sites and locations, as well as with external stakeholders such as customers, suppliers, and subcontractors. Some participants expressed the importance of this collaborative culture being engendered from the very top.

This feeling extended to the need to have strategies to give all employees access to more extensive HR contacts, whether through additional staff in the organisation, industry specialist well-being organisations (such as Mates in Construction in Australia) or experts in employee well-being, such as Employee Assistance Programs. Participants stated that in an industry already renowned for its high suicide rate, working under high-pressure industry conditions required more concentrated strategic investment in the HR side of any construction SME. Suggestions also arose for better reward and recognition strategies to demonstrate the value of employees.

Succession planning also arose as a topic. Participants raised not only the management and ownership succession of the director but also of people in all roles throughout the organisation. Employees at all levels felt it was important for everyone to know where they belong in the "grand scheme of things", with investment in learning and development to ensure that their vocational pathway continued to receive support and investment.

As an overarching strategic goal, most employees referred to some need to reiterate and extoll corporate values and objectives. Any lack of clarity or focus would have a detrimental impact on the sustainability of the firm given that the industry conditions were exerting such pressure on all participants as well as the bottom-line.

Rethinking the Conceptual Framework

Developing a new conceptual framework involves an ongoing interaction between concepts, data collection and analysis (Orlikowski, 1993). Given the issues that the Australian Construction Industry is facing, the learnings from the literature review regarding strategic responses to various elements of the same categories of issues and the importance of these underlying these factors, it was necessary to explore existing strategic management models for a means of organising these components in a logical and ordered manner.

Following a further literature review, two possible models were identified which would enable incorporation of all these fundamental components. Firstly, Kaplan and Norton's (1992) balanced scorecard (BSC) and secondly, the European Foundation for Quality Management Excellence Model (EFQM) (EFQM, 2021).

These two strategic management models have been compared in several studies (Presecan, 2020; Wongrassamee *et al.,* 2003). Whilst findings were inclusive regarding the optimal approach, for the purposes of this study there were several factors that indicate the BSC should be adopted. Firstly, the EFQM model does not offer any insight on what strategies should be adopted for improvement. The matter of Employee satisfaction is not fully addressed in the EFQM model. The Balanced Scorecard links key performance indicators to strategic objectives to clearly formulate strategy. The scorecard sets, and measures against, specific targets. Finally, the Balanced Scorecard emphasizes cascading strategic objectives to every level of the organisation including business units and individuals.

The BSC is a theoretical framework that was originally introduced to address the identified need for a performance management system which focussed organisations' strategies on longer-term goals rather than cyclical financial indicators. The BSC allows managers to view the business from four important perspectives: financial, customer, internal business, and innovation and learning. This framework has since evolved into more than a system focussed on performance. It is now widely used as a strategic mapping tool (Norton and Kaplan, 2018).

This model is used to synthesize the concepts of current industry conditions and strategic responses, as identified in the literature review, with the underlying theoretical foundations previously described together with the findings from the fieldwork with G-Force. This process follows the methodology proposed for developing a conceptual framework (Jabareen, 2009).

Figure 2 shows the new extended conceptual framework resulting from this synthesisation. It contains the perspectives of the Balanced Scorecard, (the four embedded units of analysis for this study), the identified issues at play since the onset of COVID-19 and the strategic responses to these industry conditions. Overarching all these elements is the importance of the Corporate Values and Objectives.

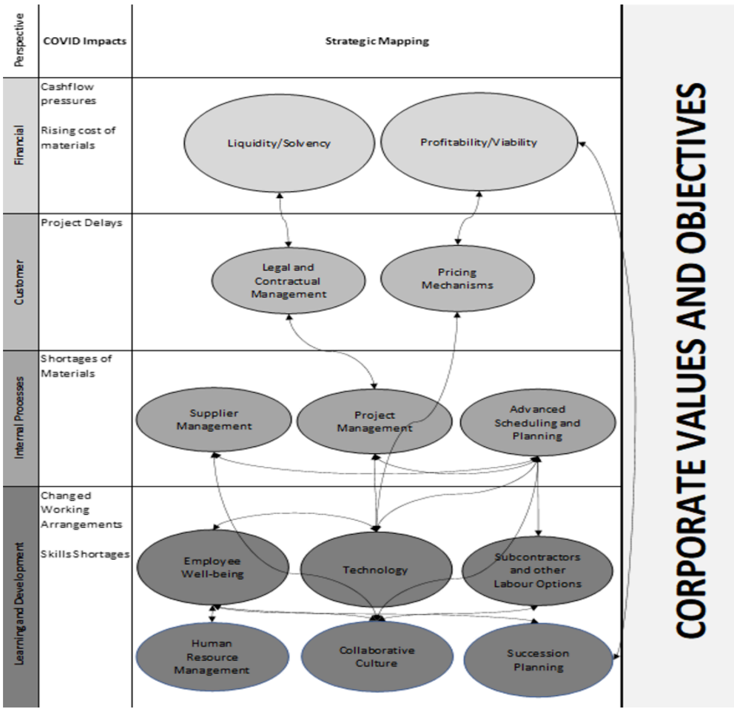

Figure 2: Conceptual Framework

DISCUSSION

From the research carried out to date, it has been possible to develop a conceptual framework for identifying, reviewing, and analysing strategic responses that are taken by SMEs in the construction industry. The initial concepts for the framework were developed using the learnings from the literature review relating to the industry conditions arising from the COVID-19 pandemic and the resultant strategic responses that were identified in the 13 selected studies across various nations. With foundations in the resource-based and stakeholder theories, this framework was used to identify the units of analysis required for each organisation, together with the relevant stakeholders whose perspectives must necessarily be considered. The results from the interviews with internal stakeholders in the case study entity allowed the conceptual framework to be further developed and enhanced, particularly in terms of learning and development unit of analysis.

Previous research has given rise to many of the tangible themes for strategic responses in the construction industry, however they have not explored at sufficient depth the reasoning and connections between those themes nor offered themes that consider all stakeholders connected with a firm. As this study continues, the reliability and validity of the emerging conceptual framework will be further established. Triangulation of the findings will provide a framework that is more robust and provides clearer direction for navigating the future in global construction. Ultimately, the framework will be developed to such an extent that it may be used to provide insights for policymakers regarding legislative decision making in regulation and, where necessary, subsidisation in times of crisis.

CONCLUSIONS

Globally, the construction industry is a vital part of everyday life, however the COVID-19 crisis revealed challenges in how SMEs can strategically manage a variety of influences. While previous studies have provided insights into the responses taken by construction firms generally, there is a lack of research regarding construction SMEs. This study has sought to fill that research gap by introducing a novel conceptual framework for reviewing, analysing, and implementing the strategies SMEs require during adversity.

Using an in-depth case study approach, the results demonstrate that sustainable strategic management requires not only that focus is given to financial well-being, but also necessitates that all resources at disposal should be encompassed, which impacts how response strategies affect stakeholders. Employees require strong strategies regarding how they are managed as a resource, their involvement in collaboration, and their future within the organisation. Above all, employees need to see that the strategies implemented in times of crisis extol the virtues of the corporation's values and objectives. These issues were incorporated into a new extended conceptual framework to provide SMEs with opportunities to analyse strategic management practices and adapt to new industry conditions. Its use is not only valuable to practitioners involved in the industry but also provides insights to governments, particularly in formulating relief packages in times of adversity but also in laying foundations in constructing for the future.

There are limitations to this study. It is focused specifically on the industry conditions experienced since the onset of COVID-19 and examined strategic responses identified in a selection of 13 studies. It was also validated through just one Australian SME. Further research is required to test the new framework's validity and reliability. Additional findings from planned research and an updated conceptual framework will be published later.

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PROCUREMENT

PUBLIC-PRIVATE PARTNERSHIP NATIONAL PROGRAMS THROUGH THE PORTFOLIO PERSPECTIVE: A SYSTEM DYNAMICS MODEL OF THE UK PFI/PF2 PROGRAMS

Sara Biziorek, Alberto De Marco and Gabriel Castelblanco[1]

Department of Management and Production Engineering, Politecnico di Torino, Corso Duca degli Abruzzi 24, Turin, 10129, Italy

Public-Private Partnerships (PPPs) have been adopted by numerous countries to alleviate fiscal pressures and transfer responsibilities to the private sector. However, the long-term sustainability of this procurement mechanism is uncertain due to social and economic limitations. This study aims to provide valuable insights for PPP decision-makers by analysing the long-term social and financial implications of one of the largest PPP programs globally - the PFI and PF2 programs in the UK, consisting of over 700 projects - from a portfolio perspective using System Dynamics. Our research identifies the key relationships driving the interaction between PPP development, societal concerns, and financial constraints. Causal-loop diagrams are developed to elucidate the causal structures within the system and estimate the long-term financial effects of PPPs on the government and society. The analysis revealed three relevant weaknesses that have led to the eventual closure of the PFI program in the UK, namely, high costs and long-term profitability of private investments in the long-term; the occurrence of recurrent cost and time overruns, and the lack of transparency that raised concerns about the program accountability. This research contributes to enhancing policies to enhance PPP programs.

Keywords: influencing factors; PPP; private finance initiative; stakeholders

INTRODUCTION

PPP projects are contracts between public authorities and private sector partners who design, finance, build, and manage public services such as health, education, and transportation (Castelblanco, Fenoaltea, *et al.,* 2023; Rojas *et al.,* 2023). These contracts typically span between 25 and 30 years and are signed with "special purpose vehicles" (SPV), which bring together private construction, facility management, and financing companies (HM Treasury, 2020; Marcellino, Castelblanco and De Marco, 2023a). This project delivery has been embraced by several countries around the world because of the benefits derived from a life-cycle perspective of projects taking advantage of the innovative, managerial, and funding capacities of the private sector (Castelblanco and Guevara, 2022b; Castelblanco, Guevara and De Marco, 2023; Castelblanco, Guevara, *et al.,* 2023; Castelblanco, Mesa and Serra, 2023; Khallaf *et*

[1] gabriel.castelblanco@polito.it

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al., 2024; Ortiz-Mendez, De Marco and Castelblanco, 2023; Salazar, Guevara and Castelblanco, 2024).

The UK government's adoption of Public-Private Partnerships (PPP) has been a significant policy development for the past three decades. The two main forms of PPPs implemented in the UK were the Private Finance Initiative (PFI) and the Private Finance 2 (PF2), which aimed to reduce public sector fiscal pressure and transfer responsibilities to the private sector. PFI was introduced in 1992 to improve the public sector's infrastructure through private sector investment and expertise (Biziorek, *et al.,* 2024). PF2 replaced PFI in 2012 due to concerns over value for money (HMT, 2016). PFI allowed for a financial mechanism to obtain private finance without affecting public borrowing and created new investment opportunities for finance capital.

The UK government implemented 704 PPP projects under PFI and PF2 with a capital value estimated at £57 billion. However, the estimated payment over 30 years was £188.35 billion, leading to concerns over the high cost of these projects (HM Treasury, 2020). The termination of PFI projects was announced in 2018, mainly due to the political opposition and the potential for inefficient management of assets when the government takes over from private entities after 25/30 years (HM Treasury, 2020).

This paper aims to analyse the long-term social and financial implications of one of the UK's largest PPP programs from a portfolio perspective using System Dynamics (SD). SD has been used previously to assess national PPP programs' financial and social management strategies to forecast demand in PPP projects and analyse the impacts of financing strategies on government and private investors' needs (Khallaf *et al.,* 2024).

This paper aims to contribute to the existing body of literature by providing insights into the causal relationships driving the interaction between PPP development, societal concerns, public policy, and financial constraints. Causal-loop diagrams will be developed to explain the causal structures within the system and estimate the long-term financial effects of PPPs on the government and society. The findings of this research will provide valuable lessons for PPP decision-makers worldwide and offer governments suitable policies to enhance the outcomes of their infrastructure portfolios in the future projects.

METHOD

SD was chosen as the overarching methodology to analyse the implications of the PFI and PF2 programs in the UK because of its ability to develop a graphical representation of the system using Causal Loop Diagrams (CLDs) so as to quantitatively model complex systems to facilitate policy analysis, engage stakeholders, and assess long-term impacts. SD was introduced by Forrester in the 1960s as a modelling and simulation methodology for dynamic management problems (Sterman, 2000). SD model consists of CLD that establish the qualitative relationships and cycles between variables that later are transformed into equations in the Stock and Flow Diagrams (SFDs) (Sterman, 2000). CLDs have the form of an oriented graph and are designed to explain the causal structures within the system through arrows that represent the influences either positive (denoted by "+") or negative (denoted by "-") among the variables (Castelblanco, Guevara and Mendez-Gonzalez, 2022b). CLDs are made of two kinds of loops: reinforcing ones that strengthen a behaviour, and balancing ones, which on the contrary, indicates that the loop counteracts the effect of a change. Complementary, SFDs allows for the quantitative modelling and are made of four main components: stocks, flows, auxiliary variables, and connectors. Stock represents cumulation, and these are modelled quantitatively as integrals of the differences between the two types of flows, namely, inflows and outflows. Auxiliary variables may be constant over time or may be changeable. The last component of the SFD are connectors which represent the relationships between all the other components, which could influence either positively or negatively the variable.

To conduct the simulation, a literature review was performed for defining the SD model according to the goal previously established and data from the PFI and PF2 projects were collected from public sources. The projects' data used for the CLD and SFD was retrieved from the UK Home Office in the form of Excel file which shows the current information available as for the date 31.03.2018 including information such as the date of preferred bidder, date of financial close, date of construction completion, first date of operations, operational period of contract, amount of unitary charges, capital value, the list of equity holders and the name of SPV company. This data allowed to establish the numerical formulation required for the model, which was entirely conducted in Vensim software. Based on the analysis of the literature on PPPs, the causal structures within the PFI programs were translated into a CLD (Figure 1).

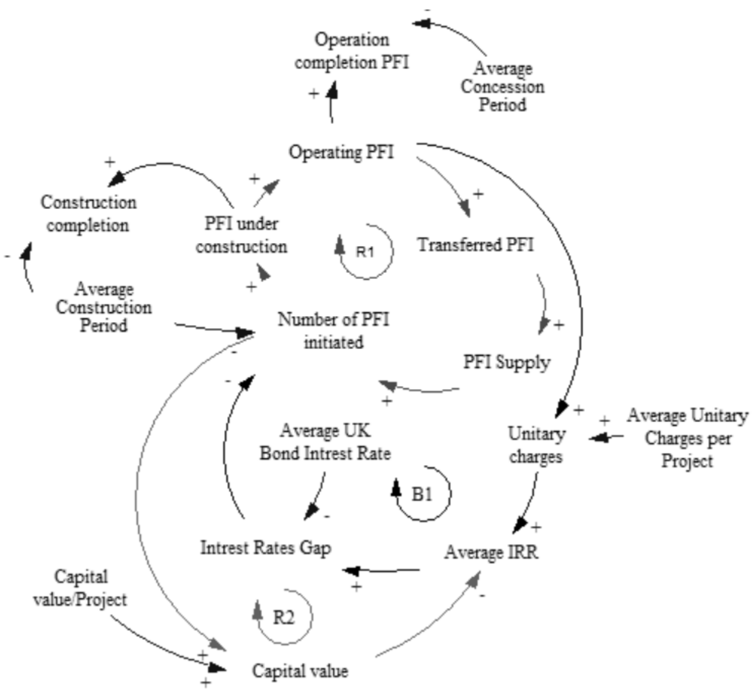


Figure 1: Causal Loop Diagram

The CLD shows two reinforcing loops (R1 and R2) and one balancing loop (B1). The reinforcing loop (R1) focuses on the pipeline of projects that constituted the PFI and PF2 programs. R1 shows that as more projects are initiated, the higher the number of projects in construction, and after the construction period ends, those projects become Operating PFI, and this results in more Transferred PFI to the public sector after the time of the operation period has concluded. The increase in PFI Supply also increases the number of projects that may be procured a second time resulting in a higher Number of PFI initiated.

The second reinforcing loop (R2) shows that that relations of PFI initiated and Capital Value. If the PFI initiated are increasing this leads to an increase in the Capital Value invested by the private sector. This will result in restricting the Average IRR, limiting the Interest Rate Gap, and, consequently, stimulating an increase in the Number of PFI initiated. Simultaneously, the balancing loop (B1) is focused on restricting the number of PFI initiated. The more operating projects, the higher Unitary Charges paid by the public sector to the concessionaires as these payments are made during the operation period. Moreover, the increase on Unitary Charges will lead to a higher Average IRR, which increases the Interest Rates Gap when compared with the Average UK Bond Interest Rate. Finally, the higher the Interest Rates Gap will result in a lower number of PFI initiated due to the erosion in the social legitimacy and, consequently, political opposition. This simultaneously will lead to lower number of PFI under construction and in result to lower number of Operating PFI.

Based on the CLD, the information of the 704 projects analyzed was translated into a SFD model (Figure 2).

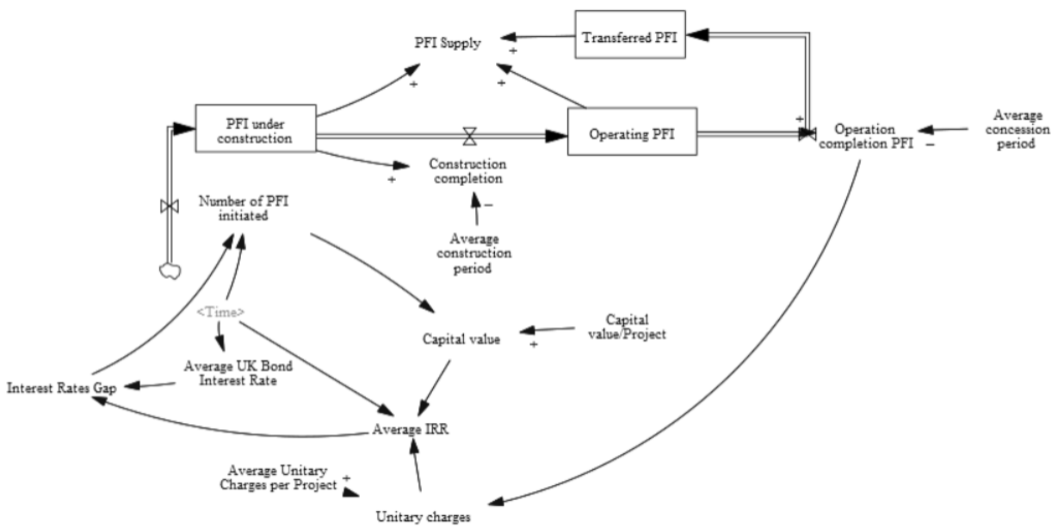


Figure 2: Stock and Flow Diagram

Table 1 lists all the exogenous parameters used for SFD modelling calculated based on the projects data. The quantitative outcomes of the SD model were validated with the information retrieved from the UK Home Office. The model incorporates three stocks: PFI under construction, Operating PFI, and Transferred PFI. PFI under construction decrease by the Construction completion, which is subject to the Average construction period. In the case of Operating PFI, this stock increases with Construction completion. The last stock, Transferred PFI increases by the Operation completion PFI. All these stocks are leading to the variable PFI Supply, which is the total number of projects regardless of the stage (PFI under construction + Operating PFI + Transferred PFI). The Average IRR is calculated depending on the Capital Value and Unitary Charges indicating the profitability for the private investor. Finally, the Interest Rates Gap shows the difference between the Average IRR and the Average UK Bond Interest. A positive gap represents a higher detrimental effect on public finance.

Table 1: List of exogenous parameters

Parameter	Value	Units
Capital value/Project	81.1	mln £
Average construction period	3	years
Average concession period	28	years

FINDINGS.

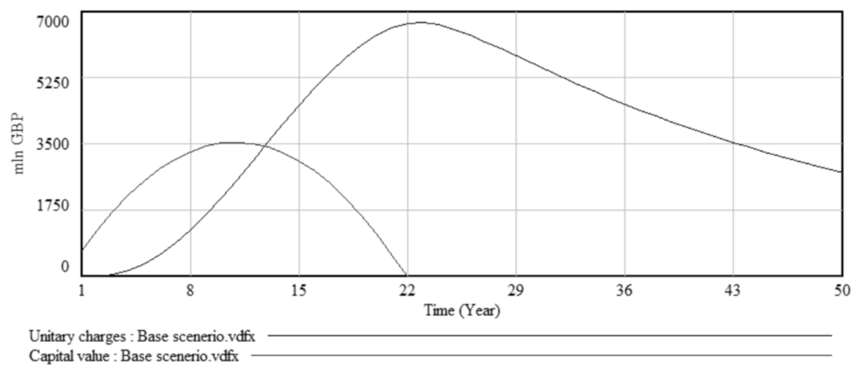
The SD model simulation was employed to unravel some relevant issues of the PFI and PF2 programs that resulted in the discontinuation of these PPP programs. Overall, the simulation unravelled three major weaknesses of the program analysed.

The first pitfall identified from the SD model is the higher costs of PFI/PF2 projects compared to traditional public sector procurement, leading to higher costs for taxpayers. To quantify the cost for the public sector derived from the PFI/PF2 programs, the data collected on capital value and unitary charges corresponding to the 704 projects developed since the beginning of the PFI program was modelled in Figure 3 since 1993 (corresponding to year 0 in the model) until 2043 (year 50). The capital value corresponds to the sum of equity and private debt required for the financial close, which usually is the amount required for the capital expenditures during the construction phase. Conversely, the unitary charges are the availability payments from the public sector to be paid on a yearly basis during the operation period. The projections for future values were estimated based on the public estimations regarding the unitary charges to be paid in a yearly basis (NAO, 2018). Figure 3 shows the difference in the order of magnitude between the private investment (capital value) and the public payments (unitary charges). This significant difference between them reflects the impact of guaranteeing private profitability in the long term. Consequently, the longer concession period of PFI projects (28 years on average) could have negative financial implications for the public sector and taxpayers that must pay more respecting public financing. It could also lead to unfavourable circumstances for the facilities once the PPP agreement concludes and ownership is transferred (Castelblanco, Guevara and Mendez-Gonzalez, 2022a).

To quantify the profitability, the data of initial capital investments and unitary charges to be paid were retrieved from public sources (NAO, 2018), to calculate IRR for each year by clustering the projects into time frames. The SD model calculates the Average IRR of the 704 projects, which is 16,3% when all the payments until 2052 are considered (Figure 4). In comparison, the average interest rate of the UK-10-year Government Bond since the beginning of the PFI program is 5,2% ("IEO Annu. Rep.," 2009). Consequently, there is a huge gap between the IRR for the private sector, based on the initial investment of equity and private debt, and the interest rate for public debt that is employed for financing traditional procurement projects. Moreover, the detrimental effect of this gap is even bigger for the public sector considering the long-term concession periods. In general, high IRR for long-term concession periods results in much higher Unitary Charges and what goes after also higher tax payments from people in comparison with short-term project deliveries such as Design-Build.

Moreover, a high debt leverage in the PFI program also implied reduced flexibility in funding sources, as the repayment of debt is mandatory regardless of the revenue generated (Castelblanco, Demagistris, *et al.,* 2023; Marcellino, Castelblanco and De Marco, 2023b) contrasting with equity investment that does not have such constraints.

Figure 3: Unitary charges vs. Capital Value



The second weakness of this PFI/PF2 program identified in this research is the cost and time overruns. Initially, when PFI was first introduced, business cases assumed that public sector projects would experience a cost overrun of 12.5% or more (D. Gaffney, *et al.,* 1999). However, the cost and time overruns in the PFI program ranged between 22% and 35% by the early 2000s ("IEO Annu. Rep.," 2009) contrasting with the range between 2% and 24 % in conventional procurement (Leahy, 2005).

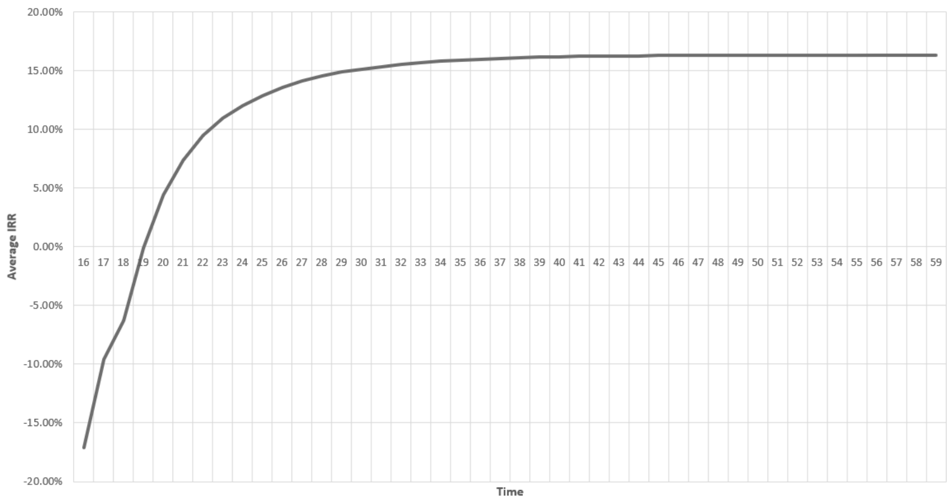


Figure 4: Average IRR

Figure 5 compares the Unitary Charges in two scenarios: the first one is the baseline scenario (without any cost overrun) which was generated with the use of the planned values gathered from the official estimations in the public data source (NAO, 2018), and the other is the cost overrun scenario which considers 24% of average cost overrun according to previous research on the performance of PFI projects (Leahy, 2005). Moreover, cost overruns, ultimately, leads to higher Unitary Charges to compensate the concessionaire, which significantly impact on the public budget and may result in rejection of potential new projects because the is required increasing budget for the ongoing PFI projects than initially estimated. Overall, recurrent cost overruns may even endanger the Value for Money estimations. Therefore, a project that reached Value for Money valuation for being conducted as a PFI project instead of alternative project deliveries may not accomplish these estimations because of the renegotiations during the long-life cycle. As a result, the public sector must use increasing resources from taxpayers than expected. The significance for taxpayers is reflected in the £10.7 billion paid between 2010 and 2015 as Unitary Charges only for hospitals and other healthcare facilities built under the Private Finance Initiative (Centre for Health and Public Interest, 2017).

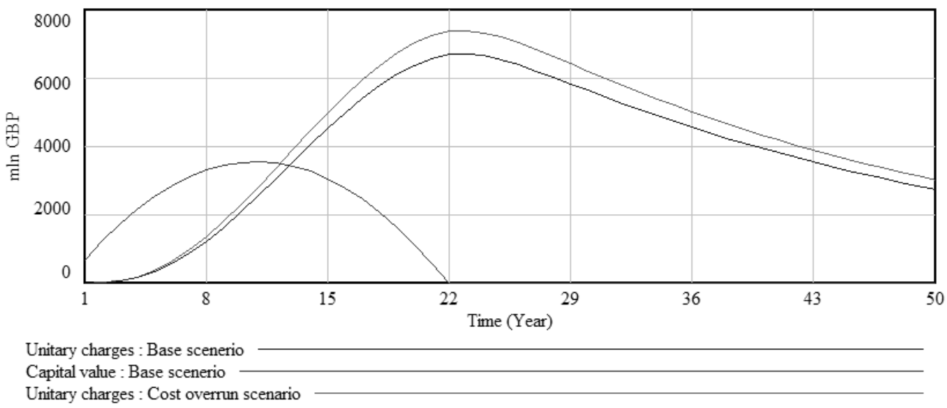


Figure 5: Unitary charges vs Capital Value under Cost Overrun

One meaningful example of projects affected by time and cost overruns is the London Underground Jubilee Line extension, which was delivered more than two years late and £1,4 billion over budget (Hodge and Greve, 2010). Another eloquent example of projects with significant costs overruns is the Crown Prosecution Service signed in 2001 for 10 years, but the estimated outturn cost was £408 million, a 70% increase due to the "improved service levels and extended to more staff" (Whitfield, 2017).

The government can also be locked into paying for services, even if it no longer requires them, as demonstrated by the Liverpool City Council project. The council is paying around £4 million each year for Parklands High School which is now empty. Between 2017-18 with the contract ending in 2027-28, it will pay an estimated £47 million, which includes interest, debt, and facilities management payments. The school cost an estimated £24 million to build (NAO, 2018). Even though there are no more PFI/PF2 projects in the UK, future charges lasting until the 2040s amount to £199 billion (Foreman-Peck, 2021).

The government is also incurring losses when it abandons projects. An example of this misbehaviour is the 2009 "Defence Training Rationalisation project" for the Ministry of Defence, which had to be cancelled since the bidder was unable to deliver an affordable proposal. The cost of cancellation of this project was £32.4 million (Whitfield, 2017).

Additionally, a significant time overrun can also lead to an overrun in cost. Time overruns may affect indirect costs during the construction phase, long-term costs during the operation phase, and financial costs. The "Northern Ireland Vehicle Licensing Agency" is an example of this misbehaviour as it was delivered six years late, and the final cost increased by £300 million (Whittfield, 2003).

The third weakness of the PFI/PF2 program is the lack of transparency in the PFI/PF2 programs. During the data collection for building the model, it was found that the public information available mainly shows information based on the business case rather than presenting updates of the status of the projects and the potential time and cost deviations and renegotiations. Moreover, this kind of information is even scarcer when the financial data is inquired. Overall, the only public information available is focused on presenting the planned capital value, unitary charges, and some basic information such as the date of the first operation and the duration of the contract. The lack of transparency regarding the real financial information impedes a proper public accountability on the projects, resulting in concerns about the potential for private sector companies to take advantage of their position and information asymmetry issues.

In summary, the three weaknesses of the PFI/PF2 programs shown in this research eroded the social legitimacy of the program, resulting in increased political opposition seeking support from voters.

CONCLUSIONS

This paper contributes to the growing body of literature on PPP programs by providing a comprehensive analysis of the long-term social and financial implications of one of the biggest PPP programs worldwide, namely the PFI and PF2 programs in the UK including more than 700 PPP projects. Using SD, this research identified key drivers that shape the interaction between PPP development, societal concerns, public policy, and financial constraints that in the future can help to establish more stable model of this kind of projects. To finance public infrastructure and services, PPP project delivery allows the private sector entities contribute with capital investments. However, while capital investment brings a relief to the public finance in the short-term, it creates a burden for taxpayers due to the high long-term IRR respecting public sector interest rate that ultimately triggered the closure of the PFI and PF2 projects." Constructing for the Future" with respect to PPP programs, requires researchers and professionals understanding thoroughly the trade-off between private capital provision and long-term returns under high IRR affecting public finance.

The analysis of the PFI and PF2 programs highlights key weaknesses that have led to their eventual closure. Firstly, the high costs of these projects, coupled with the high profitability of private investments in the long-term, has led to concerns about the value for money of these projects. Secondly, the occurrence of recurrent cost and time overruns has further undermined the financial viability of these projects, leading to further scrutiny and criticism. Thirdly, the lack of transparency in PFI and PF2 contracts has raised concerns about the accountability of private sector companies and their ability to take advantage of their position and information asymmetry issues.

The cumulative effect of these weaknesses triggered a loss of social legitimacy for the PFI and PF2 programs, leading to increased political opposition and ultimately, the termination of these programs. This highlights the importance of ensuring that PPP programs are designed and implemented in a way that maximises their social and economic benefits while minimising their costs and risks.

Moving forward, future research should analyse comparatively the projects among the multiple infrastructure types and specific public owners at a national, regional, and local levels. Moreover, future research should explore alternative models for financing and delivering public infrastructure that may serve to the UK Home Office to build a sound program that still lacking nowadays. These models may offer a more sustainable and equitable approach to delivering public goods and services, while addressing some of the key challenges associated with traditional PPP programs. Overall, this research underscores the need for a more holistic and collaborative approach to public infrastructure development, one that prioritises transparency, accountability, and stakeholder engagement to prevent excessive financial costs and renegotiations.

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WIREDSCORE WITHIN THE AUSTRALIAN CONSTRUCTION INDUSTRY: AWARENESS, BARRIERS AND INTEGRATED MECHANISMS

Angelina Papadakis, Lillian Oberer, Alexander Komljenovic, Sonali Alankarage and Nicholas Chileshe[1]

UniSA STEM, University of South Australia, Adelaide, South Australia, Australia

WiredScore certification is becoming popular in many developing countries as a system to improved digital connectivity, futureproofing of technological infrastructure, and increased value and marketability of the building. However, its uptake is low in Australia, and studies are limited in this area. Therefore, this study fills that knowledge-gap, and assesses the awareness levels, barriers, and integrated mechanisms of the certification systems among Australian construction organisations. A mixed-method approach, comprising a scoping review, survey and semi-structured interviews with practitioners was adopted. Ten barriers, and 4 mechanisms were used, with ranking and thematic analysis employed. Relative to the awareness, the majority understood the certification system. The significant barriers were 'cost and financing', 'lack of incentives', and 'lack of client demands'. The least were 'inadequate human resource and training' and 'increase in project timeline'. Mechanisms of 'proof of benefits by implementing WiredScore' and 'cooperation and commitment of professional bodies to implementing the certification system' had the most and least effect respectively. The implications are that increased awareness and education to contractors, clients, and end-users, could enhance the levels of technological certification systems adoption.

Keywords: WiredScore certification; technology; barriers; awareness; Australia

INTRODUCTION

The introduction of Internet of Things and smart buildings has caused construction industry professionals seek to integrate the latest technological advancements into their building designs and processes (Gamil *et al.,* 2020). Thus, digital connectivity and infrastructure have become increasingly important in the design and construction of modern buildings (Abioye *et al.,* 2021). Failure to do so could lead to a competitive disadvantage, as occupiers increasingly demand buildings that can support their technological needs and provide a seamless, integrated experience (Surma *et al.,* 2021). Therefore, assessing digital connectivity in buildings has gained attention considerably to ensure that buildings are equipped with the necessary digital infrastructure to meet the needs of modern businesses and tenants (Stoyanova, Vasilev and Cristescu 2021). WiredScore is a certification that rates and certifies the digital

[1] nicholas.chileshe@unisa.edu.au

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infrastructure and connectivity of commercial and residential buildings (WiredScore 2023). This addresses the growing importance of digital connectivity in buildings and to provide a standard for assessing the quality and reliability of a building's digital infrastructure (Verbeke, Laffont and Rua 2022). The WiredScore certification process evaluates a building's connectivity, infrastructure, and technology readiness, considering factors such as internet speed, reliability, and security. (Anderson, Slyziuk and Walsh-Cooke 2020).

According to Fahim (2022) achieving WiredScore certification ensures a building meets high levels of sustainability, whilst also indicating the technological capabilities of the building are flexible moving forward. Further to authors, buildings granted WiredScore certification ensure the buildings carbon footprint is reduced through efficient use of energy by optimising systems such as HVAC (heating, ventilation, and air conditioning) and lighting. WiredScore can identify opportunities for implementing smart building solutions. These solutions can include advanced energy management systems, automated lighting controls, and occupancy sensors, all of which contribute to more sustainable building operations (WiredScore 2023). Surma *et al.,* (2021) found that WiredScore-certified buildings increased occupant productivity, by utilising current technology to operate at a higher level of efficiency. Despite these benefits of WiredScore certification, there is minimal scientific information surrounding WiredScore certification across the world. However, in some parts of the world, such as the USA and UK, this certification system is becoming more prevalent within the built environment as there is a substantial number of buildings with WiredScore certification in these countries. Australia only began to implement WiredScore certification in 2019, compared to the USA and UK who began implementation in 2013 and 2015 respectively with only 34 WiredScore certified buildings (WiredScore, 2022; Cbus Property 2022). This indicates that the Australian construction market is trailing behind in the implementation of WiredScore certification.

There is a large focus within Australia to continue to move towards more sustainable practices within the construction industry, which is reflected in well-established certifications in the domain (Martek *et al.,* 2019). Due to this heavy emphasis on sustainable and environmental practices resulted many studies in sustainability and green domain (Doan *et al.,* 2017), while other certifications have been neglected - such as in the area of technology. The disregard for technologically advanced and certified buildings is somewhat counter-intuitive because a building that is more technologically advanced is likely to have a small carbon footprint and few emissions (Singh, Pai and Mahapatra 2022). Therefore, it is vital explore methods to promote technological based certification systems, such as WiredScore in Australian construction industry to gain its full benefits. Driven by the need to fill this gap, this study aimed to investigate the status of WiredScore in Australia to enable the identification of barriers, leading to workable solutions to overcome them. Addressing these challenges could increase the adoption of WiredScore certification, resulting in greater awareness and more certified buildings throughout Australia.

METHOD

The study utilized a mixed method approach. According to Creswell *et al.,* (2007) using a mix method can overcome the limitations of a single method's narrow focus and address low response rates commonly seen with single methods. I It can also enhance the validity and reliability of findings through multiple data sources. Further, diverse observations can be triangulated, leading to a consensus outcome. This mixed method approach was particularly suitable for the study's exploratory nature (Chileshe *et al.,* 2016). Data collection tools included a questionnaire survey and a series of interviews. Prior to data collection as the first phase a scoping review was conducted. A scoping review provide an overview of the available research evidence on a particular topic, which is a systematic approach to reviewing literature (Arksey and O'Malley 2005). Accordingly, journal articles, conference papers, white papers and industry reports were referred.

Phase I- Scoping Review

Given the novelty in the field of research, a scoping review was conducted on barriers to adopt WiredScore and other digital infrastructure and connectivity certification system. Grant and Booth (2009) describe a scoping review as a method of evaluating the available research literature as a preliminary assessment to determine the potential size and scope of a topic, without requiring a formal assessment of its quality. Due to the extensive variety of publications available, Google Scholar was utilized as the database for gathering articles (Alankarage *et al.,* 2023). The keywords (“WiredScore” OR “Digital connectivity”) AND “Certification” AND “Building” were used, and initial search resulted 1480 articles. Articles written in the English language were selected. Duplicates, books, theses, and literature reviews excluded. After screening the articles based on the titles and abstracts, a total of 39 papers were obtained. However, after further refining the search by reading the full text of the articles, the final count was reduced to 13 papers. Here, the articles with mere reference to the above terms without detail discussions were excluded.

Phase II- Questionnaire survey

A questionnaire survey containing 15 questions on demographic information, WiredScore awareness and barriers to WiredScore adoption was sent to individuals (unit of analysis). The summary of literature on barriers to WiredScore adoption is presented in Table 1.

Table1: Summary of literature on barriers to WiredScore adoption

No	Barrier	Supporting literature
1	Lack of client demand	(Barrett 2017)
2	Lack of awareness of end-users such as tenants.	(Bando Hano 2018)
3	Cost and financing	(Bando Hano 2018; Barrett 2017; Verbeke, Laffont and Rua 2022); Wimala *et al. (*2016)
4	Increase of project timeline	(Bando Hano 2018)
5	Inadequate human resource / training	(Verbeke, Laffont and Rua 2022)
6	Lack of expertise within the project team	(Stoyanova, Vasilev and Cristescu 2021)
7	WiredScore certification does not align with the Australian market	(Verbeke, Laffont and Rua 2022)
8	Lack of recognised value for owners	(Bando Hano 2018; Jabir and Caputo 2022)
9	Lack of commitment to certification at Concept Design Phase of a project	(Barrett 2017)
10	Lack of incentives	(Bando Hano 2018)

The sampling for the study comprised of engineers, design managers and IT specialists. A random sampling technique was used aiming to minimise biases and increase the likelihood of obtaining a diverse and representative sample of professionals in the engineering, design, and IT fields (Rowley, 2014). Further, a snowball sampling method was adopted to reach more respondents (Biernacki and Waldorf 1981), and it’s also suited where a few key individuals are selected and asked to contact or recommend other relevant individuals (Rowley, 2014). Targeting a broad array of professions ensures different viewpoints and opinions and in turn produce realistic results. The survey was deployed to 58 participants, of which 35 responses were received - providing a response rate of 60.3%. Although the number of construction professionals in the sample may appear limited, it is reasonable compared to previous studies like (Chileshe *et al.,* 2016), as, the interview data supports and adds value to the findings. If a smaller sample is carefully selected based on well-defined criteria, it is possible to obtain high-quality survey data that can still lead to meaningful and valuable findings (Yong and Mustaffa 2012).

The Relative Importance Index (RII) was utilised to analyse the quantitative data collected through the survey. This method ranks the most significant to least significant barriers and mechanisms. The RII method is a statistical analysis in which determines the ranking of different factors. The RII is calculated for each of the indicators and classified accordingly, the calculation is as follows; RII = $(\sum W)/(A \times N)$. Where, $\sum$**W** is the total sum of the weighting assigned to a barrier or integrated mechanism on a Likert Item Scale ranging from 1 to 5, by each respondent. Where 1 indicates the barrier would have the lowest significant effect on the implementation of WiredScore, and 5 would have the highest significance. **A** indicates the highest weighting of the Likert Item Scale, which is 5, and **N** is the total number of the respondents to complete the survey.

Phase III- Semi-Structured Interviews

The study utilised interviews in addition to a questionnaire survey to gather more detailed perspectives. The interviews followed a semi-structured approach, with a predetermined set of questions. The qualitative approach allows for an in-depth and detailed understanding of the current WiredScore situation in Australia and the current understanding and utilisation of the certification system. Of the 35 respondents who completed the quantitative survey, 3 were contacted to be interviewed. The researchers employed purposeful sampling, which involves selecting participants who possess specific knowledge or experiences related to the research topic (Yong and Mustaffa 2012). In qualitative studies like interviews, a smaller number of participants is often used, as the focus is on obtaining rich and in-depth insights rather than achieving statistical representativeness. Having three participants allows for a diversity of perspectives to be explored in depth, maximizing the understanding of each participant's unique insights (Yong and Mustaffa 2012). Table 2 summarises the respondents' details. The data collected from the interviews were collated and analysed using thematic analysis approach.

Table 2: Details of respondents

Respondent	Job title	Industry Experience
R1	Mechanical Engineer	14 years
R2	Masters System Integrated Engineer	6 years
R3	Technology Design Services Manager	10 years

This type of method is accomplished by searching across the data collected in the interview transcripts to identify and collate repeated trends (Braun and Clarke 2012). This process allows for constructing codes which ultimately detail found themes throughout.

RESULTS AND DISCUSSION

Wiredscore Awareness and Involvement

This aspect focuses on assessing the percentage of individuals who have been involved in one or more projects that achieved a WiredScore certification level (54%), as compared to those who are aware of WiredScore but have not been involved in any such projects (46%). It's important to note that all respondents in this evaluation are individuals who are aware of WiredScore, regardless of whether they have been involved with it. These results are promising as using the Innovation Diffusion Theory lenses advocated by Rodgers (2004), awareness is the first stage for the adoption of innovation (i.e., WiredScore certification system), and thus a precursor to the Australian construction practitioner's decision to adopt (or reject) the system.

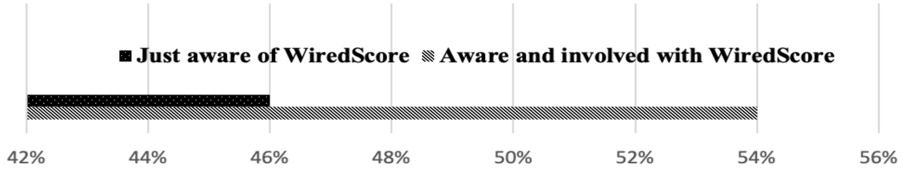

Figure 1: WiredScore Awareness and involvement

Barriers Effect on Adoption of Wiredscore

The scoping review identified 10 barriers and those were evaluated to find their significance on the implementation of WiredScore in Australia. The results of the RII analysis are summarized in Table 3. Barriers that received an RII value greater than or equal 0.700 were classified as having a high level of significance, those with values between 0.600 and 0.700 were considered to have a medium level of significance, and those with values below 0.500 were deemed to have a low level of significance. Some of the highest and least ranked barriers are discussed as follows:

Cost and Financing
Examination of Table 3 shows "Cost and financing" as the most significant barrier out of the 10 barriers presented to the survey participants, with a RII value of 0.782. This finding is consistent the study by (Li *et al.,* 2019), who found that the cost of sustainability certification was one of the major challenges in the adoption of energy performance certifications.

Table 3: RII and ranking of barriers effect on implementation of WiredScore in Australia

Barriers effect on implementation of WiredScore in Australia	RII	RII Evaluation Criteria	Rank
Cost and financing	0.782	High level	1
Lack of incentives	0.753		2
Lack of client demand	0.729		3
Lack of awareness of end-users such as tenants	0.671	Medium level	4
Lack of commitment to certification at Concept Design Phase	0.665		5
Lack of recognised value for owners	0.653		6
WiredScore certification does not align with the Australian market	0.588	Low level	7
Lack of expertise within the project team	0.565		8
Inadequate human resource / training	0.506		9
Increase of project timeline	0.424		10

Notes: Shaded areas shows the barriers with medium levels

Likewise, a study undertaken by Teng *et al.,* (2016), and which investigated the major barriers in the development of China's green buildings and the ways to overcome these barriers, identified high-incremental-cost as one of the major barriers.

Lack of Incentives and Lack of Client Demand
"Lack of incentives" and "lack of client demand" were the next two perceived greatest barriers surrounding WiredScore implementation in Australia, producing a RII value of 0.753 and 0.729 respectively. Many studies have reported that there is often a lack of financial incentives for developers to invest in certifications systems, and that clients may not always prioritise having a certification when selecting a building. For instance, Wimala *et al.,* (2016) found lack of incentives such as deficient financial support from the government and banks among the major barriers to certification issued system, namely GREENSHIP issued by the Green Building Council in Indonesia. Equally, Agyekum *et al.,* (2019) found that a lack of client demand was a significant barrier to the adoption of green building certifications.

Inadequate Human Resource / Training
Although this barrier of 'Inadequate human resource / training' was among the least ranked ones (RII = 0.506), its importance cannot be overlooked. As noted by most of certification systems such as LEED, which is like WiderScore, 'inadequate human resource' was identified as one of the eight key barriers that hinder the adoption of green certification of buildings (Agyekum *et al.,* 2019). Studies have also shown the importance of providing to construction professionals, thus leading to increased awareness on several initiatives such as sustainable construction and LEED certification systems (Shaker *et al.,* 2022).

Increase in Project Timeline
Further, results found that the least ranked barrier as "increase in project timeline (RII=0.424)" Studies have found that the impact on project timeline is often a minor concern when it comes to sustainability certifications, and that the benefits of certification often outweigh the time and effort required for certification (Guerra and Leite 2021).

Mechanisms to Overcome Barriers
This section reports the findings from the semi-structured interviews. The mechanisms suggested for overcoming the barriers that were identified as having a high level of significance based on the questionnaire findings were explained below.

Affordability to Implement a Certification System Like Wiredscore
While many developers and owners recognized the value of certification programs, they are concerned about the upfront cost and ongoing expenses associated with them (Verbeke, Laffont and Rua 2022). R2 believes the ongoing cost of the certification system, with re-certification required every two years was a cost concern. Similarly, R3 believes developers have not allowed for funding to be put towards certifying their development with WiredScore. Thus, it is necessary to make these certification systems affordable.

Proof of benefits by the implementation of a certification system like WiredScore
Implementing a certification system like WiredScore can provide numerous benefits for building owners and developers, including improved connectivity, futureproofing of technological infrastructure, and increased value and marketability of the building (WiredScore 2023). Despite the numerous benefits many people may not be aware of these advantages (Jabir and Caputo 2022). R1 who was involved in a project that aimed to obtain a 'platinum' WiredScore rating states that the developer had a change of mind, as the developer did not see the benefit in this certification system. Further, developer did not believe it brought value to the asset building when comparing to the cost of certifying the building itself. R3 also believes the limited knowledge in the

construction market regarding WiredScore certification, unlike the presence of other certification systems like Green Star, NABERs, WELL, leads developers to believe these other certification systems are more vital in attracting tenants and therefore creating a return for implementing these certifications to their buildings. Thus, the proof of benefits such as improved connectivity and futureproofing of the building's technological infrastructure, can attract potential tenants and increase the overall value of the building, providing a competitive advantage for the developer.

Clients' Interest in Implementing Wiredscore in Their Projects
Increasing awareness and knowledge of certification systems like WiredScore can be a key factor in driving interest and adoption among clients and building owners (Bando Hano 2018). R1 believes overall, tenants and developers have a lack of knowledge WiredScore and believes if this issue addressed then it would help combat the low levels of WiredScore certification. R1 also suggested that once WiredScore begins to become more popular, other developers and builders will follow suit, in turn increasing WiredScore certification numbers throughout the country. Addressing this issue and increasing its popularity could lead to a greater interest in implementing WiredScore, resulting in increased certification numbers.

Educate Tenants and Developers
Educating tenants and building occupants about the benefits of certification systems like WiredScore can be an important factor in increasing adoption and driving demand for certified buildings (Stoyanova, Vasilev and Cristescu 2021). R3 stated that initially the investors and asset owners were the target for WiredScore, however they believe WiredScore have educated developers thoroughly at this stage. R3 believes education must now shift to the tenants of the building as they seem to be lacking overall knowledge of the benefits of WiredScore. To increase adoption of WiredScore, it is important to shift the focus of education from developers to tenants to increase their understanding of the certification system.

Cooperation and Commitment of Professional Bodies to the Implementation of Wiredscore or Software Like BIM
The cooperation and commitment of professional bodies and industry stakeholders can play a critical role in driving adoption of certification systems like WiredScore. (Agyekum *et al.,* 2019) suggest that building certification programs are most effective when they are supported by industry associations, government agencies, and other stakeholders. The importance of Certification Systems contributing to raising the awareness as well as focussing the stakeholder's commitment is evident in other studies such as the adoption of circular economy (Poponi *et al.,* 2019). Clarifying the independence of WiredScore certification through resolving any partnership stigmas will help increase the confidence of developers in the certification system and lead to greater adoption.

CONCLUSIONS

The survey was a valuable means of collecting a substantial amount of information from a large sample size. Thirty five out of fifty-eight individuals responded to the survey, all of which were heavily involved in the construction industry and had varying experiences with WiredScore. The survey highlighted the major barrier of implementing WiredScore in Australia, with that being the cost of implementing the system. The survey also highlighted several other barriers impacting WiredScore in Australian with the lack of incentives, lack of client demand and lack of awareness in the industry ranking consecutively behind increased cost. The semi structured interviews with 3 industry professionals provided insights to barriers and provided mechanisms to solve them. The findings discussed suggest several implications for managers and policymakers looking to promote the adoption of certification systems like WiredScore. To increase awareness and uptake of WiredScore certification, it may be necessary to shift the focus of education from developers to tenants and building occupants, while also working collaboratively with industry stakeholders to promote the independence and credibility of the certification system. Policymakers may also consider implementing incentives or regulations to encourage developers to adopt certification systems like WiredScore, such as tax credits, building codes, or sustainability requirements. Finally, interventions such as marketing campaigns, educational programs, and industry outreach initiatives may be necessary to raise awareness and understanding of the benefits of certification systems like WiredScore among key stakeholders, including developers, tenants, and building occupants.

Whilst this study makes significant contributions in shedding light on our understanding of the WiderScore certification systems, a few limitations and assumptions are acknowledged. Firstly, the survey sample was limited to Australia and findings may not generalise to other countries. Therefore, future studies should be undertaken in another lesser studied context. The second limitation is related to the sample size which consisted of 35 respondents, whom were in the construction industry across Australia. Thus, future research could aim to complete the survey with a larger sample size to increase the precision of the results, as well as conducting additional interviews. Finally, a detailed readiness assessment informed by the Australian practitioner's knowledge of the WideScore certification systems could be undertaken to have a better understanding of the system, as well as increase its uptake.

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NO WINTER FOR SOCIAL VALUE: THE CONTINUED GROWTH OF A VALUE FOCUSED CONSTRUCTION INDUSTRY

Greg Watts[1]

SSEE, Maxwell Building, University of Salford, Salford, Greater Manchester, M5 4WT, UK

The focus on social value (SV) in construction procurement has evolved to challenge the historic triumvirate of time, cost, and quality. How contractors engage with SV is often the difference between successful and unsuccessful tenders. However, in an industry often criticised as having a traditional mindset, combined with contemporary global unrest, rising inflation rates, and material and labour shortages, the problem exists that the modern SV focus of the construction industry could halt if clients shift to a cost focus due to economic pressures. This research aims to establish if the current economic climate is having a negative impact on SV requirements. Interviews with eighteen diverse stakeholders reveal that far from the adverse economic climate serving to dampen SV enthusiasm, the current and anticipated demand for SV in the construction industry is increasing. It appears the worse the economic outlook for the UK, the greater part SV will play in construction procurement. All contractors it appears, need to be aware of the persistent growing need to focus on SV in construction now more than ever.

Keywords: procurement; narrative analysis; performance; business responsibility

INTRODUCTION

The latest UK Government data shows a stagnant 2022 economy, a forecast recession for 2023, spiralling interest rates and cost of living, a reduction in investment from many companies, rising unemployment, and a potential re-distribution of green investment funds from the UK to other countries (Jozepa, 2023). To compound such UK misery, March 2023 was the wettest on record (MetOffice, 2023). Whilst it is possibly still too early to understand the full negative ramifications Brexit may have had on the UK economy, the negative impacts of Covid have been well publicised. Prior to Brexit, pandemics, and invasions, the UK economy grew substantially, quarter on quarter from £238 billion in Q1 1992 to £445 billion in Q1 2008 and post financial crisis from £418 billion in Q1 2009 to £493 billion in Q1 2018 (ONS, 2018).

Against this broadly positive economic outlook from 1992 to 2018 (not including what can arguably be classed as a 'blip' in 2008) the focus on the social responsibility of business has also increased. Since the 1990's businesses wider responsibility to society has been more scrutinised and expected as a standard behaviour, with it serving to legitimise corporate actions and introduce a competitive edge and protect

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[1] G.N.Watts@salford.ac.uk

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against reputational risk (Carroll, 2015). These factors have served to increase the pace by which all organisations are engaging in responsible and ethical behaviour with social value the current incarnation of business responsibility. The need to evidence social value practices is at the forefront of current UK construction industry contractor requirements, with it encroaching on cost, time, and quality as a procurement criterion often being the difference between successful and unsuccessful tenders (Raiden *et al.,* 2020). Recent research has revealed that when economic times look uncertain, such as in the immediate aftermath of a global pandemic, construction contractors can return to viewing social value as 'additional' and focus primarily on cost-based project delivery at the expense of social value practices (Watts, 2020).

However, now the construction industry is facing long term economic uncertainty and disruption, there is a gap in current research around long-term social value expectations and requirements. Does a social value focus once again to retreat allowing a cost-based approach to take precedent, or will social value continue to increase in importance amongst construction stakeholders? This research seeks to address this gap. Firstly, social value will be discussed before the UK construction industry is introduced. The research methods are then outlined before the findings presented and discussed. Finally, the importance of this research and the contribution it makes to both current industry practices and academic research it outlined.

Social Value

Attempts to define social value have persisted for as long as the concept has been commonly used. Broadly, social value can be described as the social, economic, and environmental benefit a community and its residents obtain from organisations (Daniel and Pasquire, 2018). However, the ambiguity of the terms used, and the perceptions and requirements of the stakeholders involved often create varying and potentially conflicting interpretations. An in-depth analysis of UK construction contractor's non-financial annual reports found that socially responsible practices can have many labels attached to increase their legitimacy and marketable potential (Watts *et al.,* 2019). These labels include Business Responsibility, Sustainability, Corporate Social Responsibility, and latterly, social value. With each evolution from one label to the next the concept of what we currently identify as social value has arguably become more specific, metaphorically shedding, for example, the environmental focus which is now 'dealt with' as its own separate and standalone set of business practices and strategies. This can be evidenced in the changing trends of organisational reporting which now has standalone elements for environmental, social, and governance, as well as broader financial performance (Saini *et al.,* 2022). Such an evolution results in social value now considered as a standalone concept for business to embrace.

One proposed approach to overcome any issues on reaching an agreed defined consensus is to move away from attempts to articulate a definition of what social value 'is', due to often conflicting perspectives and requirements, towards capturing the 'manifestations' of social value activity (Çıdık, 2020). This aligns with earlier work that confirms no widely agreed value metrics, measurement frameworks, or sets of data are currently available with each stakeholder instead selecting an approach they feel relevant and applicable to their own social value requirements (Raiden *et al.,* 2018).

Social value is arguably a continuation of the Corporate Social Responsibility (CSR) movement that has been a growing requirement across all industries and expectation of organisations since the 1950's (Carroll, 2015). The introduction of the Public Services (Social Value) Act (2012) served to legitimise the requirement of social value as a public sector tender consideration (Watts, 2022). The launch of the UK Government's Social Value Model further solidified the importance that is placed upon social value during public sector procurement and served to direct the social value strategies and practices organisations adopt into five main themes (Watts, 2022). These five themes are: Covid 19 recovery, wellbeing, fighting climate change, equal opportunities, and tackling economic inequality (UK Government, 2020).

Despite the lack of an agreed methodology for defining, delivering, and measuring social value, the concept is increasing in importance and awareness across numerous sectors, including the construction industry, because of the Social Value Act and Social Value Model. During the last decade the industry has increasingly been recognised as having substantial social impacts that need to be balanced against any economic considerations (Çıdık, 2020).

Social Value in the UK Construction Industry

Historically, when construction projects are procured, the criteria used is focused on time, cost, and quality performance. However, social value as a criterion has slowly been growing in importance and weighting, amplified by the introduction of the Social Value Act (Watts, 2022). So much so that engagement with social value can now mean the difference successful and unsuccessful tender returns for construction contractors (Raiden *et al.,* 2020). Indeed, after an extensive literature review of previous research one study argued that the importance of social value in construction procurement cannot be underestimated (Daniel and Pasquire, 2018). The study goes further and argues that all businesses have a responsibility to consider how their actions can improve community wellbeing (Daniel and Pasquire, 2018). Some studies argue further than responsibility, and that a business's survival may depend on their social value practices as without adequate social value practices in place, a business's reputation may be damaged, and clients look elsewhere to procure goods and services (Mohd Ghazali, 2007).

Arguably, however, social value has, until relatively recently, being viewed as an 'additional' to any construction contract and project, a somewhat 'tick box' exercise (Reid and Loosemore, 2017). Whereby focus remains first and foremost on the project works themselves, with the adage of cost, time, and quality factors still ever present and social value considered as an important, but nevertheless additional, procurement criterion (Watts, 2020). It has even been suggested that contractual clause use is required to ensure social value practices included in tender returns are then carried out during the construction process (Daniel and Pasquire, 2018). It can therefore be argued that social value is growing in importance and expectation in both construction procurement and project delivery. However, there is research which reveals such a social value focus may still only be a façade of contractors, to use as a curtain to hide their cost focused intentions which are revealed when economic times become more uncertain (Watts, 2020).

Directly after the lifting of UK Government sanctions imposing a 'lock down' in response to the COVID-19 pandemic, research based on interviews with key construction industry stakeholders revealed the immediate 'knee-jerk' response of contractors was to revert focus to cost, with social value once again considered as an 'additional' (Watts, 2020). However, against the backdrop of the arguably worsening economic climate, a gap has been revealed in contemporary research regarding the importance placed upon social value by all construction industry stakeholders. Within this gap the question needs to be asked is a cost over value response to a worsening economic outlook a short-term response or a long-term prognosis of the construction industry. This is the gap this research seeks to explore by understanding the patterns and trends in construction procurement and social value delivery from key construction industry stakeholders.

METHOD

This research adopts the perspective that social value is a subjective concept and so dictates a constructivist ontological position. Meanings are socially constructed between actors and therefore best understood through the gathering of qualitative research data (Clark, 2021). This research seeks the perceptions of key construction stakeholders. Purposeful sampling was therefore utilised to ensure participants were selected who could best inform the research agenda (Robson and McCartan, 2017). In this research four participant groups were identified: construction main contractors (group A), public sector clients (B), and construction industry consultants (C), and social value consultants (D).

For group A, main contractors, a list of the top 30 construction contractors by turnover was found online and ten selected at random. From these ten, their respective websites and an online professional networking site were searched for relevant research participants. For group B, public sector clients, a list of Local Authorities (LAs) was created based on online searches for LA and social value involvement. When ten were identified their websites were searched and interview participants identified and listed. For group C, construction industry consultants, the 20 largest by turnover were identified online before ten were selected at random and their respective company websites and an online networking website were searched to identify relevant participants. For group D an online search was conducted for social value consultants who operate in the construction industry (amongst other industries). Emails were sent to the relevant participant from each consultancy after they were identified from a search of the consultant's website. Table 1 illustrates all groups of participants contacted and the number of positive replies leading to interviews for each. A represents main contractors, B represents public sector clients, C represents construction industry consultants, and D represents social value consultants.

In total eighteen interviews were conducted from forty invitations issued. All interviews were conducted via Teams and lasted between 45 and 60 minutes. The interview questions were structured around the use of narrative analysis. This is where participants are asked to answer questions based on their experience in the form of a story. Such stories are encouraged from the researcher and then information extracted from these to gain a deeper insight and understanding of the participants perspective and beliefs (Sandelowski, 1991). An example of the questions asked include "Can you think of an example of when social value featured heavily in procurement?", "Have you ever advised a construction company on their social value?", and "Have you witnessed any changes in social value from a project five years ago to the most recent project you have worked on?".

The interviews were then recorded and transcribed. The responses from each participant were analysed and categorised via a process of coding. The codes were derived naturally from the data analysis and allowed all responses to be compared for common themes and key elements to be identified.

Interview Participant	Job Role	Interview Participant	Job Role
A1	Work Winning Director	B1	Head of Procurement
A2	Social Value Director	B2	Head of Procurement
A3	Bid Manager	B2	New Project Development Manager
A4	Social Value Director	B4	Head of Strategy
A5	Social Value Director	B5	Capital Investment Director
A6	Bid Manager	C1	Project Manager
D1	Social Value Specialist	C2	Social Value Consultant
D2	Social Value Specialist	C3	Social Value Specialist
D3	Social Value Consultant	C4	Project Manager

Table 1: Participant Groups

FINDINGS

Analysis of the findings revealed several key themes:

Defining Social Value

Three main areas of consensus were revealed from analysis of the interviews undertaken. The first consensus is that there is no consensus when it comes to reaching an agreement on how social value is defined. All interviewees described and defined social value in slightly different terms and with slightly different stories. There was overlap amongst all responses, for example interviewee A3 described social value as "the difference we make in the communities we operate" implying the very nature of their construction works also made a positive difference. Interviewee A5 focused solely on the 'additional' benefits they brought to an area, defining social value as "what we can bring to a client above and beyond the project itself". There was also inconsistency in what the term social value encompasses with most main contractors considering it a stand-alone topic different to environmental issues but incorporating ethical business practices.

Whereas the public sector clients felt ethical business practices should be standard behaviour and social value considerations should include environmental impacts. Interviewee B4 stated "In order to sit at the table with us [contractors] need to meet a standard set of requirements which includes [ethical practices] …and I expect them all to list out all sustainable, net zero, environmental impacts and savings as part of their social value offering". Contrast this with interviewee A5 who's response broadly covers the consensus across all contractors "how we operate is an important part of social value, our accreditations, standards, practices…we can use them all to evidence our social value approach… they are all a part of our social value identity" and "our sustainable credentials sit outside of our social value…it's something we focus on for different reasons and is dealt with by a different team within [the contractor]".

This illustrates and reinforces arguments in the literature that no widely accepted social value definition exists (Watts *et al.,* 2019). When the interviewees were probed further it was also revealed that where there was overlap in terminology regarding inclusions within social value, ambiguity was prevalent. For example, the term social value was used by all stakeholder groups interviewed, but many gave different responses to the activities they would consider as social value itself. Previous research has highlighted the negative ramifications of this, in allowing contractors who do not engage with the concept substantially to masquerade as though they do by hiding behind obfuscation (Watts *et al.,* 2019). However, this research finds an advantage to such ambiguity in that it allows stakeholders to reach agreements and overcome potential definition barriers with the use of commonly shared terms, despite their meanings not being agreed upon fully.

Despite this advantage to ambiguous language use, the second consensus amongst all stakeholders interviewed was that social value should be agreed in as precise terms as possible at the earliest construction stage possible, to avoid any problems arising in delivery. Interviewee B2 stated "we did have the situation whereby we'd commenced the contract works but then realised the contractor was not going to delivery the social value benefits we thought would be delivered…I don't think they had intentionally set out to underperform, but we just had different expectations going into the project, and different interpretations of what we each wanted". The client then went on to discuss how the lessons learnt from that experience had informed current practices and they are now very prescriptive in exactly what social value they want achieved during the tender stage. This finding contributes to research that calls for the 'manifestations' of social value to be captured instead of effort focused on reaching a agreement over a definition prior to social value taking place (Çıdık, 2020). Potentially, waiting for social value benefits to be manifested before they are captured, and agreements reached is too late in the construction process. Whilst the benefits and definition of social value will be clear at the stage of manifestation, for some clients this will be too late to then achieve their original social value goals if such manifestations turn out to not meet their expectations.

No Social Value 'Winter'

The third area of consensus amongst interviews confirmed that social value is growing in importance. Interviewee D1 comments "we are getting work enquiries for social value support from all sectors, including the construction sector as companies are starting to realise its importance". Interviewee D2 stated that 'social value isn't going anywhere", with interviewee C1 confirming "social value is really high on people's priorities right now" and "we are seeing nearly all public sector clients, and many private sector ones, asking us about achieving the best social value outcomes".

It was confirmed that the introduction of the Social Value Act served to legitimise the requirement of social value as a tender consideration (Watts, 2022). However, awareness of the UK Government social value model was not universal. All public sector clients, construction industry consultants, and social value consultants had heard of the model. This is perhaps unsurprising given their social value focused roles (for consultants) and their public sector roles being influenced by government policy (for public sector clients). Contractors A1, A3, and A6 had not heard of the social value model however, and contractor A5 had heard of it but not seen it used in any public sector procurement process to date.

When asked if the current economic uncertainty and forecast potential downturn in economic performance and any accompanying funding cuts would influence procurement behaviour, all public sector clients were strongly adamant that social value as a procurement criterion was of benefit, something many had wanted to include for many years, and a procurement focus they would not be removing or reducing. Interviewee B4 responded "we did and introduce a social focus to procurement in the early 00's but faced a lot of push back from tenderers, not necessarily in construction but whenever we tried to shift the focus away from pure cost" and "the [Social Value] Act is great.

We can now directly ask each tenderer what their social value contribution will be". Interviewee B2 stated "we are looking to increase the focus on social value when commissioning works…we'd love to get to a place where 90-95% of the procurement weighting is purely social value focused". This was echoed by interviewee B3 who commented "it's [social value] now more important than ever. With every contract we are putting in place more lessons learnt and getting more social value outcomes achieved…this approach won't be changing". This echoes and reinforces findings in the literature that social value engagement will link directly to work winning, and so a lack of social value engagement could negatively impact business survival (Mohd Ghazali, 2007) and that construction businesses generally are viewed as having a responsibility to society to engage with social value practices as standard business behaviour,

This consensus that social value focus is increasing, even in economically uncertain times, is echoed by all social value consultants with interviewee C1 stating "social value is a high priority on the list of public sector clients we have, and for all public sector clients we deal with indirectly [through private clients wanting to win work from public sector clients]". Interviewee D3 summarises this point nicely when stating "the worse things tend to look [economically], the more attention we see put on social value…. clients want to get more bang for their spend". This was reflected by construction industry consultants C1, C2 and C3. Interviewee C4 however, was more reserved and stated, "social value is important, but the project budget it the project budget, and if the project can only be delivered for the budget the client has with no social value, then the project delivery will take priority". The need to focus on social value during uncertain economic times is even more diluted when discussing with construction contractors.

Interviewees A2, A3, A4, and A5 all believed social value will remain a high priority in procurement and project delivery, and had only grown in importance over the last decade with no short-term decline in importance during economic uncertainty. Interviewees A1 and A6 felt "social value is great to have when projects and the wider economy are going well, but we need to keep our focus on cost" (interviewee A1) and "We bid work based on what it'll cost us, and then add in any social value elements needed to try and win the project" (interviewee A6). Whilst it is those interviewees with a broader work winning job role that take a more cost focused approach and see social value as an 'additional nice to have' element, the results challenge previous findings in the literature that social value is 'forgotten' during tough economic times (Watts, 2020). Whilst some contractors may adopt a more cost focused approach when wider economic markets are uncertain, many contractors, and nearly all consultants and all public sector clients interviewed agree, a focus on social value is here to stay. The term 'winter of discontent' is often used to refer to a period of civil unrest in the late 1970's and the term 'winter is coming' has entered common lexicon to mean something bad is about to happen. A winter of economic hardship may be coming, but the results of this research reveal that for social value, no winter is coming. It appears to be continuing to grow in importance in the procurement and delivery of construction projects. Such importance is forecast to only grow further the tougher and more uncertain economic times become.

The Social Value Curtain

Despite the increased social value expectation from clients, forecast future trends from consultants, and procurement requirements experienced by contractors, it appears some contractors are still treating social value as a 'tick box; exercise, reinforcing previous research findings (Reid and Loosemore, 2017). Social value may no longer be considered as purely an 'additional' factor to be dropped for a returned cost focus in economic uncertainty as some studies have previously concluded (Watts, 2020). Arguably, social value is now viewed by consultants and public sector clients as a key factor in construction project delivery. However, this research reveals such a social value focus may still only be a façade of some contractors, to use as a curtain to hide their cost focused intentions.

Interviewee A5, a contractor who can be considered as viewing social value as highly important and evidencing high levels of social value engagement stated "we do what the client asks, and make sure we can satisfy their [social value] requirements…it does usually result in the project team having a list of [social value] requirements they need to tick off". Interviewee A2, another that can be considered as 'pro' social value also stated that "sometimes we could do more [for social value delivery] but if the client only asks for XYZ, then they only get XYZ". Interviewee D2 make similar comments with "we do often see that [contractors] can be pushed more, and we do try and push them to achieve more social value, but once they reach the threshold of client tender needs, they ease off on social value". Such contractor behaviour is further illustrated by interviewee C3 who believes "it doesn't matter how generous we are in allowing the contractors to bring their own social value ideas to tender negotiations, they often come with the same old initiatives, things we know they can deliver easily and probably are delivering elsewhere…and things they say they can't achieve at the tender stage are then achieved when put into the contract…they [contractors] can achieve so much more [social value] if they wanted to".

Social value, it appears, is increasingly being utilised by contractors to win work, and many contractors do engage with social value to a high degree and make a positive societal contribution. But such initiatives and practices are often the curtain presented to successfully win tenders. Behind the curtain the same cost focused intentions exist. Arguably a cost focus is needed to a certain degree to ensure business survival. Nevertheless, a cost focused stance will always result in social value being considered as an 'additional' factor instead of being fundamentally intertwined with cost, time, and quality. An approach that contractors will need to change going forward as the importance of social value appears to be continuing to rise and shows no sign of dissipating from the appetites of construction clients who are becoming savvier to the contractors that say they engage with social value, and those that substantively do.

CONCLUSION

Through interviews with eighteen construction industry stakeholders this research found that ambiguous language is used to define social value. Despite the limitations this has as identified in previous research, this research found such ambiguous language can help overcome procurement barriers allowing projects to commence whilst retaining a social value focus. This research also revealed that whilst a 'winter' may be coming in the form of economic uncertainty, there appears to be no 'winter' for social value. Its importance is growing, and expectations remains high. Indeed, it has been reported the worse the economic outlook, the higher the public client focus on social value will be. Finally, this research found that not all contractors engage with special value as effectively and robustly as they are able. Instead presenting a 'curtain' of social value engagement to clients, but behind the curtain retaining a clear cost focus that restricts their social value delivery to what the client requests and no more.

The limitations of this research include the focus on leading main contractors and consultants who all arguably have more knowledge, awareness, and experience of social value which may not be representative of winder industry beliefs and practices. It is recommended this research is replicated with a different set of participants to see if the trends identified are consistent. Further research should also be conducted to understand the 'curtain' of social value currently presented by contractors, and in-depth research conducted with numerous staff from the same construction contractor to better understand if the views of the interviewee participants in this study are reflected by the wider organisation.

This paper reinforces previous literature, and also challenges arguments in the literature with new perspectives and further consideration of their findings. For example, contractors immediately returning to a cost over value focus does not necessarily occur for all contractors in economic uncertain times, and should not occur if contractors want to continue to win work from clients who will be increasing their value focus the worse the economic outlook gets. Waiting until social value is manifested before reaching a definitional agreement could also prove problematic for contractor accountability and client value realisation in certain procurement situations. The findings of this research contribute to current construction industry practice by reinforcing the need for contractors to increase their social value focus as a method of work winning an also therefore of business survival. As well as serving as a warning that clients and consultants can increasingly identify those contractors treating social value as a tick box exercise and those who are substantively engaging.

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INCENTIVISING SUPPLIER INNOVATION IN MEGA INFRASTRUCTURE PROJECTS: EXPLORING THE RESULT OF INNOVATION BONUSES

Anders Wennstroem[1], Malena I Havenvid[2], Per Erik Eriksson[3] and Johan Larsson[4]

[1] *Swedish Transport Administration, Norrkoping, Ostergotland, Sweden*

[2&3] *Department of Real Estate and Construction Management, The Royal Institute of Technology KTH, Teknikringen 10B, SE-100 44 Stockholm*

[4] *Division of Construction Management and Building Technology, Luleå University of Technology, SE-971 87 Lulå, Sweden*

Prior research emphasizes that public clients need to use their client role and their procurement strategies to facilitate supplier innovation to accelerate sustainable development of the built environment. The purpose of this paper is to increase the understanding of Swedish Traffic Administration (STA), as the largest public client of infrastructure in Sweden, implementation of procurement strategies may influence supplier innovation. This paper explores an initiative by the STA to promote supplier innovation through offering innovation bonuses to four engineering consultancy firms, contracted for the early planning and design stage of the East Link mega project. The study is based on secondary data from STA's documentation of 51 innovation proposals submitted by the four firms. The result indicates that while innovation bonuses generate proposals of supplier innovation, public clients carefully need to consider how to formulate appropriate incentives and reward systems for specific windows of opportunity.

Keywords: innovation; procurement; incentivisation; public client

INTRODUCTION

During the 21st century, public demand has increasingly been emphasized as a major potential source of innovation in Europe (Hommen and Rolfstam 2009; Obwegeser and Dueholm Müller 2018). Public procurement is especially important when it comes to influencing innovation related to "wicked problems" and grand societal challenges, such as climate change, public health, and security (Edquist and Zabala-Iturriagagoitia 2012; Uyarra *et al.,* 2020). Although public procurement occurs across a wide range of sectors, it is especially prominent in construction, health, and transport (Georghiou *et al.,* 2014), where large public clients play critical roles in shaping their markets.

[1] anders.vennstrom@trafikverket.se

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Accordingly, many policy initiatives have highlighted the important role of the client in stimulating innovation that helps developing the built environment (e.g., Wolstenholme *et al.,* 2009; Barbosa *et al.,* 2017). More specifically, many studies have identified the construction client's procurement strategies as a key determinant for facilitating different types of innovation in construction projects (Tawiah and Russell, 2008; Eriksson 2017). According to Eriksson and Kadefors (2015), investigating a previous effort from STA with innovation bonuses, the client needs to carefully design and implement incentive systems that maintain an active focus in the design team. Similarly, Ninan *et al.,* (2022) argues that although incentives and rewards can motivate innovation, there is a need for an overall vision to guide preferred innovation. Despite its alleged importance, prior literature also argues that there is a lack of knowledge on public procurement of innovation, and especially on public clients' implementation of procurement strategies to spur supplier innovation (Uyarra *et al.,* 2020). More specifically, there is a lack of knowledge on how different aspects of procurement strategies affect different innovation dimensions (Larsson *et al.,* 2022).

The Swedish Transport Administration (STA), which is one of Sweden's largest public client organisations, is in a situation where "the challenges of today and the future demand both innovation and transition" (Trafikverket, 2023), not least to achieve the goals in Agenda 2030. Since the STA procures for approx. 60 billion SEK per year, it has recognized that procurement and contracting may serve as a strategic development tool for not only the STA, but for the whole Swedish construction industry. More specifically, this study explores an initiative by the STA to promote innovation through offering innovation bonuses to engineering consultancy firms in a mega infrastructure project.

Innovation is generally perceived as a multi-dimensional concept, but the specific dimensions discussed vary across different studies in different contexts (Crossan and Apaydin 2010; Larsson *et al.,* 2022). In this study, for the sake of understanding how clients can influence suppliers to innovate, three aspects of innovation are particularly interesting in; what is being innovated, how novel the new solution is, and its origin. This corresponds to the dimensions of 'type' (product or process), 'novelty' (ranging from incremental to radical) and 'origin' (generation or adoption).

Type of Innovation

In prior innovation management literature, regardless of context, innovations are typically divided into two main types: product and process innovations (Tidd 2001). Product innovation involves changes to either material goods or intangible services (Hommen and Rolfstam 2009; Edquist and Zabala-Iturriagagoitia 2012; Obwegeser and Dueholm Müller 2018). In the construction context, these changes often relate to advances in physical components, materials, or technical specifications (Rose and Manley 2014). Process innovation may be described as the "introduction of new production methods, new management approaches, and new technology that can be used to improve production and management processes" (Wang and Ahmed 2004).

Novelty of Innovation

When discussing degree of novelty (or newness) most innovation scholars classify innovations into a continuous scale from incremental to radical (e.g., Tidd 2001; Crossan and Apaydin 2010). Incremental innovation involves a variation (or small changes) in existing technologies, routines, and practices (Garcia and Calantone 2002), whereas radical innovation relates to more fundamental changes and a clear departure from existing practices and knowledge found within the organization (Crossan and Apaydin, 2010). As radical innovations mostly involve more extensive investments and high-risk, many firms often prefer more incremental innovation with lower risk and immediate reward (Dougherty and Hardy 1996).

Origin of Innovation

Some scholars in the innovation management field have distinguished between "innovation as the development (generation) and/or use (adoption) of new ideas or behaviours" (Damanpour and Schneider 2009). The generation of innovation involves a development process resulting in an outcome that is new to any organization, whereas the adoption of innovation is a process resulting in the assimilation of an existing product or process that is new to the adopting organization (Damanpour and Wischnevsky 2006; Damanpour and Schneider 2009).

Reward System

In the construction procurement literature, there are several studies on how delivery system (e.g., Rose and Manley 2014), partner selection (e.g., Kadefors *et al.,* 2007), and collaboration model (Eriksson 2017) are used as components of clients' procurement strategies and how they affect innovation. There are fewer studies on how the reward system (i.e., fixed price and cost reimbursement) influences innovation. Järvenpää *et al. (*2022) found that a fixed price may either stimulate or inhibit innovation. On the one hand, a fixed price may arguably give the supplier incentives to innovate to reduce the production cost of the project. On the other hand, the fixed price may make the supplier reluctant to try other innovative solutions since they may or may not be more costly than planned. Hence, fixed price will not incentivize innovations for other reasons than cost reduction. In more collaborative projects, cost reimbursement coupled with incentives/bonuses tied to innovation performance may be a better way to facilitate innovation (Eriksson and Westerberg 2011).

Winch (1998) also pointed to reward systems with gainsharing and partnering as part of moving from business-as-usual to more innovative type of practices. In relation to mega infrastructure projects, Davies *et al. (*2014) developed a framework that identified four opportunities, or windows, for clients to promote innovation in a megaproject, here as specified by Sergeeva and Zanello (2018): 1) the bridging window during the front-end when innovative ideas are generated, 2) the engaging window when tendering and contractual processes are used by the client to encourage suppliers to develop innovative ideas, 3) the leveraging window when all the parties involved are mobilised to develop innovative ideas, 4) the exchanging window at the back-end when innovative ideas can be combined with those of other projects in the innovation ecosystem. This framework is used to discuss the initiative by STA in terms of incentivizing supplier innovation short-term (in individual projects) and long-term (across projects).

METHOD

This study explores an initiative by the STA to promote innovation through innovation bonuses in a mega infrastructure project, The East Link Project, involving design and production of a new railroad. The study is primarily based on secondary data, in terms of reviewing of contract documents with four consultancy firms (describing type of incentivisation), and the project's internal documentation including 51 innovation proposals across the four firms. The empirical study focuses on reviewing the consultancy firms' innovation proposals, the STA's evaluation of them, and the effects of the evaluation in terms of the amount of the innovation reward (not the outcome of any actual innovation process). The material includes STA's correspondence with the suppliers including justification for not approved proposals.

In addition, semi-structured interviews with two individuals involved in the innovation council (evaluating the proposals) were conducted, one with a manager in the projects (also initiator of the council), and one with a specialist. When analysing the secondary data, each proposed innovation has been categorised in what *type* of innovation (process or product), the degree of *novelty* (incremental or radical) and its *origin* (generation or adoption). The categorisation is based on the written innovation proposals from the suppliers and comments by STA. The suppliers describe the origin of the proposal, for example: *this technical solution is used internationally"* or *"we have developed this process"*. Similarly, the *novelty* of the innovation was categorised based on whether the proposal was an improvement of an existing solution, or if the proposal was new to STA. The *type* of innovation was in a similar way traced from the descriptions of the proposal and meeting minutes such as: *"improvement of assigned system"* or *"extended requirement from STA for automation"*.

FINDINGS

Each of the four consultancy contracts comprise the same tasks: developing a pre-study and railway inquiry, with the delivery of permits, railway plans, and early design of the technical system required for the railroad. Table 1 gives a contextual description including a timeline for the studied period.

Table 1: Contextual description for the studied period

Year	Activity
2013	The mega project was established
2014	Consultancy firms 1 and 2 were procured
2015	Consultancy firm 3 was procured
2016	Consultancy firm 4 was procured
2017-09	Innovation council was defined
2020-08	New organisation was established
2021-04	Updated assignment for the innovation council
2021-02	List of approved innovation was published

Included in the contract documents for each contract is the formulation concerning innovation defined by STA:

> "The client will reward initiative to innovation during the assignment that render in cost-saving by optimisation of design for construction and maintenance of the facility. The cost-savings can relate to design as well as construction and/or maintenance of the facility. The approved innovation does not need to be new technology or an invention; it can also be an application of existing technology and knowledge - important is that it leads to cost reduction in design, production and/or maintenance.
>
> A bonus of maximum 2.5 million SEK could be rewarded. Smaller amount or nothing can be disbursed and in lump sum or spread out. The client´s project management decide if, and when, the reward is paid after processing in the steering board for cooperation."

The decisions, whether a proposal was rewarded or not, was initially determined by the project management and the steering group. In 2017, an innovation council was established to systemise the handling of innovation proposals. The purpose of the council was to increase innovation, generate more applications for innovation bonuses and coordinate the decisions. In 2017, only a few proposals had been handed in, after which the manager of the innovation council told each project manager to encourage the consultancies to send in innovation proposals.

According to the interviewees, there were doubts about the benefits of working with innovation proposals in the internal organisation of the project. In 2019, the question whether the innovation council should be shut down or not was raised. A list of approved innovations was published in the beginning of 2021 on the common share-point. The list, that includes descriptions/instructions of 17 approved proposals, was made accessible for all involved consultants. Initially there were no specific plans for dissemination, instead, according to the interviewed manager, they tried to disseminate the approved proposals through each project manager. In some of the approved proposals, for the consultancy firm to get the bonus, the innovation council had the prerequisite that the firm should develop instructions, or in another way make the idea possible to diffuse to others. Table 2 summarises the amount of approved/not approved proposals from each consultancy firm. The table also lists the type of reward system for each contract, fixed price (FB) or cost reimbursement (CR).

There is a remarkable difference between the two types of reward systems regarding the outcome of suggested proposals. The consultancy firms with FP-contracts have not been as successful, as those with CR-contracts, in getting proposals approved for bonus. In the FP-contracts, only 2 have been approved and 20 have been rejected, whereas in CR-contracts, 17 have been approved and 9 have been rejected.

Table 2: Summary of approved/not approved proposals

Consultancy firm	Approved	Not approved	Reimbursement
I	11	7	CR
II	6	2	CR
III	0	5	FP
IIII	2	15	FP

One proposal from firm 2 were noted as approved, but not on the list for diffusion and no notification documentation and another proposal was approved but withdrawn, in that case the firm referred no to be able to fulfil the requirement for diffusion.

Table 3 describes the categorisation of approved proposals. The approved proposals are mostly incremental process innovations and involve adaptive processes. More specifically, many proposals address improvements connected to the assigned system for sharing information between the client organisation and the consultancies, such as handling of 3D-models, VR-models, and GIS information.

The approved product proposals were all about railroad specific material, such as canalisation, duct, or electric supply system. However, some of the proposed products that were approved for innovation bonus were latter not implemented in the project, due to that the project itself could not solely decide on which railroad specific material to use. There is a specific process in STA for approval of technical material for railroad.

Table 3: Categorisation of approved proposals

Type	Novelty	Origin	Number
Process	Incremental	Adaptive	14
Product	Incremental	Adaptive	2
Product	Radical	Adaptive	1
Product	Radical	Developmental	1
Process	Incremental	Developmental	1

In Table 4 the different approved bonuses are summarised, and the numbers in brackets indicate the number of bonuses corresponding to the same category and amount of bonus reward (SEK).

Table 4: Summary of approved bonuses

Bonuses SEK	Category of proposals
500 000	Process/incremental/adaptive
350 000	Process/incremental/adaptive
300 000	Process/incremental/adaptive
200 000	(Information of the proposal is missing)
150 000	Process/incremental/adaptive
100 000 (3)	Process/incremental/adaptive
100 000	Product/radical/developmental
50 000	Product/incremental/developmental
50 000	Product/radical/incremental
50 000 (6)	Process/incremental/adaptive

As seen in Table 4 there is a predomination of process improvements that were rewarded larger bonuses, where most of them regarded improvement in the assigned digital environment. There are also many bonuses with value of 50 000 SEK (8). This indicates that "good ideas" were rewarded regardless of whether the proposals could be implemented or not. The decision on how to value the benefit of the proposals was under discussion and was documented in the notes from the meetings: "*if the proposal is interesting, we can pay a smaller amount, so the consultant investigate the proposed innovation further*". Several of the proposed innovations reappear in the documentations from the councils' meetings, where STA requires additional description, or investigation, before decision-making. A general question to the contributors of the proposals, according to the correspondence with the firms, was about "*What is the benefit/contribution of the proposal"*. Generally, specialists from the specific area determined the final value for bonuses of approved proposals, according to the interviewed specialist. The interviewed specialist mentioned that it sometimes was difficult to determine if a proposal was an innovation, or not, because the specialist from STA was in some cases involved in the development of the idea, as part of the "normal" exchange between STA and suppliers.

Table 5 shows proposals that were not approved and here there is a similar pattern, with most proposals aiming for process improvement. Overall, there is a similarity between approved/not approved proposals regarding type, novelty, and origin.

Table 5: Categorisation of not approved proposals

Type	Novelty	Origin	Number
Process	Incremental	Adaptive	18
Product	Incremental	Adaptive	7
Product	Radical	Adaptive	2
Product	Radical	Developmental	1
Process	Incremental	Developmental	1

There was a larger discrepancy in the topics for the not approved process improvements, compared to the approved. Both improvement of the assigned digital environment and improvement of operation methods can be found in the material.

The rejected proposals have been divided in categories depending on the argumentation from the innovation council, see Table 6.

Table 6: Argument for not approval

Argument	Total number	CR	FP
Included in the normal work for the consultant	4		4
Similar solution already exists	4		4
Not considered as an innovation	8	1	7
Already ingoing development in STA	5	3	2
Regarded as a good idea, but difficult to diffuse to another consultant	3	1	2
Not allowed in STA to use cloud solutions	2	2	
Not applicable in the project, change in specification	1	1	
Uncertainty of the practical application, not described	1		1
Not a subject for STA to handle	1	1	

The summary of rejected proposals shows a predominance of arguments related to that the proposals were not considered an innovation. Three of the proposals were considered as "good ideas", but not possible to diffuse to other consultants (mostly describing internal work processes). Table 6 also reveals that the three most common reasons for rejecting proposals in FP-contracts were: "*not considered as an innovation*", "*similar solutions already exist"* and that the innovation is considered as part of "*normal work*" for consultants. As these arguments are not at all common for rejecting innovation proposals in CR-contracts, it seems as the reward system affects the suppliers' possibilities to receive innovation bonuses.

CONCLUSIONS

There are several interesting results from this study of STA's initiative to incentivize supplier innovation in a mega infrastructure project. Through an innovation council, innovation proposals from consultancy firms in the early planning and design stage were evaluated and rewarded an innovation bonus if considered innovative and useful from a cost reduction point of view. This corresponds to the "engaging window" (Davis *et al.,* 2014) as STA uses tendering and contractual processes in terms of innovation bonuses to encourage suppliers to develop innovative ideas. The results are discussed in relation to two interesting aspects of the study: 1) the variation of the reward systems in terms of cost reimbursement (CR) vs. fixed price (FP) (i.e., an independent variable) and 2) in relation to the three innovation dimensions in focus of this study: type, novelty, and origin (i.e., three dependent variables).

Starting with the reward system, the firms with CR contracts produced about the same number of proposals (26) as the firms with FP contracts (22 proposals) whereas the former got more proposals approved for bonus; 17 (CR) compared to 2 (FP). Thus, whereas prior research suggests that FP can make suppliers reluctant to innovate due to the risk of increased costs (Järvenpää *et al.,* 2022), our findings indicate that suppliers may be willing to innovate but that the client does not necessarily identify this as innovation. Several of the non-approved proposals were regarded as *"part of normal work*" for a consultant in the early stage of a project, even if the proposed idea was considered *"good".* This demonstrates the difficulty of distinguishing potential innovations from expectations of normal work based on a broad definition of innovation. It appears particularly difficult in relation to potential innovations targeting cost reductions for suppliers within an FP contract, as this is to be expected also without an innovation bonus.

Regarding the innovation dimension "*type*", it appears that most proposals concerned process innovation and that these also rendered the highest rewards. This indicates that this type of innovation was deemed most useful from the client's point of view of resulting in cost reduction. It may also suggest that product innovation is harder to implement. Regarding the two other innovation dimensions, "novelty" and "origin", there were mainly incremental innovations (Garcia and Calantone 2002) and adaption (e.g., Damanpour and Schneider 2009) detected in this study. In several suggestions for innovation from the suppliers, they refer to "*ongoing development within their own organisation"* as origin for the idea. Evidently, the suppliers were referring to developments of their own processes that were taking place regardless of any client-initiated incentives. These developments may, however, not have become part of the specific project had the innovation bonus not been presented.

In some cases, the council considered the proposed innovation as good, but the diffusion to the other consultants was perceived as difficult, which resulted in non-approval for bonus. This can be interpreted as difficulty in linking the "engaging" and "exchanging" windows (Davies *et al.,* 2014) - i.e., tendering/contractual processes as incentivizing and then how to diffuse it to other projects. Thus, not all "good ideas" were considered easy to implement, specifically ideas concerning "process innovation". Process innovation is also more time-dependent, the ideas must be applied in the right time in the process. As seen in this study, some ideas were regarded as "too late" to implement. Therefore, public clients carefully need consider what window of opportunity for promoting supplier innovation to target and in what way, in terms of connecting the purpose of promoting innovation, to the timing of the targeted window and to appropriate incentive- and reward systems.

Previous research has highlighted the construction clients' procurement to stimulate innovation (Tawiah and Russell 2008; Eriksson 2017). Any innovation initiative from a client (Ninan *et al.,* 2022) should consider what to achieve, in this case short time cost-reduction in a specific project or long-term cost reduction. In relation to the framework by Davies *et al. (*2014) there needs to be an awareness of the different windows of opportunity, which window is aimed for and identifying the appropriate kind of incentives and reward systems for the prerequisites of that specific "window", or how to connect the opportunities of different windows if needed.

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SUSTAINABILITY

INCLUDING CIRCULAR VALUE PROPOSITIONS IN BUSINESS PORTFOLIO: EXAMPLES FROM SWEDISH AEC COMPANIES

Martine Buser[1] and Rickard Andersson

Architecture and Civil Engineering, Chalmers University of Technology, Sven Hultins gata 6, SE-412 96 Gothenburg, Sweden

The growing attention on circularity has increased focus on business solutions associating the short-term financial interest of the construction industry to maintain or increase economic prosperity with a longer-term focus on environmental and economic sustainability. Numerous researchers and consultants have forecasted and modelized the potential of these new opportunities. However, in practice, it seems difficult for many AEC companies to transform this potential into concrete implementation, and they struggle to apply circular thinking to their business. Our purpose is therefore to explore, document and analyse how a few companies have succeeded to be recognised as the forerunners of circularity. To do so, we build on the frame of circular business models which describe the organisational and financial 'architecture' of a business and the concept of legitimacy to analyse our results. Drawing on material collected in more than 40 companies, our method includes interviews, workshops, and ethnographic work. The two companies presented here illustrate a decoupling between moral and managerial legitimacy, enabling them to benefit from the green economy with rather moderate applications of circular principles in their business models.

Keywords: circularity; business models; moral; managerial; legitimacy

INTRODUCTION

The message from the last "International Planet Protection Convention" report is clear, the need to mitigate climate change is more urgent than ever. The European Commission has launched successive initiatives - Circular Economy Action Plan, Taxonomy, European Green Deal - to press the construction industry to achieve climate neutrality and rethink its work process and use of material towards circular solutions. To promote sustainable investments, EU is continuously strengthening its financial support to companies which want to capitalise on the transition to circularity (2020 a). Shifting focus from material and technical flows to the creation of a new market, the new policy identifies businesses and consumers as central actors to drive this transition process. Moreover, it suggests that the supplementary cost generated for new constructions, renovations and acquisitions should be supported by the mechanism of this newly created market (EU 2020 a, b). Although these new business opportunities have been promoted by many consultants and academics, in

[1] buser@chalmers.se

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practice, it seems so far difficult to transform this potential into concrete activities for the construction sector (Ghaffar, 2022). In Sweden, if most of the large Architecture, Engineering and Construction (AEC) companies have by now demonstrated the technical feasibility of circular building with one or two show-cases largely mediatised, they are still struggling to apply and scale up circular principles to their business services and products (Heshmati and Rashidghalam 2021, Andersson and Buser 2022, Moscati, *et al*., 2023).

Many researchers have documented the numerous barriers the sector is facing when trying to embrace the principle of circularity (Charef *et al.,* 2021, Giorgi *et al.,* 2022). The review of the existing literature reveals that past research has almost entirely focused on technical aspects and technological advancement (Adabre *et al.,* 2023). However, if the solution proposed by EU to develop circularity relying on business and consumer as key drivers (EU 2020 a) must be realized, there is an urgent need to address the potential of circularity in the construction sector by focusing on the business opportunities. So, here we choose to focus on the, still very few, examples of integration of these principles in the AEC industry. Building on the results of two longitudinal research, we select two companies- an architect, a real estate- singularised for their engagement within circularity. Our purpose is to identify the main features of their Circular Business Models (CBMs) and analyse our results through the lens of the concept of legitimacy (Suchman,1995). The question we aim at answering here is: What are the value propositions of the CBMs developed and implemented in these companies? By identifying successful stories, we hope to underline the feasibility of these circular principles and contribute to their development in the industry.

In the next section, we briefly introduce the concept of BM and the specificities of CBMs. We then present the theoretical framework drawing on the two selected concepts of moral and managerial legitimacy. The choice of these two forms of legitimacy enables us to differentiate between how the companies are perceived in relation to circularity and how they apply circular principles in their own production. Next, we present the methodological considerations and empirical data before proceeding to the analysis of our findings. In end, we conclude on the implications of diffusion of these circular principles in the Swedish AEC sector.

The social and political focus on Circular Economy (CE) is pressing the construction industry to move from a linear model of consumption to a circular one. Circularity economy requires to “redefine growth, focusing on positive society-wide benefits” by “gradually decoupling economic activity from the consumption of finite resources, and designing waste out of the system” (EMF 2015). The incorporation of the CE therefore involves a maximisation of the use of materials through the creation of a closed-loop economy promoting circular principles throughout the lifecycle of buildings (Gallego- Schmid *et al.,* 2020 EU 2020, 2020). The strategy includes : enabling reselling of construction materials by updating the construction product regulation to the introduction of recycled content requirements; promoting circular design initiative focusing on improving durability and adaptability of buildings; integrating life cycle assessment in public procurement, and a revision of the material recovery targets (EC, 2020, 2022).To improve the circularity of building materials, models are developed to facilitate and encourage the choice of sustainable solutions, as well as to optimise the supply chain and logistic processes (Hossain, *et al.,* 2020, Ghaffar *et al.,* 2022).

Circular Business Models (CBMs)

One of the management models to integrate circularity and develop new business propositions is the use of Business Models (BM) (Bokken *et al.,* 2014, Lüdeke Freund *et al.,* 2019, Aagaard, *et al.,* 2021). These models serve as a method to map the actual core features of the organisation and to define possibilities for future developments. The concept of BMs assumes that enterprises can manage and control business practice, and in doing are able to create and capture value. Building on many components and configurations these BMs can take many shapes (Foss and Saebi 2015). According to Teece however, they all describe how an enterprise delivers value to customers, entices customers to pay for value, and converts those payments to profit" (p:172). Circular BMs should help companies to redefine their value, creating activities whilst adhering to the principles of circular economy (Bokken et al.2014, Geissdoerfer, *et al.,* 2020, Ritala *et al.,* 2023). They should focus on slowing, closing, and narrowing the loops of material flow to maintain as long as possible their embedded economic value; besides they should reduce environmental impacts but still deliver customer value (Bocken *et al.,* 2019). This can be done by designing products for longevity, providing solutions preserving material integrity or recycling them. The development of CBM often brings organisational changes for a company but it often also requests the inclusion of a larger group of actors such as company's partners, key stakeholders, and shareholders (Amit and Zott, 2012). This is specifically the case for circularity which request a redistribution of roles in designing and producing building (Oluleye *et al.,* 2022). In the AEC sector, circular BM are expected to be driven by a collaboration between public and private clients, architects, contractors' companies, and suppliers (Gerding *et al.,* 2021). Common features of BM encompass the dimension below:

Table 1: Dimensions of Business Model (Lüdeke-Freund et al., 2019)

Major dimensions	Subcategories
Value proposition	Products, services
Value delivery	Target customers, value delivery process
Value creation	Partners and stakeholders, value creation process
Value capture	Revenues, cost

Theoretical Frame: The Concept of Legitimacy

To analyse our results, we build on the concept of organisational legitimacy as defined within institutional theory. According to Suchman (1995) "*Legitimacy is a generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions*". The concept refers to the perceived appropriateness of an organization to a social system and to the degree to which a company's products, practices, and structures are consistent with societal expectations (Deephouse and Suchman 2008). If the literature identifies no less than 12 different types of legitimacy (Deephouse, *et al.,* 2017), for our analysis we build on the notions moral and managerial legitimacy (Suchman 1995, Ruef and Scott 1998). Moral legitimacy occurs when the actions of the organization are consistent with social values. The well found of the concept does not however implies that the principles are applied in practices since as underlined by Suddaby and Greenwood (2005), moral legitimacy represents mostly a shift in rhetoric. Managerial legitimacy implies that organizations demonstrate how they materialize their goals and clarify the meaning of their mission and vision (Ossewaarde *et al.,* 2008). According to Suchman (1995), it is implied that organizations must be judged by what they achieve or the effects they produce. Managerial legitimacy involves mechanisms such as personnel management, accounting practices, rules of conduct or structure of the administrative staff (Ruef and Scott, 1998). The choice of these two forms of legitimacy enables us to differentiate between how the companies are perceived and how they apply circular principles. Legitimacy should not be understood as a commodity to be possessed or exchanged but reflects cultural alignment, normative support, or consonance with relevant rules or laws (Scott, 2013). For an organisation, legitimacy is also associated to its ability to access capital, governmental support or obtain license-to-operate (Deephouse, *et al.,* 2017).

METHOD

The paper originates from three complementary projects spreading between 2018 and 2023. Following the sector development during the last five years, the focus of the project has moved from sustainability to circularity demands and from the handling of waste on site to more strategic considerations including the creation of new business propositions. The frame of understanding for the present paper draws on a selective literature review drawing on CBMs publications focusing on the particularities of the construction sector and the theoretical concept of legitimacy. The three projects draw on interpretivist approaches and combine qualitative methods including interviews, site visits, meeting observations, workshops, and document analysis (Bell and Bryman 2018). This has enabled us to gain insights to the specific contexts through quotes, observations, and thick description. But the material here focuses on two companies which are systematically flagged as forerunners when discussing circularity in the AEC sector in Sweden: A large, architecture practice The A, and a real estate company The W.

Six semi-structured interviews were carried with the two selected companies and six with companies collaborating with the two first. All interviews have been taped, transcribed, and analysed according to the themes developed in iteration with the features of circularity. Besides The documents study encompasses numerous European, and national reports, professional guidelines, certification standards, legal frame, companies' websites, and professional media publications. As this study is exploratory, we have followed a rather iterative process between the interviews, the documents, and the literature (Dubois and Gadde 2002). Our intention is to deepen our understanding of the process at stake and not to obtain a generalisation of the findings.

Case Study

The A was founded in the 1950's in Sweden and counts today around 800 employees, mostly working in Scandinavia. The company is collectively owned by 500 of its staff members, 117 of whom are partners. Its goal is for all projects to be climate neutral by 2030. The company is active for around equal parts in offices, residential housing, urban design, and healthcare, the last 20% are shared between education and retail. In 2021, 51% of their projects were environmentally certified and they used wood as bearing frame in 33% of their projects. Out of their 776 million SEK turn over the same year, 46 % have spent on training, research, development, and innovation.

The W is one of Sweden's largest property companies and counts around 300 employees. The company was created in 2008 and is owned by national pension funds which require a constant and risk weighted benefit; it has delivered return of investment on an average of more than 10% during the last decennia. It manages and develops 2.4 million square metres across 166 offices and retail properties across the countries. Its market value of property portfolio totals around SEK 188 billion. In 2013 the company issued the world's first green corporate bond and in 2016 the world's first green commercial paper, with the funds earmarked for green assets. In 2018, the Gloabal Real Estate Sustainability Benchmark (GRESB) ranked The W first in Europe in the office segment and the ninth most sustainable property company in the world. The head of sustainability, here called WHS, has received the Sustainability Manager of the Year award in 2019. Both companies are regularly awarded prizes related to sustainability or circularity and their senior members are often invited to participate to conferences and public or professional debates. Both the A and the W differentiate between the challenges that a new built, a renovation or demolition project may face. However, for the sake of the argument will not refers to these differences in the case description.

Business Models and Circularity

Value proposition

The value proposition refers to the unique benefits that a company's products or services offer to its customers. The A company aims at proposing buildings appealing to their client by their form and function rather than by their circular features (The A Sustainable manager):"*We should say this is a great building and by the way it is circular, we want to avoid the patchwork or shabby chic feeling associated with recycling*". Asides of their architectural and design competences, the A offers different types of services related to circularity, for example they advise on the calculation of Life Cycle Assessment. To develop their own practise towards transition, they have organised two research units. The first one dedicated to practical research, aims at identifying current challenges, exchanging experiences and knowledge, and monitoring the development of various architectural fields. The second focus on exploring new ideas with the goal of bringing them to market. Two new services have been launched thanks to this structure. These data driven solutions are related to circularity: one used 3 D scanner to carry inventory of buildings, and then propose experts to determine which quantity and for which quality the existing building can be reused; the other relies on sensors to measure space, flows and occupation of given indoors space to optimise the utilisation of the premises. The company also underlines the role of the architect to document and follow up the development of a building. As preserving the existing is "the highest form of circularity", the relation with the architect knowledgeable about the building quality and functions should be preserved much longer than the design phase. An established relationship, they claim would allow more efficient renovation or conversion especially for complex projects like school or hospital.

The V has integration of circular principles as a request for all their projects. Each of them must go through a circularity workshop and assess the possibility of including recycling material. This becomes the norm as the WHS says "*I realized that we were hauling away products of the same brand, the same colour and the same dimensions as what we had newly ordered at the same time in another project that was running in parallel. That there was so clearly no price on nature's resources was an eye-opener*"

So far, recycling has mainly been about interior design for offices focusing on renovation or adaptation to new locals' tenants. The material has then been retrieved from other projects within the company. The W insists on the quality of their circular premises and has decided to in some cases limit the choice of material for the customers regarding carpet, flooring, or partition walls. For example, in certain properties there is only one type of floor mat. This makes it easier to repair damages or move and replace carpets during a renovation. If a piece of carpet is torn off, it can be stored in the building. Opting for classic and durable materials, should mean that more people can feel at home in the premises than if they have been fitted out in a very special style or colour. Using recycled doors, suspended ceiling tiles, floor mats and other things does not mean that the premises should be perceived as old or stale. On the contrary, the standard our interviewees claim, must be as good as new. The material recycled or reused encompasses mainly glass, inner door, partition walls, ceilings, or ventilation system. The company also develops technics to limit the damages when fitting offices like a new fixing system for the gips panels.

The value delivery
Value delivery refers to the manner the companies a delivering their products or services to the customers. The companies can create a competitive advantage, build trust with customers and stakeholders, and contribute to a more sustainable and circular economy. According to one of sustainable manager at the A, the value the company delivers to the customers is to help them to cope with the transition to circularity as they are pressed by both the legislation and the demands of their own customers to meet climate goals. The A offers both practical tools, for calculation and measurements as well as process management. Drawing on a team of interdisciplinary specialists - architects, landscape architects, engineers, BIM or solar cells specialists, ecologists, and social anthropologists- they feel equipped to understand and advice their customers even sometimes against their own will. For example, when they proposed the audit of building slated for demolition and persuaded the owner to renovate and recycle rather than invest in a new built. The interviewees also insist on the attention given to create convincing narratives. In order, to motivate their clients to innovate, they mobilise historical references or define new typology of buildings which identity should fit with circularity but without shadowing the importance of aesthetic and functionality.

If the W displays a clear environmentally friendly profile, it does not necessary mean that circularity should be the core argument to their value delivery. As stated by the WHS "*We property owners have no disclosure obligation to tell the customer that every tenth roof tile is recycled. The important thing is that we can offer good premises where our customers feel comfortable and can perform...If the customer hears that we reuse furnishings and materials, the question of a discount comes up reflexively. But right now, it is not certain that it is cheaper to reuse because it can be time- and cost-consuming to find the material on the market, or to have to refurbish it".* The high turnover of tenants meant that until recently it did not pay off to invest in high-quality materials, considering that the customer may soon move again. This strategy is slowly reversed as reusing material requests a certain quality. According to the interviewees, tenants may initially have high demands for the premises to be environmentally certified. But these demands may be forgotten when they design their own premises and "*would love to have rainforest wood in the boardroom*". The company has therefore worked to reduce the scope of possible adaptations for each new contract. However, tenants start to ask for taxonomy aligned premises as then they can take up their entire rental cost as a green capex and this is becoming very interesting for many service producing companies.

Value creation
Value creation refers to the process of creating value for customers and other stakeholders following the circular principles. It involves identifying opportunities to create value by reducing waste, minimizing the use of material, and maximizing the use of renewable resources. To develop their circular solutions, the A collaborates with university and research institutes. Besides they also have agreements with the centre for circular building, often called CCBuild, an arena where the construction industry players meet and collaborate on reuse and circular material flows during construction, demolition, and management of circular buildings. CCBuild is led by the Swedish Environmental Research Institute and is developed in broad collaboration with players in the building sector. CCBuild's partners contribute to the transformation to more circular construction by implementing and developing circular working methods and disseminate experiences to others. They provide among other a digital platform combining a data bank synchronised with an app where the companies can get figures for climate savings when reusing inventory products, or to easily inventory and label construction products before renovation or demolition. It can also be used for other applications, for example as support for circular product management within an organization or for check-in and check-out of goods at a recycling depot.

According to the interviewees, the W is still confronted to an AEC industry which probably thinks that they do not belong to the "wear and tear society" because they build houses that will stand for a hundred years, but at the same time they point out that houses from the 80s and 90s are being demolished and new built still cannot be dismantled. To get contractors more interested in buying in recycled material, the W has introduced a recycling premium so that the use of material surcharges will not hinder their efforts to reuse materials as they usually get refunded for the material buy in plus 15%. So, it has been in their interest to waste as much material as possible. The recycling premium is included in the framework agreements between the company and their contractors. As no contractor will suggest reuse if they simultaneously lose the mark-ups, they usually get in various kickback systems linked to building department stores and other material suppliers. The WHS points out at a few companies of material relatively easy to reuse- floor, glass partitions, doors- who are interested in taking back their own material. She explains "*They don't have to feel threatened anymore, but instead see the possibility that they can sell the same product twice". Those who have the best knowledge of the material take it back, recondition it and sell it again.* The W has yet not formalized agreement with any supplier but would very much like to have long-term collaborations for current deliveries of recycled material. When asked about the issue of guarantees often raised as one of the problems in connection with recycled material, but the sustainable manager downplay this concern, she claims that in the case where the guarantees a are usually invoked in new production, it is almost always about manufacturing defects, not that there is a fault with the use of the material on site.

Value capture
Value capture refers to the methods that companies use to generate revenue and capture value from their products or services. It involves identifying and implementing strategies to capture a portion of the value that the company creates for its customers. It is difficult for the A to assess the tangible benefits produced by their

implementation of circular models at least in financial term as by now only a small portion of their ongoing projects is integrating these principles. But these initiatives are giving the company a strong position in the market.

It is important for the W to insure for their pension fonds owner a benefit of their operation. They see an advantage of having a long-term circular strategy as they benefit from lower rent when borrowing money. They attract investors who are bonded by green mandates and therefore only allowed to invest in green companies or projects. Besides, between two similar properties located in the same area, the green certified one would theoretically be allocated a lower risk than the one which is not certified, which is another financial advantage. Installing recycled elements in all their projects, The W expects to spend the same amount for reused as they do for new material. So, they forecast similar cost for the delivery of their premises. Possibly, the rental of a reused premises could be formulated as a green offer. But most of all, the WHS believes in competing with the help of flexible lease agreements. There, an offer to rent in existing condition but with short notice could be a variant. However, according to the sustainable manager, the production processes of the company are not yet circular.

CONCLUSIONS

Though the companies both invest time and energy to develop CBM and aspire to be climate neutral by 2030, none of them has so far achieved the full integration of circular principles in their business portfolios. There is a generalized perception in the Swedish AEC industry that the two are forerunners of developing circularity and that they behave according to the expectations surrounding this development in the sector (Deephouse and Suchman 2008). Being awarded prizes and recognised as major actor, they both have attained moral legitimacy, increasing their ability to gain support and acceptance from stakeholders and investors. But as underlined by Suddaby and Greenwood (2005), moral legitimacy may represent mostly a shift in rhetoric and does not necessary imply that these principles are materialised in actions (Ossewaarde *et al.,* 2008). According to Suchman (1995) material legitimacy entails that organizations must be judged by what they achieve or the effects they produce. These effects are so far rather limited for our two companies if we compare their initiatives integrating circular principles to the extent of their business portfolios. Besides if circularity is an asset for the two companies' investments, it seems that its implementation in projects demonstrates less attraction for their clients. Reuse or recycle tends to be negatively connoted and their applications are therefore not advertised as a main marketing argument. So, if we come back to the EU goals to develop a market for circularity and achieve climate goals, we could be worried that even if the economic exchanges are including circularity, this does not necessary implies that the material flows are following the same trend. There is a urgent need to take a closer look at the application and possible conflicting consequences of the EU initiatives to achieve climate neutrality. The risk is to effectively create a circular economic market but dissociated from its physical implementation and that we keep building for the future without integrating the necessary changes to reach net zero aspirations.

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QUESTIONING COLLABORATION IN THE CIRCULAR BUILT ENVIRONMENT: MULTI-CYCLE, MULTI-SCALAR AND MULTI-LEVEL PERSPECTIVES IN THE RENOVATION SECTOR

Paul W Chan[1], Tomer Fishman[2], Vincent Gruis[1], Mingming Hu[2], Sandra Schruijer[3], Alfons van Marrewijk[1&4] and Ruben Vrijhoef[1&5]

[1] *Faculty of Architecture and the Built Environment, Technische Universiteit Delft, PO Box 5043, 2600GA, Delft, Zuid-Holland, The Netherlands.*

[2] *Institute of Environmental Sciences, Department of Industrial Ecology, Leiden University, PO Box 9518, 2300RA Leiden, The Netherlands.*

[3] *School of Governance, Utrecht University, Bijlhouwerstraat 6, 3511ZC, Utrecht, The Netherlands.*

[4] *Faculty of Social Sciences, Vrije Universiteit Amsterdam, De Boelelaan 1081, 1081 HV Amsterdam, The Netherlands.*

[5] *Building Future Cities, Utrecht University of Applied Sciences, Postbus 182, 3500AD, Utrecht, The Netherlands.*

Research on the circular built environment has to date focussed mainly on technical aspects of circularity in the built environment, emphasising the development of methods, tools, and frameworks to facilitate technical solutions that can narrow, slow, close, and regenerate materials cycles. Despite progress made in understanding the technical possibilities of circularity in the built environment, and although there has been longstanding acknowledgement that new forms of inter- and transdisciplinary collaboration are needed to accelerate and scale up solutions for the circular built environment, studies have also consistently highlighted the lack of collaboration as a significant barrier. In this position paper, we argue that existing research tends to focus on collaboration at the level of the building project, and this neglect calls for developing longer-term collaboration for circularity as a multi-level transition that considers the interactions between multiple parties involved in extended and multiple product lifecycles traversing multiple scales beyond the building project.

Keywords: circularity; multi-cycle; multi-scalar; multi-level; transitions

INTRODUCTION

Globally, there is growing interest in developing a circular built environment and to meet several societal and sustainability transitions, such as the energy transition and the provision of affordable housing. A critical challenge in these transitions lie in the need to transform, renovate, and adapt existing buildings at scale (International

[1] p.w.c.chan@tudelft.nl

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Energy Agency, 2020). Yet, at the same time, it is well-known that, relying on traditional linear-economy methods of 'take, make and dispose', the sector is extremely resource-intensive, consuming around 40% of the world's raw materials with only a small proportion of these (for instance, around 3-4% in the Netherlands) being reused at the end-of-life (e.g., Schut *et al.,* 2015; Pomponi and Moncaster, 2017; Kanters, 2020; Wahlström *et al.,* 2020).

Research on making the circular transition has to date focussed mainly on technical aspects of circularity in the built environment, emphasising the development of methods, tools, and frameworks to facilitate technical solutions that can narrow, slow, close and to a lesser extent regenerate materials cycles (e.g., Pomponi and Moncaster, 2017; van Stijn and Gruis, 2020; Çimen, 2021). Experimental pilots abound that stress the importance of circular designs that promote a greater degree of standardisation and modularisation to facilitate demountability and reuse of materials (e.g., Buildings as Material Banks, ud.). Despite progress made in understanding the technical possibilities of circularity in the built environment, two significant scientific and practical blind spots remain under-examined. Firstly, research has focussed mainly on circular designs for new buildings, with far less attention on renovating and adapting existing buildings. Applying circular design and construction approaches to renovation is particularly challenging, since solutions must consider limitations and barriers stemming from the original construction and current user preferences (e.g., Stolker and van Stijn, 2021). And because renovations are often conducted with the aim of increasing the energy efficiency and thereby reducing emissions during the use of buildings, a 'whole life cycle' approach is thus necessary.

Secondly, although there has been longstanding acknowledgement that new forms of inter- and transdisciplinary collaboration are needed to accelerate and scale up solutions for the circular built environment, studies have also consistently highlighted the lack of collaboration as a significant barrier (see e.g., a recent review in Çimen, 2021; and Kooter *et al.,* 2021; Sudusinghe and Seuring, 2022). Knowledge and guidance are still lacking as to what and how these new forms of collaboration can be put to practice (e.g., Çimen, 2021; Adams *et al.,* 2017; Kirchherr *et al.,* 2018; Leising *et al.,* 2018; Ollàr *et al.,* 2020; Çetin *et al.,* 2021). In this position paper, we argue that research on collaboration in the built environment will need to expand the focus to consider how collaboration can be stimulated and sustained beyond the level of the building project. Where circularity is concerned in the context of building renovation, there is a need to situate collaboration within the context of multi-level transitions (Geels, 2020) that in turn accounts for the interactions between multiple parties involved in extended and multiple product lifecycles traversing multiple scales beyond the singular building project (e.g., Dokter *et al.,* 2021; Heurkens and Dąbrowski, 2020).

This position paper is developed as follows. First, we sketch out ongoing transition towards a circular built environment in the context of building renovation, highlighting how challenges of a conservative sector navigating through the uncertainties of the circular transition can stymie the potential for engendering collaborative practices. Second, while there has been longstanding interest in studying collaboration in construction management research, studies have so far focussed on fostering collaborations at the project level. These tend not to consider collaboration that stretches over multiple product lifecycles in the longer-term. Third, using real-world examples, questions are raised with a view to better understand and develop collaboration that cuts across multiple levels of analysis and multiple spatial scales.

REVIEW OF PREVIOUS STUDIES

The transition towards circular renovation of buildings is now in a turbulent period and has attracted societal and academic attention (Leising *et al.,* 2018). Although there have been experiments in pilot projects to address circularity in building renovation, these are limited in terms of scaling up new practices (van Bueren and Broekhans, 2013), in part due to the technical focus of these pilots. Consequently, this technical emphasis downplays social and psychological aspects, which are also (if not, more) critical for driving learning and behavioural change (see Stam *et al.,* 2023). The invention and acceptance of new construction techniques by the organisations involved in circular renovation asks for a change in the kind of collaborative behaviour in the construction chain, one that moves away from the adversarial climate of power play and competition often associated with the construction industry (van Marrewijk *et al.,* 2014; van Marrewijk *et al.,* 2016).

Indeed, the conservative culture of the building renovation sector is a well-known obstacle that prevents the sector from breaking away from well-known traditional routines and scaling up new management practices (Wamelink and Heintz, 2015). For example, the 'renovation accelerator', which is the bundling of renovation work, was intended to transform the renovation of social housing in the Netherlands by exploiting synergies and economies of scale. This has reportedly failed due to ossified cultural practices in the sector (van Belzen, 2021), which reflects a larger history of failed attempts to change the Dutch construction sector into a high-quality and innovative sector (e.g., Priemus, 2004; Nijhof *et al.,* 2008; Sminia, 2011; van Marrewijk *et al.,* 2014).

While the narrative of deficiencies in previous reforms persists, past prescriptive calls and roadmaps for cultural change can be difficult to realise since these do not emphasize reflective practice that stimulates how (rather than what) cultural change can happen, the constraints and contradictions that might emerge, and how practitioners can overcome these. A high level of uncertainty regarding the costs and benefits of interventions remains (Meglin *et al.,* 2022). This uncertainty prevents actors in the building renovation sector from looking more broadly than short-term financial impacts to their respective organisations, which in turn leads to non-collaborative behaviours (Liu *et al.,* 2019).

While the technical possibilities of circular solutions are relatively well researched, a significant yet under-examined bottleneck lies in driving behavioural change through inter- and transdisciplinary collaboration (e.g., Pomponi and Moncaster, 2017; Rios *et al.,* 2022). Although collaboration has been identified as a key factor to scale up and accelerate circularity in the built environment, studies that develop new ways of collaborating are rare, particularly in the context of building renovation. Except for Leising *et al.,* (2018), studies often reiterate the perennial problem of a lack of willingness to collaborate (e.g., Adams *et al.,* 2017; Kirchherr *et al.,* 2018; Ollàr *et al.,* 2020; Çetin *et al.,* 2021; Dokter *et al.,* 2021; Kooter *et al.,* 2021) rather than to produce the practices, structures, and strategies on how to make collaboration work for the circular built environment.

Furthermore, where collaboration has been addressed in previous studies, these tend to narrowly focus on the single building project. For example, in a recent systematic review of 110 studies on collaboration in construction, Deep *et al.,* (2021) identified a number of key enabling factors, including trust, commitment and reliability, that facilitate collaboration in the context of project execution decisions that can contribute to project productivity. Koolwijk *et al.,* (2022) also found that financial rules can create or constrain the conditions lead to the building of trust and a no-blame culture, which in turn lead to the promotion or prevention of long-term project collaborations.

A common feature in studies on collaboration in construction is the characterisation of the industry as a fragmented sector of different professional actors/roles vying for their respective self-interest, often identifying critical success factors to offer prescriptions for addressing such fragmentation. Yet, already two decades ago, such research has drawn critical attention. Murray and Langford (2003), for instance, argued that scholars have focussed narrowly on the usual suspects (i.e., the client, contractor, and designer), often centring attention on a narrow set of performance measures (typically of time and cost) when addressing the problem of fragmentation (see also Chan, 2023). In responding to the trend of partnering in the late 1990s, Bresnen (2007) critiqued prescriptions of strategic alignment, standardisations, and performance benchmarking, and argued that exhortations of collaboration downplayed the complexities, fragilities, and problems of collaboration.

Two decades on and confronting the challenges of circularity in the built environment, it appears such criticisms remain relevant. In calling for innovation to develop sustainable built environment, Lizarralde *et al.,* (2014) analysed 50 peer-reviewed case studies to highlight how studies have generally focussed on internal project stakeholders while ignoring collaboration and participation of external stakeholders, particularly engagement with community actors external to the project. They noted especially the need to go beyond integration of project teams to consider how multiple clients can come together to embark on more ambitious projects and champion innovation that goes beyond the status quo to meet stronger environmental and social goals. Raouf and Al-Ghamdi (2019) also reviewed 43 qualitative studies and 24 quantitative studies on integrated project delivery to show how time and cost performance measures within the boundary of the construction project still shapes studies into delivery models and analyses of collaboration and integration.

Indeed, in tracing the social networks of front-runners in circularity in the built environment, Gerding *et al.,* (2021) also demonstrated how networks of the usual suspects of clients, contractors and designers often keep new actors such as the circularity advisor at bay, thereby reducing the influence of these actors in pushing forward the circularity agenda. Chen *et al.,* (2021) also systematically reviewed literature on construction supply chains. They concluded that previous studies tended to dwell on the project level, by focussing narrowly on design-to-production, production-to-logistics, and production-to-site-assembly phases, reinforcing the enablers such as project-level contracts and incentives, knowledge sharing systems at the project level and technological enablers such as linked databases for design coordination, design for manufacturing software platforms and automated monitoring technologies. The emphasis on project-level collaboration constitutes, as Vosman *et al.,* (2023) argued, a significant barrier in developing what they termed as "project-transcending innovation" (p.458) that can transform the built environment considering the grand challenges of climate change adaptation and the circular economy.

Thus, to achieve a circular renovation industry there is a need to investigate and develop long-term collaboration beyond the scope and scale of the project. As

Jacobsson and Söderholm (2022) recently articulated in their essay on homo projecticus, project managers are often guided by temporal and scope bracketing, which, while reducing complexity and containing uncertainty within the confines of the project, can risk becoming "blinders that prevent decision-makers from seeing the bigger picture […] unforeseen ethical consequences or consequences related to sustainability occurring as a long-term, or parallel, effect of the actions taken" (p.318). In the next section, questions are raised as to how, in addressing these sustainability consequences through the reuse of building materials and components, there is merit in considering the significance of multiple and extended product lifecycles, accounting for the dynamic interactions between multiple levels from projects to industry regime to society at large, and across multiple scales covering cross-sectoral cooperation at an area-based neighbourhood scale.

DISCUSSION

Raising new questions about collaboration in circular building renovation: towards multi-cycle, multi-level, and multi-scalar perspectives

Unlike project-based design and construction of new buildings, a key distinguishing feature of circularity in building renovation is the longevity of built environment products (e.g., structural elements, building services), with many lasting several years or even decades (e.g., Dokter *et al.,* 2021). The variety of built environment products also means that collaboration in the circular built environment must extend beyond the building project ('here and now'), to consider multiple product lifecycles that extend into the longer-term future (Rodríguez *et al.,* 2020). For example, solar panels are increasingly offered as a renovation option to provide a useful source of renewable energy to meet the energy transition. In 2020, the number of solar panels installed just in Amsterdam grew by 70%, with nearly half a million panels already installed in Amsterdam. Yet, more and more panels are replaced prior to reaching their end-of-life, leading to unnecessary use of new, increasingly scarce, and toxic metals (see Kerp and Jönsthövel, 2021). Furthermore, in the European context, new solar panels tend to be produced and imported from far away countries like China. Therefore, there are long-term uncertainties surrounding the supply, long-term maintenance, and safe decommissioning of solar panels at the end-of-life so that the hazardous materials contained in these panels can be reused safely and efficiently. Yet, this requires collaborative arrangements that go beyond the lifespan of the single project to cover the lifetime of the solar panels set within the uncertain context of renovation and maintenance decisions over the lifetime of the building. Thus, there is also the likelihood of developing collaborative relationships with not-yet-known parties in the chain, especially given how the lifespan of a building and its products may outlive the lifespan of the firms providing the products and services in the first place.

While projects have been conceptualised as portals of innovation for sustainable building (van Bueren and Broekhans, 2013), optimisation of project decisions can also jeopardise wider societal challenge of resource and energy efficiency. To avoid what Hall and Bonanomi (2021) termed as the "tragedy of the project" where partners withdraw too many resources from the project leaving a depletion of resources available in the common pool, project decisions need to be situated within a multi-level transition framework so that decisions for circular renovation can be done in coordination with transforming the regime and changing broader behavioural and societal norms and values (Heurkens and Dąbrowski, 2020; Rios *et al.,* 2022; Stam *et al.,* 2023). To date, though, consideration of multilevel perspectives in relation to construction projects is rare (see e.g., van Uden *et al.,* 2022; Chan, 2023).

In challenging current narrow focus on the building project, there is a need to rethink spatiotemporal dynamics of the activities and relationships (e.g., Jensen *et al.,* 2016) in producing the circular built environment. A perennial challenge with circularity is to secure the appropriate reusable and recyclable materials at the time and place that is needed (Chan *et al.,* 2021). This requires the timely involvement and embedding of emerging new actors that are currently not integrated, e.g., circularity advisors (Gerding *et al.,* 2021). In addition to inter-organisational project collaborations, there is scope to consider presently-underexamined inter-sectoral collaborations (e.g., between construction, manufacturing, and the logistics sectors) with a neighbourhood focus (e.g., Koch-Ørvad *et al.,* 2019; Hedborg and Karrbom Gustavsson, 2020; Çimen, 2021). Koch-Ørvad's *et al.,* (2019) study is a noteworthy example of taking a multi-scalar collaboration approach. They presented a case study of Gamle Mursten, a Danish company the specialises in cleaning and selling reused bricks. Although there is an estimated potential to reuse 47 million bricks a year, as a disruptor, Gamle Mursten faced many obstacles including the ability to stimulate demand in the market, getting access to old bricks, and regulatory hurdles in certifying the structural strength and quality of reused bricks. Koch-Ørvad *et al.,* (2019) observed that Gamle Mursten tackled these challenges by concurrently starting six projects, half of which were aimed at addressing the problem of access to reused bricks (i.e. supply-side problem) and the other half targeted at improving the documentation and certification problem (i.e. to stimulate demand), in order to build the ecosystem and secure their position as intermediary to stimulate supply and demand for reused bricks in Denmark (see also Vosman *et al.,* 2023).

Koch-Ørvad's *et al.,* (2019) study raises an important knowledge gap in terms of seeing beyond the construction project. When the 'project' is often examined in construction management research, there is often a tacit assumption that the project is a 'building' project. Attention is then placed on identifying optimal pathways to ensure that the building is completed on time and on budget. Yet, the analysis of Gamle Mursten shows that alongside the 'building' project, companies can often start other concurrent projects to facilitate change and innovation. This multi-project context is rarely considered in the construction management literature. Indeed, their study was also revealing of the multi-level practices of confronting and negotiating the existing regime (e.g., by offering alternative value propositions and collaborative opportunities to demolishers and finding ways to circumvent prevailing certification schemes) through micro-level routines in the building project. In so doing, they also show how Gamle Mursten combined both exploration and exploitation in growing the use of reused bricks.

CONCLUDING REMARKS

This position paper builds on growing interest in the sustainability transition of moving towards a circular built environment. While studies on circularity have focussed on the design and construction of new buildings, circularity in the context of building renovations is relatively under-examined. Despite recognition of the importance of collaboration in the circular transition, existing studies have tended to highlight the challenges and problems with collaboration while falling short of presenting possible solutions. In this position paper, an argument has been made to consider collaboration beyond the project level, to take into account multiple and extended product lifecycles, multiple levels of engagement in the circular transition, and multi-scalar collaborations that consider the ecology of adjacent projects alongside and beyond the 'building' project.

In taking multi-cycle, multi-level and multi-scalar perspectives to study and develop ways to collaborate in circular renovation, several critical questions can be raised for future research. First, from a multi-cycle perspective, there is a need to shift our thinking away from project-based collaboration to collaboration over multiple product life cycles. Yet, given that part of the ambition of circularity is to prolong the lifespan of products, there is a need to address the challenges of collaboration in the context of the uncertainties associated with not-yet-identified partners, particularly in the repair and maintenance of products and especially since products are, in principle, likely to outlive the lifespan of the firms that produce these products in the first place. Second, from a multi-level perspective, the shift away from project-based collaboration necessitates collaboration with the less-usual stakeholders in the regime. How can new actors such as the circularity advisor and local communities external to the project be embraced and empowered to influence choices made at the project level? How can lessons be captured and spread from collaborations at the project level to transform the regime?

Third, from a multi-scalar perspective, in moving away from simply looking at the 'building' project, questions remain as to how scholars and practitioners can strengthen coordination across multiple projects, perhaps at a neighbourhood level. To date, research is limited in explaining how actors in/from one project (can) coordinate with actors in adjacent projects, within a firm (as in the case of Gamle Mursten) or across firms at an area level, so that the demand and supply of secondary materials in the market can be better connected. What are the opportunities and obstacles of collaboration beyond the local context of the project, including collaborations with actors at multiple scales such as neighbourhood area, city, national and inter-national scale, to facilitate the transition in circular building renovation? In any case, taking multi-cycle, multi-level and multi-scalar perspectives will likely alter the framing of the construction manager and her/his role beyond the narrow confines of delivering the project in a timely and cost-effective manner. In what ways will taking such perspectives alter the role of the construction manager, and their facilitation of collaboration beyond the project, remain an area for further investigation.

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CIRCULAR INFRASTRUCTURE IN TERMS OF INSTITUTIONAL LOGICS

Tom B J Coenen[1], Leentje Volker[2] and Klaasjan Visscher[3]

[1&2] *Department of Civil Engineering and Management, University of Twente, Drienerlolaan, Enschede, The Netherlands*

[2] *Department of Technology, Policy and Society, University of Twente, Drienerlolaan, Enschede, The Netherlands*

The concept of the circular economy (CE) has gained popularity in addressing concerns related to environmental sustainability. However, difficulties arose in scaling up and integrating CE solutions into the infrastructure sector. This paper argues that the institutional logics underlying the current infrastructure sector are incompatible with the logics on which CE is based. To examine this, we conducted a study using literature and empirical evidence from the Dutch infrastructure agency though in-depth interviews. By relating the arguments of interviewees to values, norms, and worldviews, we were able to establish and compare the prevailing logics held by infrastructure professionals with those related to CE. The results reveal a conflict between the dominant market logic in CE development and the prevalent state and project logics that guide infrastructure practices. These findings highlight the importance of strong leadership from public clients to incorporate CE principles into construction processes. By addressing the institutional barriers to CE scaling, this paper contributes to the ongoing discussion on implementing CE in the infrastructure sector and provides valuable insights for policymakers and public clients.

Keywords: circular economy; institutional logics; transition; infrastructure; agency

INTRODUCTION

In European countries, circular economy (CE) has gained significant attention in addressing environmental sustainability concerns within construction. CE is generally understood as an integral set of principles to close, slow, and narrow resource loops (Mhatre *et al.,* 2021). Being in line with a sustainable future, circularity is presented as one of the promising directions for a future-proof construction sector. Despite its growing popularity in policy and the emergence of many pilot-scale initiatives and innovations, there is a gap in achieving upscaling and systemic embedding of CE solutions in the infrastructure sector (Circle Economy, 2023; PBL, 2023). In contrast, solutions in the domains of energy transition and carbon reduction seem to experience a more vigorous institutionalization, although falling behind their targets (OECD, 2022). While public organizations can stimulate and enforce circular requirements in projects through procurement and legislation, the systemic nature and contested solution direction of CE prevents the transition from being top-down implemented

[1] t.b.j.coenen@utwente.nl

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(Coenen *et al.,* 2023). Why is it difficult to get impactful circular solutions implemented and upscaled in the infrastructure sector? We argue that the institutional logics that underpin the CE concept are incompatible with the dominant logics of the public and project-based infrastructure sector. To support this argument, we examine in this paper the institutional logics that the CE concept has drawn from over the past decade through a review of literature and utilize empirical evidence from the Dutch infrastructure agency to compare the prevailing logics with infrastructure practices and to assess their (in)compatibility with CE.

Theoretical Background

Institutions and Institutional Logics

Institutions are generally understood as the humanly installed structures of formal and informal rules and norms that shape and constrain behaviour and interaction, or put more briefly, 'rules of the game' (North, 1991). Although institutions are persistent, they are reproduced by agency and can change over time. Rather than being tangible and enforceable devises, Dequech (2009, p. 70) described them as “socially shared patterns of behaviour and/or of thought”. Institutions are situated in specific contexts, with, for example, spatial, cultural, domain-specific, and temporal dimensions. Within the field of institutional theory, which looks at the processes of change, creation, and persistence of these institutions, institutional logics acknowledge the often-implicit inclusion of the role of culture in institutional analysis (Thornton *et al.,* 2015).

Friedland and Alford (1991) introduced institutional logics as specific meta-level institutional contexts, defined by Thornton and Ocasio (1999, p. 804) as “the socially constructed, historical patterns of material practices, assumptions, values, beliefs, and rules by which individuals produce and reproduce their material subsistence, organize time and space, and provide meaning to their social reality”. In addition to the structures of institutions mentioned above, institutional logics provide the symbolic aspects that help actors obtain legitimacy, status and reward incentives and include both the implicit and explicit values and assumptions that guide agency (Thornton *et al.,* 2015). Individual actors and actor groups can be confronted with multiple institutional logics and are argued to be capable of combining and exploiting multiple - possibly contradictory - ones to achieve their goals (Durand and Thornton, 2018).

Logics on the organizational level and organizational hybridity

Besharov and Smith (2014) highlighted that most organizations face organizational complexity resulting from the presence of institutional pluralism relating to multiple institutional logics in the organizational context. This multiplicity requires the organizations to respond to various institutional demands (Kraatz and Block, 2008). Existing logics can conflict, coexist, and blend and might be employed to navigate governance, yet they can also be a hindrance (Greenwood *et al.,* 2011). Organizations that draw from multiple logics are referred to as hybrid organizations (Jay, 2013). This hybridity concept is useful to study both the power struggles between internal logics that precede organizational change and the approach of organizations towards multiple institutional contexts. In this paper, we are primarily interested in the latter.

Hybrid organizations respond in diverse ways to external institutional pressures and demands. As Greenwood *et al.,* (2011, p. 342) remarked, “institutional pressures […] are interpreted, given meaning, and ‘represented’ by occupants of structural positions”. Therefore, the interaction has different consequences for the organization in different situations (Farid and Waldorff, 2022). This notion of hybridity necessitates specific responses for which some organizations or individuals within organizations may be better equipped than others, partly depending on their ability to draw from various logics. In public infrastructure, for example, demand is articulated by the society through the Government, while also the private sector parties executing infrastructure works have specific demands and practices that call for specific responses.

To capture both the public and private sector logics, in this paper we study the infrastructure sector from the perspective of a pivotal type of organization that acts as an intermediary between political clientship and market parties: infrastructure agencies. These organizations deal at least with the political institutional environment that governs the organization on the one hand (Brandsen and Karré, 2011), and on the other hand the professional logic-grounded project logic that arranges the interactions between private contractors and the public client organization (Frederiksen *et al.,* 2021; Matinheikki *et al.,* 2019). Public client organizations are inherently hybrid and, therefore, employ internal strategies to deal with these pluralistic institutional contexts (Kraatz and Block, 2008). These organizations are hence appropriate subjects to study the alignment between existing logics and logics that relate to CE in infrastructure.

The Logics of Circular Economy

This paper focuses on the external institutional demand related to the introduction of a systemic sustainability-oriented concept, the Circular Economy (CE). While environmental concerns are traditionally pushed by individuals and organizations with intrinsic and idealistic concerns, the realm of sustainability-orientation is often linked to economic models that are contra-capitalist and advocate degrowth (Khmara and Kronenberg, 2020). This clashes with the dominant neo-liberal market logic that aims for economic return and growth (Kemper *et al.,* 2019). From the early publications on CE onward, the reduction of environmental impact has been deliberately coupled to value retention and value creation, for example through the reinvention of business models and the concept of value to make sustainable behaviour economically profitable (e.g., Ellen MacArthur Foundation, 2013).

Although others advocate against it (cf., Bauwens, 2021; Corvellec *et al.,* 2022), the "economic viability" is often one of the main motivations for CE enthusiasts and has for that reason gained popularity in business and policy environments. To illustrate this, Aarikka-Stenroos *et al.,* (2021, p. 262) observed: "the CE seems to (re)shape the logic of value creation, not only for individual firms but also for value chains and networks, as the firm needs to acknowledge more and diverse actors and stakeholders for which the firm creates value." DiVito *et al.,* (2022) go even as far as to speak of a "circularity logic" as opposing to linear logics. Nevertheless, the high degree of contestation of CE (Coenen *et al.,* 2022), as well as the lack of institutionalized circular practices (Buser *et al.,* 2021; Greer *et al.,* 2021), indicates that CE is not yet a logic in itself, however draws from several existing logics - primarily the sustainability logic and the market logic. To embed CE in the infrastructure sector, it is vital to understand how these logics relate to and align with the logics that are dominant in structuring infrastructure practices.

METHOD

The goal of the study is to analyse how the logics on which CE is developed correspond with the dominant logics in the public and project-based infrastructure sector. In the public infrastructure sector, which focuses on the construction and management of infrastructure assets such as roads and waterways, there is an apparent difference between public and private sector institutional pressures that result in misaligned and conflicting logics (Kuitert *et al.,* 2019; Van der Wal *et al.,* 2008). The executional body acts as a pivotal actor in the system, since it intermediates the Ministry as a formal client and market parties as executors and have many roles, including client, asset owner, and legislator. By examining the logic multiplicity of an infrastructure agency, sectoral institutional pressures and their interactions are revealed, which allows for comparison with logics related to CE in the sector.

To study the hybridity and compare the constellation and dynamics of logics to which the organization responds with the CE concept, twenty-one in-depth semi-structured expert interviews were conducted. Although being executed as open conversations, the interviews were semi-structured around several guiding questions (Hammer and Wildavsky, 1993): How is circularity part of your work? What are your actions to implement circular solutions, and why? What do you get and need to implement circularity? What stimulates and hinders you in advancing circularity in the organization, and why? What is the role of your organization in becoming circular?

To capture and represent the institutional pluralism in the sector, individuals were selected from across all ranks and divisions of the organization, including executive staff, line management, asset management, project management, management of major organizational programmes, strategy department, regional divisions, and the sustainability/CE department. This also included individuals on the organizational boundaries, such as members of public-private projects and policymakers. This resulted twenty-one interview transcripts of 7.000 to 12.000 words each. These transcripts were coded on four categories: values, CE implementation process, infrastructure management process, and institutional logics. Here, values refer to specific aspects of perceived importance; the CE implementation process to the activities related to the execution of circular practices and strategies; and logics to general categories of collections of practices, assumptions, values, beliefs, and rules that motivate individuals to act in a particular way. Indeed, values are also part of the logics yet are coded separately to emphasize and nuance differences in judgement of what is important to public infrastructure. Each theme was iteratively developed during the coding process and consists of 11 to 40 first-order codes. These were aggregated in second-order codes (Saldaña, 2013).

By linking the codes to interviewed individuals and their position within the organization, clusters of individuals were identified with respect to their adherence to specific collections of related logics. This collection of clusters and their associated features allowed us to study the interaction between internal clusters, the clusters in relation to the infrastructure management process, and between the logics related to the CE concept and particular clusters.

FINDINGS

First, the institutional contexts of the infrastructure agency are explained in terms of the four dominant clusters of logics. Second, these clusters are compared with the logics dominant in CE as explained in the theoretical background section.

Organizational Hybridity in the Infrastructure Agency

The studied infrastructure agency operates as the executional body of the Ministry of Infrastructure. This public nature is reflected by a state logic that emphasizes procedural orientation and adherence to traditional bureaucratic values. An illustration of this logic was stated by an executive staff member: "It is up to the Ministry to consider how we spend the resources effectively and they will always try to justify [these spendings]. And we [as an infrastructure agency] just implement this policy." This quote highlights the organization's perception of its executional role in accordance with the state logic, which results in a devotion to transparent procedures and accountability for operational actions and expenditures. This logic can be found at the executive layer of the organization but is also dominant throughout middle and higher management and highly reflects the position of the Government.

The organizational production line is predominantly guided by the professional logic yet manifests itself in two distinct ways. Towards planning, budgeting and maintenance, there is a dominant asset management logic that is primarily concerned with the preservation of existing infrastructure through monitoring and maintenance. This cluster incorporates a long-term and asset-oriented view regarding the purpose of the infrastructure organization, with plannability, risk-aversion, and integrality as key values. However, it is worth noting that there are elements of both state logic and market logic at play, as a regional asset manager pointed out: "We leave a great deal of actual execution to market parties. When we need certain maintenance activities, we leave quite some room to manoeuvre to the market for selecting their preferred solutions". The asset management logic is strongly present in regional departments but can also be found in the central strategic planning departments.

Related but different is the project logic. This cluster is strongly represented among the interviewees and is highly task oriented. This logic draws more heavily from the market logic compared to the asset management logic, with a focus on project efficiency, feasibility, and scope delivery. As such, individuals that come under this cluster interact with external private sector parties in temporal organizations (i.e., projects), with project boundaries taking priority over asset boundaries. This was illustrated by a portfolio manager who stated: "we get the project scope imposed by the Ministry in an order form, including project budget. […] If they think circularity is important, they will include it in the scope form, and we will execute it." This group serves as the interface with private sector organizations in the sector and dominates the logics of contractors in the sector. Yet, most public organizations, including the infrastructure agency, can be identified as project-organizations too, given their project-oriented approach towards managing, maintaining, construction, and replacing infrastructure assets.

A distinct cluster within the organization is composed of individuals in the strategic and knowledge departments. This group is strongly motivated by personal and societal concerns and follows a sustainability logic that prioritizes values such as knowledgeability and innovation, and derives legitimacy from national and supranational agreements, missions, and ambitions in the environmental sustainability domain. However, within this cluster, there is a dominant believe that CE impact on infrastructure should be made in projects and that the existing explorative and knowledge-producing approach does insufficiently account for this. As a manager of the CE knowledge programme explained: "For years, the CE programme […] was very divergent by nature […]. However, as a team we are increasingly transforming from an explorative mindset to a demand-driven approach in relation to the formally designed transition pathways". While this group is grounded in sustainability logic, they are increasingly drawing from other logics to implement CE and foster change, and to bridge the various logics both within and beyond the organization. While the number of individuals that draw from this logic is limited and scattered throughout the organization, it is represented in their relations with, e.g., consultancies and knowledge institutes, and draws from wider societal pressures.

Alignment of Logics Between the Infrastructure and the CE

How do these four clusters identified in infrastructure align with the logics related to CE concept discussed in the theoretical background section? The long-term treatment of infrastructure assets is determined by the asset management and state logics. These are in the hands of public asset owners and related to continuity, as well as clear and transparent procedures and processes. The logics in which CE is grounded (i.e., sustainability logic and market logic) do have little chance to be aligned in this planning and budgeting phase, since the values prioritized by these clusters, such as accountability and transparency, conflict with values that are covered by CE, such as sustainability and profitability.

Moreover, the institutionalized practices and processes leave little room for deviation, which was mentioned by many interviewees as a main barrier for implementing CE in the infrastructure processes beyond the project scope. Nevertheless, when reflecting on the role of CE, an asset manager remarked: “If we manage the assets, along their lifecycle, then we should be the ones that formulate [circular] requirements, particularly towards projects. […] But we do not have that role and leeway.” While the major CE impact can be unquestionably made in these early planning and budgeting, there the least room to do so. Also in most interviews, projects were seen as primary vehicles for change, e.g., through procurement requirements and incentives for innovations, while the more systemic changes should be sought earlier in the asset management and planning process.

After the order form is formulated by the Ministry, and reaches a project manager, there project manager must stick to the scope. Here, often no particular CE goals or requirements are included by the state logic-centred Ministry. Following the project logic, the project management team is focused on completing the project according to the predefined boundaries. Only this late in the process, the sustainability cluster is involved, in which the knowledge department with the sustainability logic points at opportunities for CE. However, due to the restraining project boundaries, project managers and other project employees are reluctant to CE suggestions and knowledge from the knowledge and strategy departments. This is the case even though most of the interviewed project members are personally in favour of circular values yet, at this stage, CE logics conflict with the project boundaries. Illustrated by a project manager: “For who works in projects goes: […] there is a lot of thinking and dreaming on circular solutions, but is it tradeable for higher costs? Or for risks? Who [at the top] says, just do it and we will arrange the finances...” Therefore, implementing CE at this stage will take the project team a lot of effort, and additionally increases project risks.

It is only after this point that, often in consultation with engineering firms, private sector parties (i.e., contractors, suppliers, consultants) engage in the construction process. Following the market logic, occasionally combined with sustainability logic, these parties have in the past showed significant interest in CE, ranging from material innovations to novel business models. Since the scope of the projects is at this stage already strictly defined before entering the market space, there is little space for market parties to insert their circular solutions, especially when these require modification of processes beyond the project scope. Since the contractors are dominated by a market-oriented project logic, interviewees experienced a lack of investment by these parties, even if circular solutions are included in the tender. Even more so when the solutions are either radical or when they address higher levels on the waste hierarchy due to the demand-driven nature of infrastructure solution. This is illustrated by a project manager in one of the few occasions in which the circular reuse of bridge components was established: “I receive the reusable [components], but I am not going to deconstruct them from the previous asset, nor am I going to store them in the meantime. […] That would be a project in itself.” A market party could hence introduce a novel way of reusing components, but if the project governance on the client side (which is guided by project logic and eventually planned through state logic) is not aligned, the solution will not be implemented. This is propelled by the lack of knowledge and contestation on how circular solutions look like throughout the sector, which prevents further embedding in processes and norms.

Apart from the regular process, interviewees mentioned several initiatives in which the community logic was employed to create a safe space for both public and private actors to collaborate on and explore circular initiatives, leading to several successes. However, these initiatives remained outside the organizational structures, which limits chances for learning, institutionalization, and upscaling. In some cases, this is linked to market logic, for example regarding as-a-service business models, but more often, it is linked to match solutions with opportunities for implementation in a single pilot project. Given the demand-driven character of the infrastructure sector, the dependence on practices that draw from the state logic remains large - and systemic innovation and implementation opportunities therefore limited.

DISCUSSION

The results show that the decisions on how infrastructure is organized, managed, and built is strongly reliant on groups of people that draw from state logic. Being considered as systemic in nature (Aarikka-Stenroos *et al.,* 2021), as well as being coined as a “corporate-led model” (Corvellec *et al.,* 2022), indicates that the market logic plays an important role in CE. For instance, this could mean that entrepreneurs use specific types of recycling or reuse to eventually reach economic efficiency while reducing environmental pressure. The discussion from the CE perspective is primarily on building systemic incentives to make sustainability profitable, which is currently only practiced on the project level. The asset management logic and state logic, that eventually have the largest consequence on asset lifecycle choices of infrastructure (and hence material flows), lack a fundamental incentive to make sustainability profitable and hence cannot implement circularity the way it is promoted for many other sectors. As a result, the actors that eventually draw from the same logics as the CE concept, i.e., private sector parties, come only into play when the major lifecycle choices of infrastructure assets (e.g., maintenance, replacement, removal, reuse) are already made. This is a major reason why the majority of circular solutions relate to project-scale solutions, such as substitution materials, rather than solutions that fundamentally reduce resource use or environmental impact (PBL, 2023).

This differs from other developments and concepts in the domain of environmental sustainability, such as carbon reducing alternatives, as these can be achieved to a large degree within a traditional value frame (Kuitert, 2021). Therefore, these fit within conventional logics in the sector. Results of our study show that the existing logics in infrastructure do not facilitate the logics behind CE and therefore require other processes of implementation. This observation might seem disappointing, yet merely indicates that CE cannot be fundamentally implemented within the current alignment of logics and construction processes in the infrastructure domain. As such, it cannot be expected that the transition towards a circular infrastructure sector will come from market parties (as would be expected considering the logics on which CE is based), but rather depends on how principles from the CE concept are embedded in the processes from the government side (Flynn and Hacking, 2019).

There are several ways in which the CE principles can be embedded in or aligned with existing logics. Particularly the asset management logic provides several opportunities to CE principles, especially related to strategies regarding lifespan extension, infrastructure planning, and a network perspective on infrastructure assets. However, this requires a strong leadership role of policy and public clients and lesser dependence on one-off public-private projects. For the individuals that are confronted with state logic, this is more complex since it would require a top-down order to change practices and processes into circular ones. This implies a close connection to political decision-making, with, apart from a potential lack of political will, the drawback that the people that are guided by state logic are usually not the ones that have in-depth knowledge on the infrastructure assets and related asset management processes. This group of policymakers should therefore draw from the sustainability logic, which can be provided by the experts in or outside the organization.

CONCLUSIONS

In conclusion, this paper provides insights into the challenges of implementing and upscaling circular economy solutions in the infrastructure sector using an institutional logics lens. Our study suggests that the institutional logics that underpin the current infrastructure sector are incompatible with the logics on which CE is developed. As a result, circular solutions are mostly limited to project-scale initiatives and do not fundamentally reduce resource use or environmental impact. Our research highlights the need for strong leadership from public clients to embed CE principles into infrastructure processes. As such, this paper contributes to the ongoing discussion on the challenges of implementing CE in the infrastructure sector and provides insights for policymakers and public clients on CE upscaling in the infrastructure process.

The ongoing alignment of logics suggests the ongoing emergence of a new, CE logic within the sector, even though it is not institutionalized yet. This CE logic should be sector-specific, since the large dependence on public clients does not allow for bottom-up institutionalization of innovative technologies, practices, processes, or norms. When constructing for the future, anticipated directions for change in the sector must align with the logics carried by the actors responsible for doing the work.

Future research could explore how CE can be integrated into existing institutional logics in the infrastructure sector, and how to overcome the current institutional barriers to the upscaling of circular solutions. Moreover, the paper sheds light on the emergence of a new logic, the CE logic, which requires sector-specific institutionalization. Future research can investigate how the CE is institutionalized in the infrastructure sector, and the role of the various public and private sector actors in this process.

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POLICIES FOR THE TRANSITION TO CIRCULAR CONSTRUCTION: A SYSTEMATIC LITERATURE REVIEW

Jieling Huang[1], Mohamed Abadi and Jillian Yeow

Department of Engineering Management, School of Engineering, The University of Manchester, MECD Campus, Manchester, M13 9PL, UK

Policy support is an indispensable enabler to provide top-down momentum towards the transition to circular economy (CE) in the construction industry. However, CE implementation in construction is still in its infancy impeded by various barriers. Little is known about the impact of policy tools on initiating behavioural changes. This study aims to investigate how CE policies impact on the transition to circular construction through the lens of the theory of planned behaviour (TPB). A systematic literature review was undertaken to identify CE policy instruments and relate them to the main constructs of TPB, namely attitude, subjective norms, and behavioural control. Results presented 17 CE policy tools classified into economic incentive, regulation control, and supporting activities. This study revealed that existing policy instruments showed relevance to the three behavioural determinants in TPB implying their positive impact on encouraging circular behaviour. However, their effectiveness in driving behavioural change is still unclear. Future studies may consider policy evaluation methodologies, such as system dynamics modelling, to understand the effectiveness of policies through scenario analysis.

Keywords: circular economy; policy; systematic review; planned behaviour

INTRODUCTION

The construction industry faces widespread criticism for being highly resource-demanding despites its pivotal role in the national economy. In Europe, construction activities account for half of total raw material consumption and one third of total waste generated (European Commission, 2019). Against this backdrop, circular economy (CE) emerges as a promising strategy for decoupling economic growth from resource depletion and has gained increasing traction worldwide as a pivotal part of national policy agenda (Yu *et al.,* 2022). For instance, the European Union (EU) set out its aspirations to gravitate towards circulating material flows and improving resource efficiency in its CE Action Plan (European Commission, 2019). CE seeks a paradigm shift from the linear 'take-make-use-dispose' to a closed-loop process that sustains the circulation of resources and retains their value (Nasir *et al.,* 2017). The fundamental principles embedded in CE are the R frameworks ranging from 3R, 4R to 9R, among which the 3R (reduce-reuse-recycle) is the most well-received framework that guides the course of action in policies or regulations, such as the Waste

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[1] jieling.huang@postgrad.manchester.ac.uk

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Framework Directive in the EU and the CE Promotion Law of the People's Republic of China (Yu *et al.,* 2022). The construction industry has been the focal target of CE policies due to its high resource intensity (Hjaltadóttir and Hild, 2021), whilst CE in construction is still at the nascent stage of development governed by supply-push impetus with more influence of stakeholders at levels higher than the project network, such as academic institutions, think tanks and the authority (Huang *et al.,* 2022). Numerous research endeavours were undertaken to ease the transition to CE in construction by identifying the associated barriers/enablers (e.g., Adams *et al.,* 2017; Hart *et al.,* 2019; Hossain *et al.,* 2020), where policy instruments are considered crucial determinants that facilitate the top-down momentum of shaping and scaling up CE initiatives (Yu *et al.,* 2022). Bottom-up initiatives are derived indicating a shift in stakeholders' behaviours because of the interventions by policymakers (Adabre *et al.,* 2022). The behavioural dimension arises as a breakthrough to the CE transition (Pomponi and Moncaster, 2017), as the goal of policy 'push' is to create a 'pull' environment driven by behavioural change (Huang *et al.,* 2022). Enabling policies will help develop behaviours required for achieving circularity in constructing for the future as a pathway to sustainability. This study thus seeks to explore CE policies in construction from the perspective of behavioural aspect.

LITERATURE REVIEW

Policymakers are still puzzled on how exactly CE ambitions should be translated into tangible policies in construction (Yu *et al.,* 2022). Fitch-Roy *et al.,* (2021) examined current CE regulatory policies packages in 60 countries and questioned their effectiveness in realising CE targets. They claimed that achieving CE requires transformative disruption to current linear modes of production and consumption, while current policy landscape is conducive to applying incremental 'patching' and does not initiate a radical change towards circularity. There has been a limited amount of research on how construction companies respond to growing policy emphasis of CE implying a disconnection between policymakers' emphasis on CE and their awareness of how CE is currently implemented in practice (Ghisellini *et al.,* 2018). This issue is reaffirmed by Hjaltadóttir and Hild (2021) who investigated construction firms in Luxembourg and Sweden regarding their circular practices and uncovered that CE discourse in construction gave greater attention to 'sayings' (i.e. developing CE's framing and meaning) rather than 'doing' (i.e. undertaking actual CE initiatives). Yu *et al.,* (2022) sought to inform better policy design of CE in construction by establishing a framework for guidance. They depicted CE policy making as a dynamic, interactive, and iterative cycle and proposed a five-stage policy cycle comprising of agenda-setting, policy formulation, policy decision-making, policy implementation, and policy evaluation.

However, policy development alone does not suffice in this transition that also entails a shift in stakeholders' behaviours to act in accordance with CE targets (Hart *et al.,* 2019). Parajuly *et al.,* (2020) perceived a mismatch between individuals' claims and their actions in terms of 'circular behaviours', where individuals assert that they are willing to undertake CE initiatives (e.g., leasing, use of recycled/reused products), but their practices do not reflect their claims. This discrepancy can be attributed to various factors, such as individuals' preference for ownership, tendency for the latest fashion, price sensitivity, and short-term vision (Bastein *et al.,* 2013). Pomponi and Moncaster (2017) suggested that behaviour patterns towards the use of reclaimed materials vary in different materials under consideration, as they exemplified that clients may be resistant to equip their brand-new buildings with unattractive reused steel but willing to use reclaimed wood due to the aesthetic appeal. Moreover, Hao *et al.,* (2022) examined construction workers' pro-environmental behaviour towards waste management practices and uncovered that physical stress, environmental awareness, and tedious construction processes are the key behavioural determinants. The above discussions have revealed the complex nature of human behaviour that can be explained in relation to behavioural change theories.

This study focuses on the Theory of Planned Behaviour (TPB) which is one of the most widely used psychological theories in pro-environmental behaviour research developed by Ajzen (1991) and applies it to the implementation of CE policy. As presented in Figure 1, TPB suggests that individuals' intention of undertaking a certain behaviour can be explained by three main constructs, including a person's attitude (i.e., favourable or unfavourable evaluation of the behaviour), subjective norms (i.e., pressure from surrounding community as to whether or not conduct a certain behaviour), and perceived behavioural control (i.e., the perceived ease of difficulty of performing the behaviour). The three constructs are antecedents of the behavioural intention that denotes the level of motivation towards enacting the behaviour. The fundamental assumption behind TPB is that the likelihood of performing a certain behaviour is positively correlated with the level of behavioural intention, while sometimes individuals have strong intentions but fail to take actions unless they are capable of controlling the behavioural performance (Li *et al.,* 2018). There have been numerous studies hinging on TPB to address CE from different aspects. For example, Mak *et al.,* (2019) used the three constructs in TPB to define questions for semi-structured interviews to identify critical factors that determine recycling intention of construction and demolition waste. Adabre *et al.,* (2022) interpreted CE indicators, barriers, and drivers in construction based on TPB to provide a holistic source of knowledge on CE determinants.

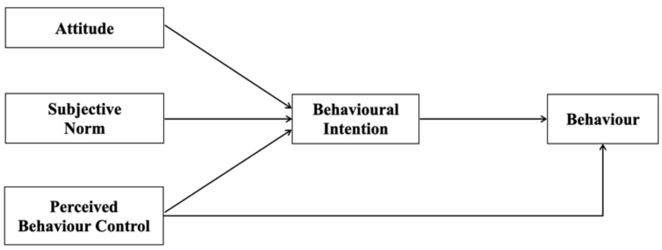

Figure 1: The Theory of Planned Behaviour (Ajzen, 1991)

As aforementioned, the effectiveness of current policy packages is questionable in shaping circular behaviour among stakeholders. There has been a perceived disconnection between 'sayings' specified in policies and 'doings' witnessed in practice (Hjaltadóttir and Hild, 2021). Meanwhile, TPB offers theoretical grounding for explicating the growth of pro-environmental behaviour. However, little is known about the linkage between CE policies and TPB. Bridging this gap would point out areas of improvement in existing policy settings and inform more effective design of policy directions. Therefore, this study aims to examine the impact of current CE policy landscape through the lens of TPB. It is primarily revolved around the three constructs, namely 'attitude', 'subjective norm', and 'perceived behaviour control'. Accordingly, four main questions are formulated as follows: 1) What policy tools are available to facilitate CE development in construction? 2) What are the attitudes of industry professionals towards CE policies? 3) What are the impacts of CE policies on social environment in terms of nudging towards circular behaviour? 4) What are the impacts of CE policies on individuals' perception of the ease or difficulty of implementing CE in practice?

METHOD

A systematic literature review (SLR) was undertaken to investigate the policy dimension of CE development in the construction industry. It followed the procedure of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) that comprises a items checklist and flow of information through different phases and allows a transparent reporting of SLR (Moher *et al.,* 2009). Figure 2 presents the four procedures of the PRISMA process including identification, screening, eligibility, and inclusion. Scopus was selected to retrieve relevant articles as it is considered the largest databases of peer-reviewed articles. As policy tools are the focal determinants of CE adoption, the literature search sought to target research that focuses on drivers and barriers of CE in construction leading to the selection of keywords used for search as shown in Figure 2. The article searching initially yielded 721 articles and the following selection criteria were applied to refine the search: 1) temporal range between 2013-2023, 2) journal articles and reviews, 3) English language, and 4) Scopus subject area limited to environmental science and engineering. Afterwards, the returned articles were assessed for their eligibility following two main steps: 1) title/abstract/keywords scan for their relevance to drivers/barriers involving CE in construction, and 2) full-text reading to identify discussions related to CE policies. The final sample includes 55 papers and MS Excel was used to store the associated bibliometric information and discussions extracted relevant to CE policies for further analysis.

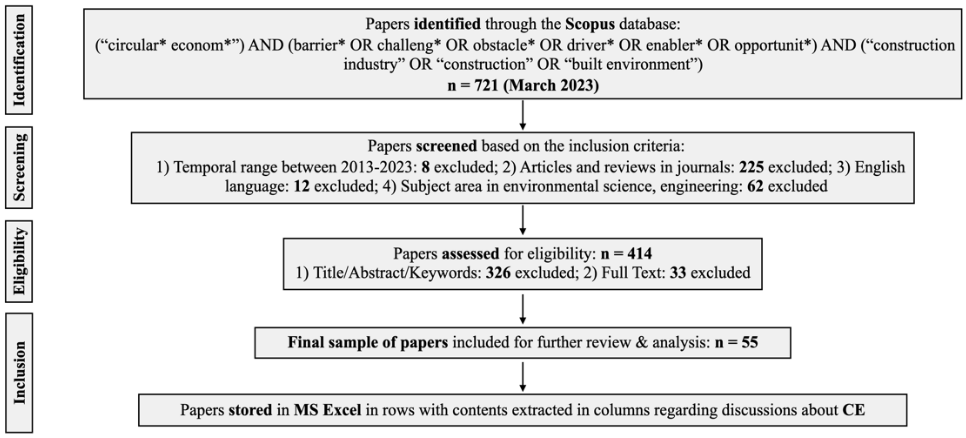

Figure 2: PRISMA Flow Diagram

FINDINGS

Description of the Sample

Figure 3(a) depicts the temporal distribution of the selected papers. Interestingly, CE started to gain momentum from 2013 led by a series of influential reports by the Ellen MacArthur Foundation, but it was until 2017 that the recognition of the policy dimension as a crucial CE determinant started to steadily develop in the literature with a significant increase in relevant papers witnessed in 2022. This indicates that stronger effort has been put into strengthening the awareness of the demand for an effective CE policy landscape. Figure 3(b) presents the journals where the selected papers were published, among which 'Journal of Cleaner Production' stands out as the most popular sources of studies related to drivers/barriers of CE in construction followed by 'Building Research and Information' and 'Resource, Conservation and Recycling'. This implies their great interest and influence in facilitating the transition to CE. 'Other' consists of journals that have contributed one paper to the sample. Moreover, the areas of focus of the selected papers can be broadly classified into four categories: CE in general (14/55), specific CE strategies (19), construction demolition waste management (13/55), and CE policies (9/55).

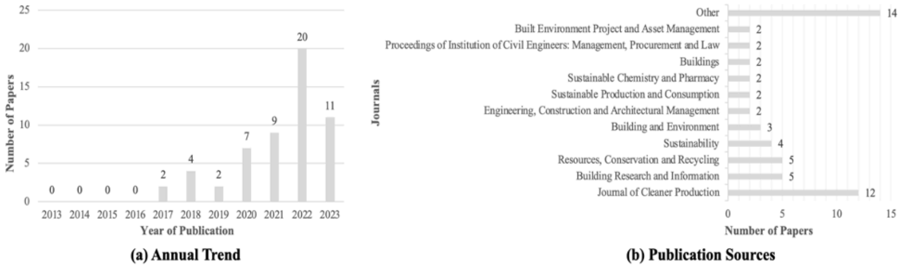

Figure 3: Chronological and Journals Distribution

Policy Instruments for CE

Reviewing the selected papers identified 17 CE policy tools classified into regulation control, economic incentives, and supporting activities based on the framework by Chang *et al.,* (2016). A policy gear model informed by Chang *et al.,* (2016) is presented in Figure 4, which comprises the identified policy tools and shows the driving forces of circular transition from a policy perspective. Specifically, lack of regulation has been extensively recognised as a tough inhibitor and possible areas for improvement were provided in the gear model. As for economic inventive, the use of taxation tools is the most mentioned fiscal instrument that involves tax increase on virgin materials, carbon emission, and landfill disposal as well as tax relief on reused/recycled materials, labour, and circular practices. Moreover, non-legislative supporting measures help build confidence in adopting CE in practice.

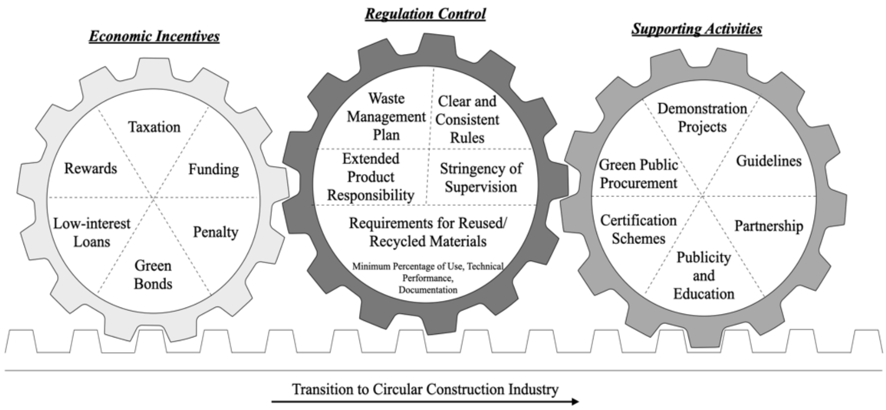

Figure 4: A Policy Gear Model for Moving Towards Circular Construction

Attitude about the Impact of Polices on CE Adoption

Reflecting on TPB, the 'attitude' is explicated as the positive or negative evaluation of current policy landscape in terms of its effectiveness in promoting CE adoption. The policy gear model exhibits a range of feasible policy instruments that contribute to positive outcomes. Nonetheless, the literature showed concerns over the deficiency of the current policy architecture. First, CE goals appeared mismatched with policy directives. Shooshtarian *et al.,* (2022) undertook an industry-wide survey in Australia and found that current regulations and policies are ineffective in facilitating waste recovery. They revealed the main areas of improvement were illegal waste disposal, definition of waste versus resource, and extended producer responsibility, whereas the policy framework does not harmonise with these areas. Second, there was a lack of coherence in the setting of national policy. Zaman *et al.,* (2023) noted inconsistencies in waste management regulations across Australia that thwarted the collective national efforts of shaping towards the circular construction. This issue was also seen in the US where some states had higher environmental consciousness and were more prone towards circular initiatives (Guerra and Leite, 2021). Third, some important aspects of CE were overlooked. Existing resource policies concentrated on efficient use of resources, instead of reducing resources demand in the first place (Hossain *et al.,* 2020). zu Castell-Rüdenhausen *et al.,* (2021) reviewed the national CE policy framework in the Nordic countries and unveiled that CE requirements are more focused on end-of-life activities with less attention paid to the design and construction phase. In a nutshell, despite great potential of various policy instruments, the existing regulatory guideline fell short of enabling effective CE implementation among industry professionals (Yu *et al.,* 2022).

Policy Impact on the Social Environment

The 'subjective norm' in the TPB refers to the social pressure in execution of behavioural actions (Ajzen, 1991). It can be categorised into descriptive norms and social norms. Descriptive norms emphasise the influence from behaviours that others are conducting. However, the social environment has been uninviting for CE adoption resulting in nudging towards an undesired direction mainly owing to the lack of collaboration among supply chain actors as well as industrial inertia. Construction supply chains confront many challenges, such as fragmented value chain and incompatible business interests, leading to rework and waste production going against circular principles (Chen *et al.,* 2022). Resistance to change is another long-standing problem embedded in the risk-averse construction industry. These issues have formed the broader social environment that discourages intentions to undertake CE practices. Nevertheless, policy instruments present potentials for improving the social environment, such as promulgation of BIM technology that strengthens information sharing and collaboration across the supply chain (Chen *et al.,* 2022), and the uptake of economic incentives to relieve the resistance to change (Guerra and Leite, 2021).

In addition, social norms set expectations on how individuals should behave. However, knowledge and awareness about CE was identified as the most frequently mentioned barrier in the literature (Huang *et al.,* 2022). Industry stakeholders were unclear about how they should behave in accordance with CE. Some of them may be aware of the concept, but they are not equipped with sufficient knowledge to take actions (Adams *et al.,* 2017). The comforting fact is that numerous policy tools can address this concern. For example, the authority can take advantage of their social influence through various media to promote publicity and education (Liu *et al.,* 2021). Partnership between universities and the industry can be formed to promote research and development (Munaro and Tavares, 2023). Furthermore, regulations have undoubtedly set out rules that individuals should behave against. However, illegal waste disposal was witnessed in many instances implying the willingness of going around the law (Mhatre *et al.,* 2023) indicating more stringent supervision from the government (Munaro and Tavares, 2023). Overall, the available policy tools have provided powerful solutions to the possible social issues in the circular transition.

Perception of Ease or Difficulties towards CE Implementation

The 'perceived behavioural control' is defined as individuals' perception of ease of difficulties in executing a certain behaviour (Ajzen, 1991). Policy levers have resulted in both easing and hindering CE implementation. On the one hand, governmental investment in technology and waste facility contributes to minimisation of construction and demolition waste and improvement in recyclability of construction materials (Shooshtarian *et al.,* 2022). Material certification schemes can be specified at a certain level of compulsion to control the quality of recycled materials. These are conducive to building the confidence of a circular market both on the supply and demand side. The promulgation of BIM is also a representative example, and the uptake of BIM is required by the legislation for companies that intend to bid for governmental contracts in Denmark (Giorgi *et al.,* 2022). This facilitates design for disassembly, accessibility of the property information of reusable materials, management of waste during construction, and integration with other emerging technologies that contribute to CE (e.g., material passport, blockchain, internet of things) (Chen *et al.,* 2022).

On the other hand, requirements in building regulations can backfire sometimes resulting in preference for new products over reclaimed alternatives. For example, Knoth *et al.,* (2022) undertook a feasibility study in a project to identify all relevant construction products and materials suitable for reuse according to visual inspection, but several of them that had been considered suitable were no longer qualified for reuse due to the need to fulfil requirements for documentation. Moreover, a great amount of capital and time circular material suppliers is required to process building waste into new products and satisfy requirements for documentation and a certain level of recycled content. This increases the price positioning of recycled products that sometimes exceeds the price of new products in some cases, preventing the purchase of recycled products (Liu *et al.,* 2021). In general, policy levers are powerful tools to ease the transition to CE, but it is also of significance to identify possible difficulties they may cause to different groups of stakeholders in the stage of policy setting.

CE Policies through the Lens of TPB

Previous sections have examined existing policy framework against the three main constructs of TPB (i.e., 'attitude', 'subjective norms', and 'perceived behavioural control'. First, the review of the literature about CE determinants in construction consistently pointed out the lack of polices and regulations as a critical inhibitor to CE, despite a range of policies tools being identified. This discrepancy may arise because national policies vary in different regional contexts and the literature review collected the policy evidence at a global scale. For instance, Italy does not have a restrictive landfill ban, resulting in lower landfill fees compared with Belgium, Netherland, UK, and Denmark (Giorgi *et al.,* 2022). A positive 'attitude' towards the effectiveness of CE policies is still left to be desired. Second, 'subjective norms' concern the social environment of CE where circular behaviours are determined by moral expectations of how decision makers should behave (i.e., social norms) and pressure from industry stakeholders regarding how they behave (i.e., descriptive norms). Reflecting on CE policies, 'social norms' are relevant to measures that promote knowledge and awareness gradually depicting CE adoption as a moral obligation because of recognised environmental benefits. The industrial setting also affects the social environment. CE implementation requires wide acceptance by all actors across the supply chain, but project-based businesses featured fragmentation and lack of collaboration. These challenges have formed 'descriptive norms' that created resistance to embrace CE, where incentives are needed to tackle the resistance. In this regard, CE policies contribute to addressing 'subjective norms' given their possible impact on tackling organisational and social barriers of CE. Third, CE policies can impact on 'perceived behavioural control' in both positive and negative ways. For example, governmental funding for technological development of CE infrastructure has eased the CE implementation, while stringent requirements for documentation can discourage CE practices.

CONCLUSIONS

This paper investigates the impact of circular economy (CE) policies on the transition to circular construction through the lens of the theory of planned behaviour (TPB). A systematic literature review (SLR) was undertaken to identify CE policy instruments and relate them to the main constructs of TPB, namely 'attitude', 'subjective norms', and 'perceived behavioural control'. Results revealed 17 CE policy tools classified into economic incentive, regulation control, and supporting activities. The use of taxation tools is the most mentioned fiscal instrument in the literature. Despite various policies tools available, a positive 'attitude' towards CE policies is still left to be desired given the extensive agreement in the literature regarding the lack of effective regulations and policies in different regional contexts. In addition, CE policy levers are capable of addressing 'subjective norms', such as publicity and education to improve behavioural consciousness (i.e., social norm) and incentives to promote supply chain collaborations (i.e., descriptive norm). Moreover, 'perceived behavioural control' has relevance to policy tools that promote technical aspects of CE implementation. The uptake of TPB has provided a new thread of thinking about how CE policies can be better devised to enable behavioural change. Existing policy tools showed relevance to the three behavioural determinants in TPB implying their positive impact on encouraging circular behaviour. However, it is still unclear about the effectiveness of policy instruments in tackling the barriers related to the three constructs, and performance indicators should be established to evaluate the level of achievement of the three constructs and investigate the threshold of activating the behavioural intention. Future studies may also consider some policy evaluation methodologies such as system dynamics modelling, agent-based modelling to understand the effectiveness of policies through simulating different policy scenarios.

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BUILDING COMPANIES IN DESIGN BUILD COMPETITIONS AIMING AT CIRCULARITY

Christian Koch[1] and Magnus Roenn

[1] *Department of Build Environment, Aalborg University Copenhagen, AC Meyers Vænge 15, 2450 Copenhagen SV, Denmark*

[2] *ACE, Chalmers University of Technology, 49122 Gothenburg*

While the research of architectural competitions is rich, there is less focus on other frequent participants in competitions: Building contractors, project developers and real estate companies. This is the research gap this paper address. Moreover, project competitions are probably confounded with the more profiled architects' competitions. Here the focus is on competitions about the right to build on a real estate owned by a municipality. We wonder who are the actors participating in such competitions, what is their aim, what experiences do they get and do their participation strengthen sustainable and circular solutions? Using institutional change as theoretical frame we analyse 10 companies participating in three project /design build competitions in Sweden. Interviews and document analysis was used. It is remarkable that most participating building contractors, project developers and real estate companies are small local companies, which draw on their knowledge about the sites. The municipalities try to obtain circular and sustainable solutions, but get relatively rudimentary proposals, resonating with the participating companies that are also critical, even if the jury judge winning proposals having high quality. The implication of this research could be to develop national guidelines and organised exchange of experiences.

Keywords: design build; competitions; circularity; institutional theory

INTRODUCTION

Competitions is a highly celebrated tool in public procurers' policy to provide housing in municipalities. Albeit slightly more ambivalent this is even celebrated by the main bidding participants, the architects. It seemed even fair to extend this ethos to the other bidders, the building companies. This is the research gap this paper address: we wonder who exactly are the other actors participating in such competitions, apart from the architects, what is their aim, what experiences do they get and do their participation strengthen sustainable and circular solutions?

Using institutional change as overall theoretical frame, the competitions process is understood as arena for tensions between logics, denoted dilemmas here. Thus, leading to the following question of interest:

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[1] Christian.koch@hh.se

Koch, C and Roenn, M (2023) Building Companies in Design Build Competitions Aiming at Circularity *In:* Tutesigensi, A and Neilson, C J (Eds) *Proceedings of the 39th Annual ARCOM Conference,* 4-6 September 2023, University of Leeds, Leeds, UK, Association of Researchers in Construction Management, 751-760.

How does tensions between logics develop within an institutional field and what relations occur between apparently competing logics?

The empirical material come from 10 companies participating in three project /design build competitions in Sweden. All three competitions involved sustainability demands and two of them circularity. In this context circular processes in architecture and construction are about the reuse of design concepts and the reuse of building materials (Lüdeke-Freund *et al.,* 2018, Rönn and Koch 2022a). Circular economy is defined by the Ellen Macarthur Foundation (2015) as businesses that restore design and aim to keep products, components and materials at their highest possible utility and value. In total 30 interviews were carried out. Interviews and document analysis was used.

The results show remarkable high participation of local players. Building contractors, project developers and real estate companies are small and medium sized local companies to a much higher degree than national players (the participants are denoted building actors below). The municipalities on their side try to obtain circular and sustainable solutions but get relatively rudimentary proposals. Maybe slightly more surprising is that the disappointment from the municipality side resonate with the participating companies' opinion. They are also critical, also to their own proposals, even if the jury have ruled that the winning proposals had high quality. It therefore seems that even if a result is obtained that is a momentary stabilised constellation of logics, this precarious balance dismantles shortly after. This evaluation should trigger reflections on ways to learn from experiences across competitions, municipalities, and companies. Two possible avenues could be common national guidelines and organised exchange of experiences for example in industry associations.

METHOD

The overall theoretical approach is interpretive sociology adopting concepts of institutional theory. Empirically the focus is on three design build competitions in Western Sweden. The R&D project seeks answers through the study of municipal documents, review of competition proposals and via interviews with organisers, architectural offices and building operators.

Because R&D projects are limited in time and scope, it has been important to report the motives behind the choice of research object in a transparent manner. Applicants for contemporary land designation competitions with stated requirements for design, sustainability and innovation have taken place in a selection process that includes the following five steps:

The first step is an online search for municipal competitions in West Sweden. Gothenburg is excluded due to the municipality's overly dominant role. The search terms used were "land allocation", "land allocation" and "competition". In terms of time, the search for contemporary competitions was limited to the years 2018-2021. This initial search resulted in a preliminary selection of 10 land designation contests of potential interest.

The second step in the selection process is a review of the competition program and land allocation policy of the competing municipalities. The requirement was that the competition programs should contain competition tasks, evaluation criteria and submission requirements aimed at quality in architecture and construction, ecologically sustainable solutions, and innovations. This analysis of the competition programs was combined with an investigation of how municipalities reported in their policies the grounds for assigning land to housing construction. The review resulted in three competitions being considered suitable as a basis for planned studies.

The third step in selection processes includes collection of competition proposals, jury songs and documentation of participants in the competition processes. The competition proposals contain, in addition to architectural directions, illustrations and explanatory texts, information about the companies behind submitted contributions. The organiser's evaluation of the competition proposals reports both the composition of the jury and their ranking of the contributions. Based on this analysis of the competition documents, 12 competition proposals have been selected for in-depth review. The selection includes 3 winning proposals from one competition. The 3 highest ranking contributions from the second competition and 6 winning proposals from the third competition. The two first competitions in reflect practice. The third competition is part of a large urban planning project with design teams selected after prequalification. The competition task is to transform a centrally located industrial and harbour area into an attractive district with housing and businesses.

The fourth step in the selection process is the identification of key persons at municipalities and companies who had an active role in the competitions as representatives of the organiser and proposer. It was easy to obtain information about the names of the jury in the competition documents. To find out which people at the companies participated in the competitions, an in-depth analysis was required. There were 28 companies and 77 people named in the tender documents. Through direct contact with the companies in the design teams, it was identified which representatives had a leading role in the competition process. Interviews have then been conducted with people in a leading position in the 12 design teams.

The fifth step is the planning and execution of interviews with representatives of organisers, architectural offices and building operators in design teams. Selected people have been interviewed for 1-2 hours based on a questionnaire organised into four themes: 1) The Land Designation Competition (questions about the competition process in each municipality from the announcement to the competition program, competition task, submission requirements, assessment criteria, jury including the implementation of winning proposals), 2) Sustainability and climate (questions about business steps in the field, method and technology development, climate adaptation in the competition, climate declarations, circular principles and processes and certifications, 3) Strategic processes (questions about choosing participation in the competition, organisation of design teams and competence needs, risks and costs for the development work, solutions and benefits, 4) Innovation in architecture and construction (from about innovative elements in the competition programs, innovations in the competition proposals and the development work of the design teams, competition

The interviews have been analysed with the support of Kvale (2005). This applies both to the planning of interviews, analysis of collected interview data and critical reflections on the choice of interview methodology. The interviews have been transcribed prior to analysis through "close reading", a method developed in literary studies. The interviews have been supplemented with document analysis. The method has been used for reviews of the competition proposals, the organisers' competition programs and the municipalities' policy for land designations. The municipalities' competitions are examples of cases that need to be understood in their local contexts). The review of the design team's solutions to the competition task includes analysis of architectural expressions. The competition site, together with the design team's understanding of the competition programs, has had a guiding function for the architectural work.

Framework of Understanding

This section develops the framework of understanding starting with the introduction of the basics of institutional theory including complexity and pluralist approaches, approaches to institutional change introducing an institutional conceptualisation of the competition process.

Institutional Theory

Institutionalist theory posits non rational, cultural socially constructed explanations of societal order and change (Scott 2001). Institutions can be understood as "social structures that have attained a high degree of resilience… [institutions] provide stability and meaning to social life…. Institutions connote stability but are subject to change processes, both incremental and discontinuous…". Scott (2001: 48). Institutionalists (Scott 2001, Thornton *et al.,* 2012) conceptualise institutions as consisting of three types of elements: cultural cognitive, normative, and regulative. Though aiming originally at explaining organisational homogeneity and stability, most recent contributions have underlined the more dynamic aspects of the formation of these institutions and focused on institutional change, such as the studies of institutional work ("institutional entrepreneurs" as change agents (Garud *et al.,* 2007, Munoz 2011), or studies of deinstitutionalisation (Greenwood *et al.,* 2002, Røvik 1996) or institutions within societal and other non-organisational change (Thornton *et al.,* 2012). Even if most institutional theories tend to think in terms of one dominant institution in a field or organisation, possibly challenged by one other (Dimaggio and Powell 1987, Greenwood *et al.,* 2002, Scott 2002), there is an increasing number of contributions that conceptualise institutionalism in terms of two or more institutions that coexist is various ways (Gestel and Hillebrand 2011, Kraatz and Block 2008, Smets and Jarzabkowski 2013, Thornton *et al.,* 2012, Zietsma and McKnight 2009, Waldorff *et al.,* 2013). Thornton *et al.,* (2012: 13) initially observe that "the influence of one institutional order does not necessarily or completely replace another". They first note dual and dialectic coexistence of two institutions as a possibility, but then move on to appreciate jurisdictional overlap of institutional orders creating institutional complexity (Thornton *et al.,* 2012: 57).

Institutional Change

Contributions to the understanding of institutional change provide concepts for how an existing institution would be deinstitutionalised, delegitimised, and how one or more future institution(s) could develop through gaining legitimacy and support (Greenwood *et al.,* 2002, Lawrence *et al.,* 2002, Zietsma and McKnight 2009). Legitimacy is not given but must be formed through conscious actions by various organisations, businesses, associations, and actors in a socio-political process (Greenwood *et al.,* 2002, Zietsma and McKnight 2009). Zietsma and McKnight (2009), drawing on Lawrence *et al.,* (2002), suggests thinking of the early institutionalisation process after a deinstitutionalisation occurs as a dynamic emergent coexistence and competition among institutional logics. Zeitsma and Mcknight (2013) note that deinstitutionalisation may occur without pointing to any new institution and may leave "litter" from the previous dominant institution such as associations, and after deinstitutionalisation it is plausible that more than one contester might arise. Actors' alliance(s) associated with the logics would develop the content of the new emergent institutions, i.e., the practices, rules and technologies and adapt them to the surroundings. The processes of re-institutionalisation can be lengthy and involves a series of mechanisms of gaining legitimacy, power, and position, such as building alliances amongst actors and organisations. Distance to old institutions might be important for the emergence of a new proto institutions. As demonstrated by Zietsma and McKnight (2009) a range of symbolic and material resources and devices are brought in play to develop support for new institutions. This includes arranging events and establishing associations. As Zilber (2011) suggests "organisational field and the multiple institutions within them come alive through trans organisational sites and structures that serve as the medium through which actors, interests, and issues are identified and negotiated". The author describes the use of conferences to maintain institutions and thereby maintain institutional multiplicity. This can be seen as parallel to the process of competitions where a series of spaces and occasions for corroborating or weakening new institutions can occur.

The Competition Process

The competition process is here understood as interorganisational arenas where field and organisation interact. The different institutions in play would relate in different ways, conflictual and/or om dual dialectic coexistence. As a further conceptualisation of these coexistences, it is suggeste to view them as dilemmas. The following five dilemmas can be identified: 1. Organiser's dilemma: How to set a frame for innovation in the program phase? 2. Design team's dilemma: How to understand the brief and translate requirements into design-solutions in the competitions? 3. Professional's dilemma: How to support design teams' work with innovations? 4. Jury's dilemma: How to develop and appraise identified innovative solutions in the evaluation of proposals? 5. Client's dilemma: How to maintain innovative solutions throughout project implementation?

FINDINGS

Case

(Only one case is described here due to space constraints)

The organiser of this competition was M - municipality. They did not involve external consultants. The competition type "general competition" was chosen. The competition assignment was on residences with the possibility of business remises. The place was in the main town of the municipality with about 15 000 inhabitants. There were 5 competition plots. The competition program consisted of 12 pages + appendices: design program, Plan program, etc. The jury consisted of 7 people: 5 civil servants and 2 politicians. The assessment criteria have the following weights: Durability 30%, design 30%, implementation 40%, land price, max 10 p. The evaluation principle was a calculation of scores and an overall assessment. The proposal was handed in anonymous as a requirement from the municipality. The municipality received 6 proposals 6 from 5 companies, 3 became winners.

Analysis

Many of the building actors primarily operate locally in Western Sweden. Several companies do projects in more than one region. Only two out of ten interviewed companies are nationwide. The building actors in the study work in three business areas; construction contract, project development/housing development and property management within own company. Some building actors in the design teams collaborate with other companies that, together with the architects, cover the competencies that the competition requires. For example, the design teams in competitions may include a construction contractor, a real estate company and an architectural office. All three municipalities have legally adopted a land allocation policy (see Rönn and Koch 2022b). What is common is that the competitions for land designation in each policy is presented in an overview without further specification. Organisationally, responsibility for the land allocation competition lies with the municipalities' land and exploitation unit. Administrations/public servants involved in architecture and planning are absent from the policy. Their participation is dependent on the degree of design requirements in the respective competition program. One municipality has strengthened its architectural function after the competition. One in ten building actor express having developed the proposal in the competition about the municipality's political level. The building actors in general have no comments on the municipalities' land allocation policy or competition rules expressed in competition programs. This can be interpreted as the informants like the freedom and therefore do not want clear competition rules. The interpretations of competition programs are highly prioritised by building actor. Several readings and comprehensive dialogues in the design team are common to understand the municipality's intentions. The competition program is coordinated in the companies against their own business models, partly the actors make internal priorities of the competition program's orientation towards their own requirements, partly the competition is tested against comprehensive internal compilations. The design team sees the competition entry as a commercial product - the competition proposal is the basis for a business agreement that includes both costs for the development of the proposal and continued assignments in the event of a competition win. The competition contribution can be seen as a first negotiation, a reconciliation of the municipality's intentions in the competition program with the company's requirements, the location of the plot, land price and financial conditions for construction and management, etc. There are different values among building actor about the quality of the competition program. Some give the program a good rating, while others feel that the municipality makes too many demands without prioritising, which leads to the design team having to choose the focus of the competition proposal instead of the municipality. The site's location is decisive for the builders' decision to participate in the competition. The business opportunities in building a property on a specific plot of land are closely linked to how building operators value its geographical location. Then, at a detailed level, there are different viewpoints behind the valuation of the plot, such as proximity to the city/town, prospects, location in the region, forms of ownership, etc. In the three competitions, the organiser applied different combinations of quantitative and quantitative assessments of the proposals. Common is that the competitions contain assessment criteria for design and sustainability (social and ecological). The differences concern the view of land price, control of building actor and choice of competition form (Rönn and Koch 2022b). The relationship between price and quality varies in the competition programs. The building actors must tender for the land in two competitions. The third competition has a fixed price for land. The building actor must compete with quality. A second difference concerns how the companies' organisational and financial ability to implement their competition proposal should be followed up. One municipality of chooses to check the building actor' finances and competence in advance through prequalification. Another municipality requests that the building actor supplement their competition proposal with documents showing the company's financial status. The third municipality has chosen to follow up the finances of the builder behind the winning proposal after settling the competition. There are no explicit requirements for circular solutions in the programs for the competitions in two of the competitions. Here, instead, it is the design teams who independently propose the reuse of materials. In the third competition, on the other hand, the organiser requests proposals that promote circularity. However, the concept appears unclear to the building actors. According to the program, the organiser wants the buildings in the competition area to participate in a circular transformation of society. Several building actors take responsibility for guarantees and quality when reusing materials. The responsibility depends on who is the developer and who is responsible for the operation of the property. Companies that build for an "own" real estate company interpret that the responsibility for reuse is easier to handle from a legal point of view. Several competition proposals include reuse of bricks and recycled cellulose material for insulation. A landscape proposal allows for paving with recycled granite. Reuse ideas and experiences from other projects in the competition. The location is unique, but the proposal is to combine the municipality's desire for variety in the development with a cohesive solution supported by experience from other assignments. Previous projects form a knowledge base that the companies reuse and implement in the proposal, such as ideas about sustainability, energy systems and blue-green perspectives. The design teams have reused layouts, technical systems, methods, and procedures from previous housing projects. Floor plans for apartment layouts in the competition proposals are based on known principles from the previous project that have been applied in a new context (Rönn and Koch 2022a). Corresponding in terms of house types and volumes. Design elements and concepts are processed to fit the competition plot. There are proposals in the competitions that involve applying the sharing economy for both businesses and housing. So, for example, bicycle workshops are included where residents share tools and rooms for changing things. These examples are also seen as expressions of circularity and reuse during the operation and management of housing. There is a need to systematise the reuse of materials in the construction sector. One way to overcome barriers could be to create 'donor buildings' for groups of materials that can be reused in the construction of winning competition proposals. Another complementary way is to increase cooperation with a platform for recycling such as "CC Återbruk" in Gothenburg (established in 2018). Corresponding platforms for recycling exist in Western Sweden which include logistics solutions. However, no such solutions to recycling can be found in the winning proposals. It therefore seems that even if a result is obtained in the jury decision, and the decision represent a momentary stabilised constellation of logics, this precarious balance dismantle shortly after as participants actors reiterate the dilemmas anew when interviewed afterwards.

DISCUSSION

The building actors (which include the contractors) are busy with the next stage in the process where the concrete construction parts are to be produced. It is natural because the construction operators behind winning proposals are waiting for land approval followed by construction. Contractor representatives also believe that the construction phase may generate innovations, both in process and in product (for example material selection). In contrast to architects and competition organisers, innovation is a task that for building actors takes place later in the process, the implementation of the winning competition proposals. Sustainability and circularity are developing areas of knowledge. The competitions were announced in 2019, 2020 and 2021. Since then, both methods, solutions and alternative materials have emerged. For example, wooden frames in the proposals are less dominant compared to what we see in competitions announced in 2022 that aim at sustainable solutions by minimising CO2 emissions. When the competition programs contextualise sustainability as a concept open to many different interpretations, proposals with green roofs, poles with electric chargers or rooms for the exchange of used furniture risk being perceived as 'greenwashing'. The competitions need to prioritise the climate challenges in society in a more systematic way. Reviewed solutions in are 'point-of-care' and are not accompanied by accounts of how the climate impact is calculated. But at the same time, too detailed sustainability requirements in competition programs can, on the other hand, lead to the construction operators only submitting proposals that confirm that confirm the municipalities' specifications. Renewal and improvement need to be promoted. A possible answer to the dilemma between open sustainability concepts with great scope for interpretation and detailed sustainability requirements is competition programs that more clearly invite design teams to creativity and innovation in the design of solutions to the competition task. Sweden has a national regulatory framework aimed at sustainable buildings through requirements for climate declarations. The Housing Authority has been commissioned by the government to develop the work with the transition to a circular economy in the construction sector. The new goals should give municipalities the opportunity, as organisers of competitions, to be more specific in their requests to building operators and architectural offices. The development of the competition as a municipal tool for innovation and designation of land means that the municipality can become a driving actor in the creation of a sustainable society. In the role of organiser, landowner and planning authority, the municipality has a toolbox that can be used in a more efficient way to drive turnover towards sustainable community building. An interesting paradox in the study is that, on the one hand, the competitions are presented as a tool to promote creativity and innovation, while on the other hand, we received cautious answers when we asked for examples of innovations in our own competition proposal. There are few companies that highlight innovative solutions in the competitions. This applies to both builders and architects. (Rönn and Koch 2022a). The informants also do not describe the competition programs as innovative or as support for new thinking and creativity in the work with the competition proposal. The jurors, on the other hand, see innovations in the competition, both in the development of the competition programs and in the design teams' response to the competition task. The conclusion is that the land designation competition has several faces from an innovation perspective. The key actors (organiser, jury, and competing companies) see different things in the competition processes. For the municipalities, the land allocation competition is a new and partly unproven tool for allocating municipal land to building operators. The municipality of Marks, the municipality of Laholm and the municipality of Varberg have only carried out a handful of land allocation competitions. By setting demands on design, the competitions have been organised as collaborative projects between administrations assigned the role of dealing with matters of land and development and architecture and planning respectively. The composition of the jury is a clear expression of this cooperation. Municipal policy documents with overarching goals have been translated in the competition programs into competition tasks, assessment criteria and requirements for submission of drawings, illustrations, and description of the proposal. The competition programs generate a diversity of solutions to the competition task that the jury receives for assessment. Some of these entries are more innovative than their competitors. The jury's task is to find a winner. To rank the proposals, the jury members must identify differences and value these as better/worse solutions to the competition task. This encounter with proposals that deliver different answers to the competition task means that the jury sees innovations in the competition in a different way than construction operators and architects. The architects do not perceive the reuse of design elements and concepts in competition proposals as innovations, but rather as expressions of practice, although the competition is generally perceived as a tool that promotes innovation and creativity. To reuse solutions from previous assignments and adapt them to one. The ten competing construction operators included in the survey prioritise participation in land designation competitions to gain access to buildable land. The prioritisation is shown by the fact that the companies have internal decision-making processes when interesting competitions are announced. Then the construction actors draw up a budget for the development of the competition proposals. Most construction operators have regular partners, mainly architects and property companies. A few choose new partners for the concrete competition (Rönn and Koch 2022a). Most construction operators participate in 2 to 5 land designation competitions annually. This means that the companies are more used to competitions compared to the organising municipalities. The competitions are seen as costly. Architect offices and construction operators typically share hourly costs and risks. The building actors establish a budget for the development of competition proposals and the architects are expected to contribute their own time. The specific competition project is concluded for the architect's office through the submission of competition proposals. If the competition is won, the architect's office can receive full payment for the work plus bonus and future design assignments. For the builders, the implementation of winning proposals can take a long time as the land needs to be made available by drawing up a new detailed plan for the area. It is thus seen how the pre-existing dilemmas are prevailing and it appears the entering sustainability and circularity corroborates this. Even if a result of the jury is obtained that is a momentary stabilised constellation of logics, this precarious balance dismantled shortly after. This status raises the question of possible strategies for improvement. Two possible avenues could be common national guidelines and organised exchange of experiences for example in industry associations. The national guidelines should attempt to condense the experiences and lay out ways in which the dilemmas of competitions can find room to be solved locally, In other words detailed rule-like guidelines will have limited value if one appreciate the deep embeddedness of the dilemmas identified.

CONCLUSIONS

We initially wondered who exactly are the other actors participating in design build competitions, apart from the architects, what is their aim, what experiences do they get and do their participation strengthen sustainable and circular solutions? And we framed the competition process as institutional, potentially involving change. However, recognising that dilemmas between logics exist, which led us to ask: How does tensions between logics develop within an institutional field and what relations occur between apparently competing logics? In our analysis of the competitition process we saw how the pre-existing dilemmas are prevailing and it appears the entering sustainability and circularity corrobates this. Even if a result of the jury is obtained that is a momentary stabilised constellation of logics, this precarious balance dismantled shortly after. We would maintain, along with the actors that design build competitions for land designation is a suitable tool used correctly to achieve a community building that is sustainable, attractive and with cost/value in balance. Municipalities and participating building actors can produce a legitimate basis for local housing development. A difficulty lies in the fact that the organiser of the competition does not compensate the participating companies for their delivery of the approved competition proposals. This makes the competition a costly investment and will corroborate the conpetion dillemmas in the future. The profit for the builders is in the access to a buildable plot at market price. The competition as a tool for innovative, sustainable, and circular solutions requires continued development work, both in terms of national competition rules, competition programmes, competition proposals and the free transmission of competition documents that provide a more efficient exchange of knowledge. The goal should be to promote innovations (product, process, and organisational innovation) in collaboration with relevant business models in the building industry.

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FACILITATING NET-ZERO TARGET IN THE BUILDING SECTOR THROUGH ONLINE TRANSACTION PLATFORMS: FEEDBACK FROM INDUSTRIAL PRACTITIONERS

Kehan Ma[1], Wei Shen[2], Weiwei Chen[3] and Zainab Dangana[4]

[1,2&3] Bartlett School of Sustainable Construction, University College London, Gower Street, London, WC1E 6BT, UK

[4] Sustainable Technology, Wates Group, Drummond Street, London, United Kingdom, NW1 2HN

In recent years, the increasing demand for reducing building energy consumption in support of sustainable development and achieving net-zero goals has created opportunities for trading low-carbon technologies and solutions in the building sector. Tradition transaction is still being commonly used now in building industry, and digital transaction platforms have not yet been popularly adopted, although they have been used in many areas of people's life, such as retail and publishing. It is still not clear how the building sector perceives and can utilise digital transaction platforms to facilitate the net-zero process. To address this issue, fifteen industrial practitioners, including nine suppliers and six buyers, were interviewed in this study and four types of changes that platforms could bring were identified along with nineteen influencing factors. The results indicated that integrating transaction platforms in the conservative building sector is challenging due to the uncertainty of performance and the high knowledge barrier of low-carbon products and services. The study helps to better understand how to promote the transition of the building sector from the traditional transaction method to digital online method.

Keywords: built environment; sustainability; platform; net-zero; factors

INTRODUCTION

To mitigate global climate change, the Paris Agreement has committed 164 countries to decarbonise (UNFCCC. Secretariat, 2021), and a net-zero goal has been set to limit the carbon emissions from human activities to protect our environment (UN, 2020). As a primary source of greenhouse gas emissions (Joensuu *et al.,* 2020), the building sector plays a vital role in this process (Martiskainen and Kivimaa, 2018). To contribute to this 2050 net-zero target, the UK government has started to put homes, workplaces, schools, and hospitals at the centre of the green economic recovery (HM Government, 2021). This process, however, relies significantly on the adoption of low-carbon technologies, such as smart façade, heat pumps, energy-efficient appliances etc. (IEA, 2021). Although there are many low-carbon technologies and solutions (LCTSs) available in the market, the potential buyers appeared to have

[1] kehan.ma.19@ucl.ac.uk

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limited willingness to adopt these new technologies, given the inherent feature of the industry (Dubois and Gadde, 2002). Therefore, the application of LCTSs remains lagging.

As a loosely coupled system, the building sector involves a complex network, which needs collaborations from various aspects, such as actors, actor activities, and resources (Dubois and Gadde, 2002). This inherent feature facilitates mutations and novel solutions but forestalls the spread of innovations over the whole system (Weick, 1976). Consequently, the building sector has been widely denounced of failing to uptake new techniques, such as 'industrialisation' of manufacturing processes (Li and Yang, 2017, Gann, 1996) that help improve the performance of other industries. The reason for this could be the management techniques not been transferred according to the building sector's inherent complexity context (Dubois and Gadde, 2002, Gidado, 1996).

Digital transaction platforms act as intermediaries to facilitate direct exchanges and transactions of products, service, and information between different parties (Bonina *et al.,* 2021). According to Perren and Kozinets (2018), transaction platforms have the capability of intermediation and consociality, which means they hold an intermediary role and facilitates certain level of social interactions between practitioners. Nowadays, the DTPs have disrupted the traditional interaction mode of many industries (e.g., retail, travel, and publishing) (Cusumano *et al.,* 2020). In the building sector, the integration of Digital Transaction Platforms (DTPs) is still at the emerging stage, and currently there is still no matured aggregated DTP in this industry. In traditional building sector, linear businesses are supported by regulative and habitual practice, and the value generated from this process was created by the providers and then was passed to the buyers through the transaction process (Sarja *et al.,* 2021). In contrast, subjected to network effect, the value of DTPs is positively related to the number of total available users and functions (De Reuver *et al.,* 2018). However, it is still vague in how interactions change in DTP environment and what factors may affect this process. There is, therefore, an urgent need to explore how DTPs can fit the inherent features of building sector practices.

To fill this gap, this study has explored how DTPs interrupt and reform the interactions between the participants of low-carbon technologies/solutions (LCTS) transactions. The study was carried out by interviewing relevant practitioners in the building section, from both provider side and buyer side. This study aims to provide insights into the way of the building sector adopting new LCTS, considering its inherent complexity and uncertainties. The results will help to overcome the barriers of adopting LCTS to accelerate the process of digitalisation in this specific industry for sustainable development.

DTP and LCTS

DTPs have been used in many business areas, such as retail and publishing, to create awareness and facilitate novel and more effective interactions between diverse parties (Kahn *et al.,* 2018, Gawer and Cusumano, 2014). This has been enhanced further during the pandemic period, when people were forced to stay at home and separate with others (Jena *et al.,* 2020). By aggregating useful information in one place, DTPs help to reduce information asymmetry, which has been recognised as a major barrier of adopting LCTSs (Gillingham and Sweeney, 2012).

As an emerging part in the building sector, the implication of LCTS faces not only the inherent conservation and pragmatism of the industry, but also the problem of how to be known and accepted as innovations. According to the Roger's Diffusion of Innovations theory (Brook, 2018, Rogers, 2010), the pioneering users play a significant role in promoting the innovation to other potential users. On the other hand, awareness creation also plays an important role because people will not purchase a product/service if they are not aware of or do not understand its functions. This becomes even more important for industries with high knowledge barrier, such as LCTSs. With the ability of gathering useful information, DTPs therefore, have the potential of helping overcome the information and knowledge gap between providers and buyers, especially from the buyers, who may not know the technologies very well (Rabhi and Pal, 2019). In this sense, DTPs could facilitate introduction and application process of LCTSs.

METHOD

In this study, in-depth interviews were conducted with in total fifteen interviewees (six buyers and nine providers). Given the expertise of interviewees and the complexity of the issue, it is anticipated that fifteen interviewees could potentially offer valuable insights as phased discovery. The interviews consisted of two parts, with the first part collecting basic information about the interviewees (e.g., job position), and the second part exploring their experience and opinions towards the application of transaction platforms in the building sector. The interviews were conducted in a semi-structured manner, with specific questions aiming at gathering relevant information for the study, with improvised and adjusted follow-up questions according to the answers from each interviewee. These follow-up questions allow extra flexibility compared to rigid structured interviews, encouraging interviewees to give their unique verbal expression (Kallio *et al.,* 2016).

The data collected were then analysed by thematic analysis (Creswell, 2017), using Microsoft Excel. The thematic analysis began with a careful reading of the interview transcripts to establish familiarity with the data. From this reading, initial codes were generated by identifying significant recurring patterns and ideas. These initial codes were then organised into potential themes. To ensure the reliability of findings, the analysis adopted a systematic process constantly comparing codes and themes across the dataset. In the end, four themes were identified, followed by nineteen factors. All participants of this study possess solid expertise and experience in this industry, thereby providing sufficient power in information (Malterud *et al.,* 2015).

FINDINGS

Based on the interview results, the changes DTPs could bring to this specific industry were classified into four themes: creating new transaction opportunities, time, cost saving, reducing information asymmetry, accelerating knowledge and information sharing, establishing trust-based environment. To elaborate further, by aggregating useful information and counterparties in the one place, DTPs can increase the number of successful transactions. In addition, DTPs provides integrated and efficient communication channel with the help of internet and communication technologies (ICT), which is ascendant compared to traditional work mode in cost-sensitive building sector. Furthermore, DTPs facilitate the exchange of knowledge and experiences. This process involves documenting and discussing authentic case studies, practical experiences, and data. Consequently, not only are knowledge and experiences accumulated, but also trust is fostered among participants, as emphasized by industry practitioners in interviews. And then, unique factors influencing the changes were identified, as shown in table 1.

According to the involved parties (i.e., providers, buyers, and platform) in a digital transaction application for low-carbon technologies/solutions, this study identified five types of interactions between them, as shown in Figure 1. They are 1) providers-buyers, 2) providers-platform, 3) buyers-platform, 4) providers-providers, and 5) buyers-buyers. As this study considered DTPs as one single intermediary that facilitates the transactions between two parties, the interactions inside the DTP were not concerned.

Figure 1: Five types of interactions between DTP, providers, and potential buyers

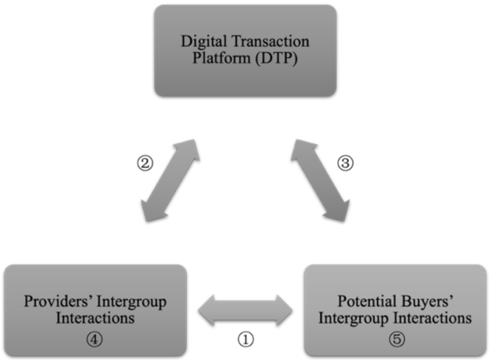

Table 1: Influential factors in facilitating transactions of LCTSs

Factors	Interactions	Change Themes
Extending S-B network	Providers - Buyers	Creating new transaction opportunities Time, cost saving Reducing information asymmetry Accelerating knowledge and information sharing Establishing trust-based environment
Fostering trust-based relationship		
Maintaining good relationship		
Creating harmonious communication atmosphere		
Enabling efficient contacts		
Enabling higher customization		
Aggregated information about market needs	Providers - Platform	
Two-way visibility		
New opportunities from platform's existing customers		
Creating firm value		
Information's high aggregation level	Buyers - Platform	
Education towards deeper acknowledgements to LCTSs		
Regularly update		
Uniformity of information		
Help finding cooperation opportunities	Providers - Providers	
Extending interfirm network		
Case study sharing	Buyers - Buyers	
Facilitating spread of eWoM		
Time and cost saving		

Interactions between Providers and Buyers

As the interaction mode accounting for the largest proportion, DTPs help facilitate transactions by extending the provider-buyer network. The provider-buyer interaction mainly concerns with the scope and depth, as well as the trust issue involved. Among all the providers being interviewed, around 60% are start-ups, and they emphasized on importance of increasing awareness. A major reason for them to join the DTP is to obtain convincing backup from the platform through well-established quality control process. Moreover, the innovative feature of LCTSs makes it difficult for potential buyers to actively approach the technologies/solutions they are targeting for. It is, therefore, necessary for providers to obtain better exposure, suggesting “This kind of solution is something that nobody thinks they need and until you've had a conversation with them”.

In addition, the industry practitioners also face the problem of dislocation of connections. In other words, providers need “getting talk to the right person at the right position”. By creating a unique and professional environment for interaction, DTPs can foster efficient contacts. According to the answers by the interviewees, it seems like the current main approach adopted by providers are LinkedIn, industrial events etc. About 20% of the providers also highlighted the importance of social media marketing and communication. After an intense work on contacting potential buyers, the reply rate only ranged between 1% and 20%. Using the DTP environment, however, providers are able to make direct contact to the “right person”, if the potential buyers also use the platform.

In the process of provider-buyer interaction, 70% of the buyers stated that most current LCTSs in the market do not fit the market’s need, they say,

> “There’s a lot of people out there spending lots of money… developing things which no one wants”.

By providing a more efficiency interaction tunnel, the potential buyers can engage earlier and deeper, facilitating customisation and make the LCTSs closer to demand. Given that as a loosely coupled system, most of the innovations are project-based and cannot be applied in another case directly. The early and deep communication between providers and buyers are particularly important in facilitating customisation and therefore increasing the success rate of matchmaking. However, it is noteworthy that the aforementioned activities are predicated upon the fundamental principle of trust.

Trust plays an important role in transactions, especially in the building sector. The interviewees refer to the concept using different words, including but not limited to “credibility”, “believe”, and “trust”. Trust requires collaborative work and interaction from various parties. In the transaction of LCTSs, sixty percent of the potential buyers shows concern about the promotion information provided by the providers, including standard alignments, and said only “real building data” is credible. Other potential buyers consider adhering to standards (e.g., ESG and BREEAM) credible. They suggest:

> "Somebody to be able to assess those products… that has to be an application process potentially to assess the claims that people will be making. So if you say that my product reduces carbon emissions by 80% percent on a on a building, we need to be able to test that."

At most of the circumstances, when it comes to choosing an appropriate LCTS, potential buyers tend to adopt the advice or experience of existing buyers facing similar challenges who they have cooperative relationship with, "It would be really helpful to know which other organisations they have implemented this technology with… it (talking to peers) gives us sort of reassurance that we are not missing anything."

Interactions between Providers and Platform

Upon discussing about the interacting with the platform, providers frequently mentioned a significant limitation in the traditional mode of selection, whereby they are unable to effectively discern customer preferences until potential buyers make proactive contact and communication. In contrast, the platform offers a distinct advantage by providing browsing habits, such as extended periods of time spent on specific pages within the platform environment, thereby allowing providers to gain insights into potential buyer preferences.

> "So having an understanding of if someone viewed it, what they viewed...if we were to go into our website and take a look at the analytics, we can see what pages they've looked at, where they've looked at it, how long they've looked at it... (if) no one goes on to it, why would we put the time and effort into to update it and if we knew that people were looking at it, of course we would be hot on keeping that absolutely as up to date as possible."

With two-way-visibility, it is possible to establish a virtuous cycle where providers maintain their platform image with increased diligence, resulting in the platform becoming more appealing to potential buyers due to the abundance of information it offers. This situation leads to active attitudes of both buyers and providers.

In addition, within a platform containing a significant amount of aggregated information, engaging with the platform can facilitate providers in identifying their own unique positioning, leading to the development of a more compelling value proposition for their company.

> "Before engaging in platforms, all I thought was selling… and then I thought about is building connections and deploy my product in as many places as possible."

Interactions between Buyers and Platform

In the interaction between potential buyers and DTP. The buyers No.1 focus is the aggregation level of the DTP. By aggregating as much information as possible, DTPs help in reducing information asymmetry. Potential buyers in building sector show great expectation to visiting a DTP with high aggregation level as it contributes to time and money saving in search new innovations across the industry:

> "The Internet platform that I would use is a kind of aggregation platform… have lots of different sources of energy data, som e from the suppliers… and we have a web platform where all of that is aggregated, and we can look at."

Nowadays, there is still huge information asymmetry between providers and buyers. The information source come mainly comes from connection introductions and through industrial events (e.g., The UK Construction Week). These efforts are made to ensure that no information is missed out. Therefore, it is important for DTPs to keep constant update of information.

> "You almost need… go compare these websites… all the other websites to get the up-to-date information."

In this base, all the potential buyers investigated expressed the expectation for an DTP with high aggregation level:

> "I need an integrated platform that can provide all information needed."

On the other hand, due to the immaturity of the industry, there is no existing unified standard for presenting and introducing LCTSs. The uniformity of information enables comparability between similar kind of innovations and contributing to the most suitable decision-making.

> "We wouldn't buy through these platforms necessarily, but we would use them to compare the environmental performance…The key is to make sure the information…is transparent and comparable."

Providers' Intergroup Interactions

Numerous providers have emphasized the significance of peer communication. Despite the advancements in information and communication technology (ICT), providers remain largely isolated. Presently, the primary means of communication between providers is at industrial events, which function similarly to DTPs and assemble diverse stakeholders in the same location and time. Through interfirm communication, the primary aim for providers is to identify opportunities for cooperation among various entities.

> "I had a chance to speak to some of them, and that was the first time…there's very little sort of (opportunities to communicate). We're all part of the same partnership apart from one other brand within the partnership that I can think of. None of them are direct competitors for us. And so my first thought is there must be overlaps where we can help each other."

Despite that, the providers also concern about learning the latest knowledge of advertising and business expansion.

Buyer' Intergroup Interactions

The buyer-buyer interaction is like that of the provider-providers. Sharing experiences among buyers, particularly those belonging to large companies, presents a greater challenge due to the safeguarding of their own commercial interests. In the selection process, around 90% of the potential buyers highlighted the importance of "trial" before final decision-making. Currently, there is a dearth of appropriate and reliable platforms to incentivise the exchange of experiences among buyers on a significant scale.

> "For me it would be really helpful to know which other organisations they have implemented this technology with...What has been the actual feedback from those organisations and well, actual savings they have...From the technology developer, a lot of time they are very focused on showing the success rather than actually show how the technology has worked…But there isn't really a place where you can go right now and say: OK, I can see that these colleagues in these five organisation…So perhaps it deserves A conversation."

During this process, extensive communication can aid in disseminating electronic word-of-mouth (e-WOM) and simultaneously conducting a screening process, thereby elevating the lesser-known providers to the forefront. This will also facilitate the conservation of time, energy, and financial resources for the buyers during the selection process.

DISCUSSIONS

In general, both providers and potential buyers exhibit a cautious yet inquisitive attitude toward integration of digital transaction platforms (DTPs) in their traditional workflow. Notably, providers, who are typically small and medium-sized enterprises (SMEs), express a fervent inclination towards DTPs, citing its potential to enhance their visibility and communication with potential buyers. Conversely, potential buyers tend to be more sceptical regarding the reliability of DTPs and the providers participating, aligning with the cautious and conservative culture that characterises the building sector. During the interviews, all potential buyers indicated that they are regularly contacted by numerous providers each day and will put limited time and effort to screen them. On one hand, the amount of reaching is too large to be went through one by one. In general, understanding towards DTP is not widespread in this industry, for some of the practitioners, although have joined the platform, they do not fully comprehend the purpose of joining. On the other hand, despite the large amount of LCTSs in the market, a substantial number of these innovations lack diversity, which lead to disappointment on the market and less interest in exploring. Therefore, education towards the nature of DTP is as important as that of the significance of LCTSs.

When queried about their willingness to participate in a new DTP, the potential buyers conveyed a sense of dissension. Approximately fifty percent of the participants indicated that despite their previous suboptimal experiences, they would still consider joining to “keep up with the market”. Conversely, the remaining participants expressed apathy towards the prospect. This lack of interest could be attributed to the nature of the buyer, as relatively disengaged buyers are typically affiliated with large organisations or enterprises that possess established suppliers, customers, and hold a relatively conservative attitude towards innovation, which conforms to the traditional characteristics of the building sector.

As a cost first industry, the practitioners tend to remain conservative, and trust comes with time and money consuming trials and real experiences. Therefore, the pragmatism of the industry could be one of the one of the most significant barriers hampering the adoption of DTPs. Future research may quantify how industry pragmatism affect the functioning of DTPs. The pace of low-carbon transformation in the building sector is slow. In this situation, the ability of creating an interaction environment with more rapport and facilitate the sharing and accumulation of knowledge and experiences could be one of the most outstanding contributions of integration of DTP, which could reduce both time and monetary cost of trial process thus making trading more efficient and credible to the potential buyers. This process could be contributed to the unique network effect of DTP.

In summary, the findings reveal a cautious yet inquisitive attitude among the stakeholders. Providers, primarily SMEs, are eager to leverage DTPs to enhance their visibility, while potential buyers are more sceptical about their reliability. The study identified four themes of changes DTPs could bring to facilitate the introduction and application process of LCTSs, as well as the unique factors in this process. Trust emerges as a key factor in facilitating transactions, particularly in the building sector. The findings suggest that DTPs can effectively extend the depth and breadth of communication between provider and buyer sides, reduce information asymmetry, and create opportunities for cooperation and customisation. However, the importance of education on the nature and benefits of DTPs is highlighted, as well as the need to build trust and share experiences among the industry practitioners to enable a more efficient and reliable adoption of low-carbon technologies.

CONCLUSIONS

The present research endeavours to comprehend the efficacy of incorporating DTPs to enable the building sector to achieve the net-zero emissions target. Through interviews with both providers and potential buyers, this inquiry elucidates the conventional transaction mode of LCTSs and identifies four themes' DTPs can help with to facilitate the transactions of LCTS along with the influencing factors. Based upon which, this study identifies the critical factors that can facilitate the transaction of LCTS. The research outcomes offer insights into the integration of DTPs and suggest prospects for extending these findings to adopt novel technologies in the building sector.

The limitation of this study could be contributed to the sample size of interview, future work should extend the sample size to enrich and validate current findings. Additionally, all interviewees in this study are business participants, restricted by a business-to-business (B2B) working pattern. To broaden the study's scope, future research could explore other business modes (e.g., B2C).

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SYNERGISING CONTINUOUS IMPROVEMENT WITH CIRCULAR ECONOMY FOR ADVANCING INNOVATION IN THE CONSTRUCTION SECTOR: A TEXT MINING APPROACH

Temitope S Omotayo[1], Bankole Awuzie[2] and Obi Lovelin[3]

[1] *School of Built Environment Engineering and Computing, Leeds Beckett University, City Campus, Leeds, West Yorkshire, LS2 8AG, UK*

[2] *School of Construction Economics and Management, University of Witwatersrand, 10b Yale Rd, Braamfontein, Johannesburg 2000, South Africa*

[3] *Department of Architecture and Built Environment, Northumbria University, Sutherland Building, Northumberland Road, Newcastle-upon-Tyne, NE1 8ST, UK*

Integrating continuous improvement and circular economy principles can promote sustainable construction practices (SCPs) and deliver long-term environmental, social and economic benefits. This study demonstrated how text mining could be applied to explicate the linkage between continuous improvement and circular economy principles in enhancing sustainable construction practices. The research applied unsupervised machine learning using text mining analyses through collocations to identify thematic areas where the integration of continuous improvement and circular economy principles would foster sustainable construction. Eighty-nine (89) peer-reviewed publications were extracted from the Scopus database for text mining analysis. The findings from text mining presented seven cogent themes through which continuous improvement and circular economy can be integrated. The optimal integration of the linkages advocated in this research can facilitate improved SCPs such as design for disassembly, modular construction, adaptive reuse, eco-friendly materials, innovative technologies, industrial symbiosis, life cycle assessment, cradle-to-cradle design, and lean construction practices. This investigation elucidated the utility of machine learning text mining in thematising and advancing sustainable construction research.

Keywords: sustainable construction; improvement; circular economy; text mining

INTRODUCTION

The construction industry contributes significantly to global resource consumption, waste generation, and greenhouse gas emissions (Giesekam *et al.,* 2016). Adopting sustainable practices is essential to reduce the environmental impact of this sector. Continuous improvement is a management philosophy that facilitates incremental change to achieve long-term sustainable growth (Omotayo *et al.,* 2018). Continuous improvement and circular economy are key to promoting sustainable construction

[1] t.s.omotayo@leedsbeckett.ac.uk

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(Bocken *et al.,* 2016). In sustainable construction, continuous improvement involves identifying, prioritising, and implementing strategies to improve environmental, social, and economic performance during construction (Azhar *et al.,* 2011). This approach fosters a culture of innovation and encourages new technologies and processes, such as Building Information Modelling (BIM) and off-site construction. This significantly reduces waste and improves resource efficiency.

This investigation demonstrates how text mining can be applied to elicit and link themes associated with continuous improvement and circular economy towards promoting sustainable construction practices (SCPs).

LITERATURE REVIEW

Osobajo *et al.,* (2020) and Obi *et al.,* (2023) asserted that integrating continuous improvement and circular economy principles is vital for promoting SCPs. Continuous improvement in construction applied the Deming circle of plan-do-check-act to reduce physical and non-physical waste (Omotayo *et al.,* 2022; Tezel *et al.,* 2023). These concepts encourage the adoption of innovative technologies and processes, enhance resource efficiency, and contribute to economic growth, providing a strong foundation for a more sustainable and resilient construction industry. Circular economy involves a paradigm shift from the traditional linear 'take-make-dispose' model to a regenerative system that aims to minimise waste and maximise resource efficiency (Ellen MacArthur Foundation, 2013; Osobajo *et al.,* 2020). Circular economy emphasises the importance of designing for disassembly, reuse, and recycling to keep materials in circulation for as long as possible (Bocken *et al.,* 2016, Ramakrishna *et al.,* 2020).

Circular economy principles can be implemented in the construction sector through various strategies, including modular design, adaptive reuse, and eco-friendly materials (Arup, 2016). The adoption of these concepts in the construction industry not only contributes to environmental sustainability but also provides economic benefits. By reducing waste, conserving resources, and promoting innovation, SCPs can lead to cost savings, new business opportunities, and increased competitiveness (Giesekam *et al.,* 2016). Although the term continuous improvement is not very popular, it is important to emphasise the relevance and recency of continuous improvement in construction cost management, procurement, construction, and building information modelling (to mention a few) through the publication of Omotayo *et al.,* (2022); Tezel *et al.,* (2023) and Rashidian (2023).

Continuous improvement has been applied throughout construction since the 1980s through lean philosophy to reduce construction waste (Omotayo *et al.,* 2022; Tezel *et al.,* 2023). Integrating continuous improvement and circular economy principles in sustainable construction creates a synergistic effect that enhances overall environmental performance. For example, continuous improvement can help identify construction material reuse and recycling opportunities, leading to improved circular economy performance (Bocken *et al.,* 2016). Azhar *et al.,* (2011) further noted that circular economy strategies, such as designing for disassembly and using recycled materials, can be incrementally improved through continuous innovation and learning. Suffice it to state that the combination of continuous improvement and circular economy principles will encourage the development of a more resilient and adaptive industry better equipped to address future sustainability challenges (Arup, 2016). Therefore, establishing measures for integrating continuous improvement and circular economy principles could lead to effective Sustainable construction practices and performance.

This study aims to explicit the function of text mining analysis in mapping and establishing interconnectedness between continuous improvement and circular economy towards improving SCPs and performances within the construction industry.

METHOD

Text mining is extracting useful information and patterns from unstructured text data using computational techniques (Feldman and Sanger, 2007). This includes multiple techniques such as natural language processing (NLP), unsupervised ML, and statistical techniques to analyse and understand text content and structure (Nassirtoussi *et al.,* 2014). Unsupervised ML pertains to a situation where the algorithm learns from unlabeled data without the influence of specific data for outputs. Hence, the outputs are generated automatically by the algorithm. Text mining applications are extensive and span areas such as sentiment analysis, topic modelling, and information extraction (Aggarwal and Zhai, 2012). Text mining enables researchers to extract valuable insights from large amounts of text data that are difficult to analyse manually. As part of this analysis, collocations were used in R Studio's text mining process.

Text mining collocations involve identifying pairs of words frequently occurring together in a corpus more often than expected by chance (Manning and Schütze, 1999). Collocations provide insights into language patterns and help uncover meaningful associations between words, which can be useful in various NLP tasks, such as sentiment analysis or information retrieval (Evert, 2008). Analysing collocations can help reveal hidden semantic structures and improve the understanding of the relationships among words in the context of the text (Baker, 2006) as the exclusion criteria. The text mining data was extracted from Scopus using the keywords “continuous” AND “improvement” AND “circular” AND “economy” AND “the” AND “construction” AND “industry”. Four hundred and sixty-one (461) documents were retrieved from Scopus. Only peer-reviewed articles published between 2012-2022 and in English were considered for use because of quality and validity requirements for the text mining operation (as the exclusion criteria). Additional manual reviews of the document were undertaken to eliminate irrelevant publications. Through this process, eighty-nine (89) peer-reviewed publications were deemed relevant to be included in the text mining collocations analysis.

The formula for calculating collocations in R typically involves using measures such as Pointwise Mutual Information (PMI) or Log-Likelihood Ratio (LLR) to identify pairs of words that frequently co-occur in a corpus (Evert, 2008). PMI is defined as:

$$PMI(w1,w2)=\log_{2}(P(w1,w2)/(P(w1)*P(w2))) \qquad (1)$$

where P(w1, w2) is the probability of observing the two words w1 and w2 together, and P(w1) and P(w2) are the probabilities of observing the individual words (Church and Hanks, 1990). To calculate collocations in R, the "quanteda" package can be used to tokenise text, remove stopwords, and extract n-grams, while the "text2vec" package can be used to compute the PMI or LLR measures (Benoit *et al.,* 2018; Selivanov and Wang, 2016). The text data was analysed using the R script (Figure 1) to identify collocations. The R script is divided into several steps, as highlighted below: related to the terms "improvement”, “continuous”, “circular”, and “economy”.

Step 1: Data pre-processing: Cleaning, tokenisation, and removing stopwords and extra words.
Step 2: Bigram extraction: Extracting bigrams from the tokenised text.

Step 3: Corpus creation and cleaning: Converting the text data into a corpus and removing unnecessary words.
Step 3: Co-occurrence statistics calculation: Calculating co-occurrence statistics for the term "improvement", "Continuous", "Circular", and "Economy".
Step 4: Association strength: Creating a data frame and bigram table with the association strength of the collocating terms.
Step 5: Visualisations: Visual representations of the collocations through a dendrogram and network graph.

Figure 1: R script for collocations of continuous improvement and circular economy

```
#load all files
All_CIfiles <- read_docx("CI.docx")
Contents<- docx_summary(All_CIfiles)
#read text from the content variable
paragraph<- Contents %>% filter(content_type == "paragraph")
Doc_Data<- paragraph$text # Access actual text
paste0(collapse = " ") %>%
  stringr::str_squish() %>%
  stringr::str_remove_all("- ")
Doc_split <- Doc_Data %>%
  as_tibble() %>%
  tidytext::unnest_tokens(words, value)
# create data frame
ci_words <- Doc_split %>%
  dplyr::rename(word1 = words) %>%
  dplyr::mutate(word2 = c(word1[2:length(word1)], NA)) %>%
  na.omit()
ci2grams <- ci_words %>%
  dplyr::mutate(bigram = paste(word1, word2, sep = " ")) %>%
  dplyr::group_by(bigram) %>%
  dplyr::summarise(frequency = n()) %>%
  dplyr::arrange(-frequency)
```

FINDINGS

Framework of Continuous Improvement and Circular Economy

In developing a framework for linking continuous improvement and circular economy principles through text mining collocations, a dendrogram and network diagram, as illustrated in Figures 2 and 3, were produced. The dendrogram categorised the texts from the collocations analyses, and the network diagram exhibited the strength of the collocation in the thicker lines. The dendrogram and network diagram findings can be categorised as a continuous improvement for development; integration into the supply chain; industrial manufacturing processes; organisational culture and leadership; quality and site management; cyclical economic flow; and PDCA decisions.

Table 1 itemises 20 collocations with corresponding frequencies, lengths, lambda values, and Z scores. The lambda score is the measure of association between two variables and the z score is the number of standard deviations a specific variable is away from the mean value (Baker, 2006. The lambda and Z scores reveal the relevance of the collocations. More relevance is suggested by higher lambda and Z scores. For instance, "Continuous Improvement" is a notable keyword in Table 1 because it has the highest Z score (21.97) and the highest lambda score (6.75). Like "Circular economy," with a high lambda (3.95) and Z score (19.00), "Life cycle" also highlights the relevance of these concepts. The Z scores typically decline down Table 1, indicating decreased relevance for these collocations.

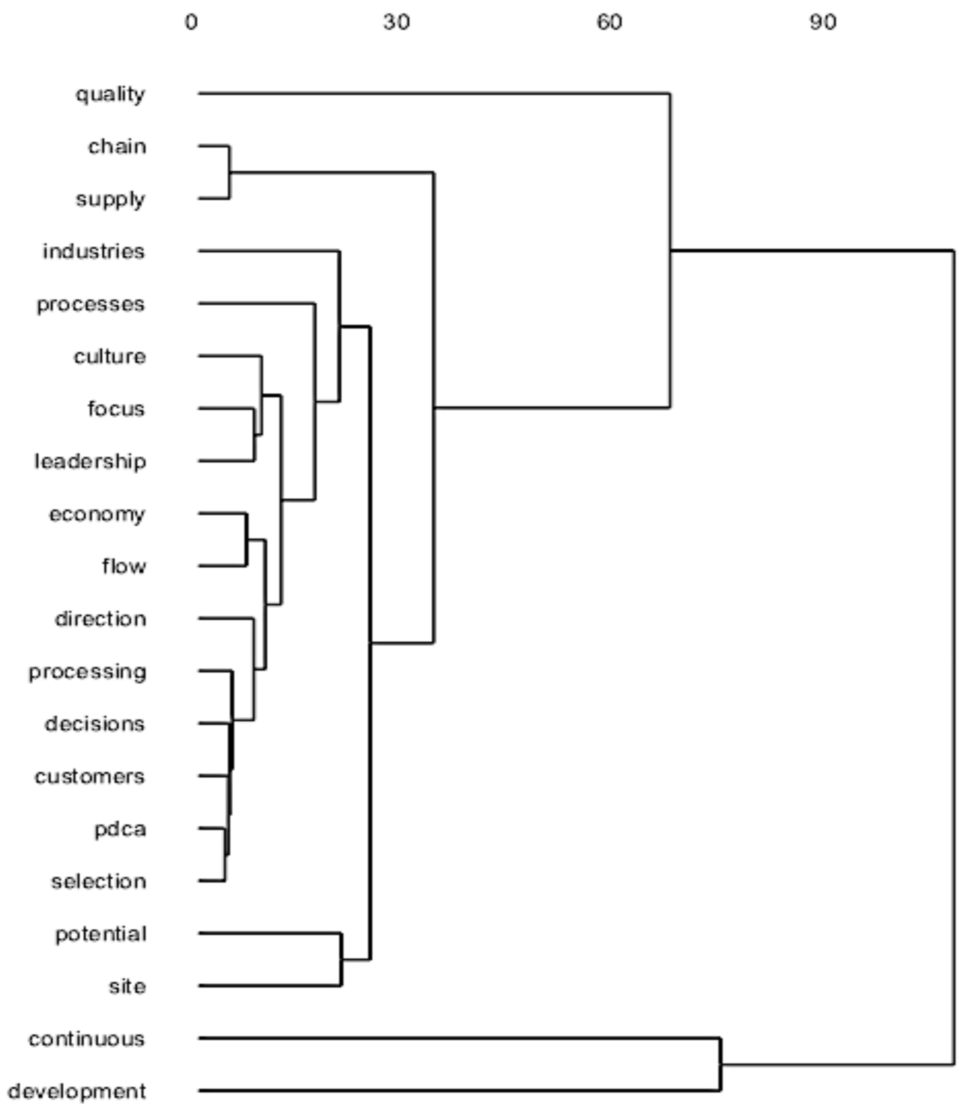

Figure 2: Dendrogram from text mining collocations

Figure 3: Network diagram of continuous improvement and circular economy

To synergise continuous improvement with circular economy principles from Figures 2, 3, and Table 1 text mining collocations produced thematic application areas in the construction sector.

Table 1: Text-mining collocations showing lambda and z values

S/N	Collocation	Count	Length	Lambda	z
1	Continuous Improvement	53	2	6.747401	21.965519
2	Circular economy	47	2	3.949813	19.003393
3	Life cycle	17	2	5.781885	13.695019
4	Construction Resources	11	2	6.408618	13.419721
5	Construction technologies	13	2	8.326186	12.341994
6	Building Information	9	2	6.853042	11.823485
7	Practical Implications	7	2	7.219799	11.523591
8	Modular construction	8	2	7.964179	11.166175
9	Customer Satisfaction	7	2	8.134601	11.095890
10	Safety Performance	9	2	4.463799	11.073083
11	Material Transportation	6	2	7.623686	10.895436
12	Cost Control	6	2	5.733656	10.737258
13	Design Quality	10	2	3.993786	10.736981
14	Green Building	7	2	7.564401	10.706928
15	Construction Projects	14	2	3.867110	10.667298
16	Lean construction	6	2	7.807408	10.458364
17	Soil Recycling	5	2	7.313531	10.373453
18	Life Cycle	5	2	7.456721	10.364844
19	Material Technology	7	2	4.963791	10.339321
20	Workforce Productivity	10	2	7.523062	10.289716

Industrial Symbiosis in Construction

Industrial symbiosis is a concept derived from circular economy that facilitates the exchange of resources, energy and knowledge between different industries to create mutually beneficial relationships (Ramakrishna *et al.,* 2020). An example of industrial symbiosis in the construction industry is using waste from other industries as raw materials for new construction projects (Yuan and Shen, 2011). This practice reduces waste, reduces demand for new materials and contributes to a more sustainable construction sector.

Life Cycle Assessment in Construction

Life Cycle Assessment (LCA) is a method of evaluating the environmental impact of a product or process throughout its life cycle, from raw material extraction to disposal (Rebitzer *et al.,* 2004). By applying her LCA in the construction industry, decision-makers can identify areas for continuous improvement, including material selection, design optimisation, and waste management strategies (Khasreen, *et al.,* 2009). Construction organisations can make more informed decisions and minimise their environmental footprint by implementing their LCA in construction projects.

Cradle-to-Cradle Design in Construction

McDonough and Braungart (2002) and Ricard *et al.,* (2023) detailed that cradle-to-cradle design is a concept that facilitates the development of environmentally friendly, recyclable, and renewable products and processes. The cradle-to-cradle design fosters continuous improvement by encouraging the development of innovative materials, technologies and construction techniques that minimise waste and maximise resource efficiency. Lewandowski (2016) noted that this approach could be applied to the construction industry by using biodegradable materials, integrating renewable energy systems, and designing buildings that can be easily dismantled and reused.

Lean Construction Practices

Lean Construction is an approach focused on minimising waste and maximising the value of the construction process through continuous improvement, collaboration, and efficient processes (Koskela, 1992; Akinade *et al.,* 2018). By implementing lean construction practices, companies can improve resource efficiency, reduce project delays, and improve overall project quality (Salem, Solomon, Genaidy, and Minkarah, 2006). By integrating lean principles into circular economy, we can develop more SCPs and achieve long-term environmental, social and economic goals.

CONCLUSION

This investigation highlighted how text mining as an analytical approach could aid the incorporation of continuous improvement and circular economy principles to promote sustainable construction practices and performances. The research created crucial links between these concepts and their influence on sustainable construction by utilising text mining. Key thematic areas that link continuous improvement and circular economy principles were identified. These include the design for disassembly, modular construction, adaptive reuse, eco-friendly materials, cutting-edge technologies, industrial symbiosis, life cycle assessment, cradle-to-cradle design, and lean construction techniques. Resource efficiency, waste reduction, extended building lifespans, and improved environmental performance. This study also emphasises the significance of machine learning text mining for finding and advancing sustainable construction. Further research applications must be conducted on larger datasets to optimise sustainable construction research for the built environment.

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SUSTAINABLE INNOVATION PROCESSES IN THE ASPHALT PAVING SECTOR: A SYSTEM INNOVATION APPROACH

Angie Ruiz[1], Joanne Vinke-de Kruijf, Joao Santos, Leentje Volker and Andre Dorée

Department of Construction Management and Engineering, University of Twente, Drienerlolaan 5, Enschede, 7522 NB, The Netherlands

The asphalt paving sector is committed to achieving sustainability targets and the adoption of innovations, such as alternative materials and more efficient production and construction processes, offer a way forward. Despite the progresses already made, widespread implementation of such innovations is lagging, mainly due to social and institutional aspects of the transformation such as policies and regulations, cultural values and norms, lack of awareness and knowledge. This study employs a system innovation approach to determine which key elements shape sustainability innovation processes in the asphalt paving sector. To identify elements, we critically compare empirical patterns that were identified using the Dutch asphalt sector as case study with theoretical patterns that resulted from a literature review on drivers and barriers to sustainability and innovation. We conclude that the system innovation process is determined by a set of fifteen elements including institutional rules, inter and intra-organizational dynamics, and actors' roles. This set of elements can be used to build the structure of the system and explore its dynamics and enable the sector to reach more efficient innovation processes.

Keywords: Asphalt paving; socio-technical systems; innovation; sustainability

INTRODUCTION

The asphalt paving sector is committed to moving towards a more sustainable path by adopting innovations, such as alternative materials and more efficient production and construction processes (United Nations, 2020). However, the widespread implementation of such innovations is lagging. To better understand the implementation of sustainable innovations, we adopted a system innovation (SI) approach to conceptualize the process as a socio-technical system (STS) (Elden *et al.,* 2004). Academics and practitioners in the construction sector recognize the relevance of employing STS to approach sustainability and innovation challenges (Li *et al.,* 2019; Pelle, 2021). However, most studies in the construction field tend to focus on the characterization of the technical dimension, which is frequently considered as an endogenous process in single organizations (Arshad *et al.,* 2021; Ershadi *et al.,* 2021). Although the social dimension in STS is recognized, it is usually considered as an

[1] a.l.ruizrobles@utwente.nl

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external element when analysing innovation, leading to a poor understanding of the influence of other as institutional rules, cultural values, and actors' preferences in the implementation of innovations in the engineering field.

Insights from SI literature highlight that considering the dynamics of both technical and social dimension is relevant for promoting the implementation of sustainable innovation, specifically, the interactions among the actors involved in process success R&D, production, market, and policies (Sour's and Roelofs, 2014). The decisions and activities made by the actors of the system shape its structure which accounts for its ability to respond autonomously, adapt to the context, and be steered towards a goal (Geels and Kemp, 2007). In other words, technological innovations are important to achieve sustainability targets, but they require a link to the social dimension (actors, networks, and institutional rules) since the latter establishes the structure of STS and is responsible for the capacity of the system for fulfilling its purpose (Organisation for Economic Co-opertaion and Development OECD, 2015; Smith *et al.,* 2010). Consequently, a proper understanding of the social elements and their link to the technical elements is needed to strengthen the implementation of sustainable innovations.

Our study aims to identify the elements that shape the decisions and actions of the actors involved in the innovation process by examining the system innovation processes in the public sector domain. To accomplish this, this study applies pattern matching to combine insights from a case study in the asphalt paving sector in the Netherlands (Ruiz *et al.,* 2023) with broader insights from the literature on system innovations for exploring the key socio-technical elements in the asphalt paving sector within the context of developing and adopting technological sustainable innovations.

METHOD

We used pattern matching to identify and define the most influential elements that facilitate or hinder the implementation of sustainable innovations in the asphalt paving sector. We compared empirical patterns with theoretical patterns to identify matches and relationships between them (Yin, 2015). First, we identified a set of empirical elements based on insights collected through interviews with experts in a case study of sustainability innovation in the Dutch asphalt paving sector as described in Ruiz *et al.* *(*2023). We selected the asphalt paving sector in the Netherlands as a case study because it offers the opportunity of analysing the implementation of innovation in a complex context where both the public and private sectors are responsible for delivering public services. Specifically, the Netherlands has a dense road network of high quality, that is mainly managed by public authorities, which commission parts of the private sector to carry out construction and maintenance work (Government of the Netherlands, 2022). The country is committed to reducing CO2 emissions, with sustainability innovations being encouraged in various sectors, including the infrastructure sector (Ministry of Infrastructure and Water Management, 2020). Our case study research revealed that "testing and validation" and "scaling-up" require a higher level of interorganizational interactions than earlier stages where problems are identified, ideas developed and prototyped. Therefore, we decided to focus our analysis on these stages.

Second, for identifying the theoretical elements, we conducted a literature review on socio-technical system elements and drivers and barriers to innovation and sustainability. We selected 26 articles for our critical literature review based on several criteria. We focused on recent publications within the last 10 years to ensure that our review captured the most up-to-date research in the field. Additionally, we limited our review to articles that addressed the social dimension. Furthermore, the literature review is conducted using a "snowball sampling" approach (Wohlin, 2014), which involves selecting key studies and then identifying further relevant sources through their reference lists. This method is useful for efficiently assessing the range of research resources related to a particular subject and for the effective retrieval of pertinent literature (Gordon *et al.,* 2023; Greenhalgh and Peacock, 2005).

Third, to define the set of key elements, we employed pattern matching to compare the empirical elements observed in our case study with theoretical elements identified in the literature review. By examining similarities and mismatches between them, we established connections that helped us to identify the key elements relevant to our research objective. This process allowed us to validate elements that have been identified in previous studies and uncover elements that have not been explicitly addressed and generate a deeper understanding of the elements influencing the innovation process. Additionally, we adopted three categories for grouping the identified elements: institutions, actors, and interactions. The three categories reflect a common view of system innovations across different disciplines; system innovation processes are shaped by the variety of interdependent actors interacting in social networks and institutional contexts (Elzen *et al.,* 2004; Suurs and Roelofs, 2014).

Finally, we conducted a synthesis of elements based on the pattern matching. Specifically, we merged the set of empirical elements according to the description of the elements provided in the articles reviewed. For instance, elements such as knowledge exchange, collaboration, and communication initiatives were merged into collaboration since they represent different aspects of the same overarching concept, emphasizing the importance of information sharing, cooperative efforts, and effective communication in driving the implementation of sustainable solutions, i.e., they represent similar types of interactions among actors.

FINDINGS

This section describes the structural elements identified in the process that led to implementing sustainable innovations in the Dutch asphalt paving sector. First, we matched the empirical elements with the theoretical ones to identify those that were consistently mentioned in other studies. For example, the case study showed that accessibility to the testing location was an influential element in the Dutch asphalt sector. This element was then compared with the findings reported in the literature and it was found that 35% of the studies reviewed also identified it as a key element.

Table 1 presents the results of the pattern matching, with the first column showing the three pre-defined categories (i.e., institutions, actors, and interactions), plus a fourth one (i.e., "other") for those elements that did not fit in the previous three. The second column lists the 24 empirical elements identified in the case study, and the third column the literature sources (including the percentage of the 26 articles) in which the corresponding empirical element was highlighted. Based on the pattern matching results, we defined a consolidated list of 15 elements in the four categories. In the subsequent sections, we provide a concise explanation of each category, specify the elements within the category, including the percentage of papers in the literature review that identified them, and demonstrate its application in the context of asphalt.

Institutions

Institutions refer to set of rules, norms, and conventions that govern the actors' behaviour in a particular context. They can be formal, such as laws and regulations or informal, such as social norms and shared values (Hodgson, 2006). The first element in this category is "legal and policy factors", where actors adapt their behaviour based on a law or practice established by other actors or society. This type of element was identified in 77% of the studies reviewed. The studies particularly stress that regulatory uncertainties, inadequate policies, and incentives can hinder the implementation of sustainable innovations. In the Dutch asphalt paving sector, the innovation process is extremely shaped by policies and regulations. For instance, recycled materials and low-temperature asphalt mixtures are dominant among innovations because of being strongly promoted and requested by road authorities.

The second element is the "mindset", which was identified in 62% of the studies reviewed. It is influenced by factors such as awareness and consciousness, resistance to change, values, beliefs, trust, and fear. Actors in the asphalt paving sector are reluctant to accept radical innovations and focus on short-term project perspectives in decision-making which is also hindering the progress towards sustainability. The third element in this category is "conservative assessment criteria". The assessment criteria are the set of rules or norms to determine the potential of sustainable innovations. Most studies highlight assessment criteria as an influential element. However, 27% of the studies specifically mentioned that the challenge is that the current criteria in different fields tend to prioritize stability over change, making it difficult to introduce new technologies. In the asphalt paving sector, the main challenge regarding the conservative assessment criteria is that sustainable innovations are assessed following standards developed decades ago and are expected to perform technically in the same way as traditional asphalt materials.

The last element of the institutions is "lack of harmonization" across and within levels of the system. It was identified in 58% of the studies, which highlighted the lack coherence and consistency in policies, procedures, focus areas, and standards. In the Netherlands, sustainability standards and assessment criteria can vary from project to project or from client to client. This leads to confusion among actors and can create uncertainty, especially for contractors who may not know where to focus their resources.

Interactions

The elements in this category represent the main ways in which actors across the system interact and communicate. The main element is "collaboration", which was found in 54% of the studies (including communication initiatives and knowledge exchange). This percentage shows that collaboration with suppliers, participation in R&D networks, co-creation of products and services, and closer interaction and networking can lead to successful sustainable innovation implementation. In the asphalt paving sector, actors are aware of the need of collaborating, but most of these happen in the form of best practices exchange. This alone is insufficient to generate comprehensive joint efforts. To effectively accomplish the implementation of innovations, the sector must bridge the gap between practice exchange and robust collaborative actions.

Additionally, several other types of "inter-organizational interactions" were also identified in 23% of the studies. This includes communication channels, and relationships with suppliers, clients, public organizations, and communities. The literature highlights that inter-organizational interactions tend to be a challenge, especially when the relational power lies in one or a few organizations. This is the case in the asphalt paving sector, where the public actors are dominant, generating a relational power imbalance, which leads the private actors to face challenges in gaining support for innovating.

The third element in this category is "intra-organizational interactions" and in particular, the hierarchical ones that require interactions at different levels of the organization. It was identified in 35% of the studies reviewed, which highlights that many organizations struggle to adopt sustainable innovations due to inappropriate organizational structure that leads to poor communication. In the asphalt paving sector operational-level actors, such as the specialized staff, find it difficult to exert influence at the strategic level. This calls for an improvement of vertical communication channels. Emphasizing the need for cross-functional teams that helps to coordinate and engage multiple actors.

Actors' Roles

The last category includes five key roles in innovation: managers, specialized staff, framework setters, evaluators, and coordinators. The first one is the role of "managers", which was mentioned in 62% of the studies as crucial in the implementation of sustainable innovations. Studies have shown that top managers' support is essential for sustainability innovation processes. The decentralization of decision-making within top management teams means that actors with leadership powers have a significant impact on the sustainability dimension of any organization. In the asphalt paving sector, top managers were identified as key actors in the innovation process, particularly asset managers since they decide which kind of projects would be developed and when.

The second key role is the "specialized staff", which was identified in 54% of the studies reviewed. Usually, it was mentioned as a barrier, due to the lack of skills and training, and deficiency in knowledge. In the asphalt paving sector, the specialized staff is directly involved in the development of assessment methods and criteria in the testing and validation and scaling-up stages. Specifically, LCA and pavements experts provide inputs in these stages. However, the specialized staff usually serves as consultants but are not the ones making the decisions. The involvement of specialized staff in decision-making processes can help in developing innovative solutions and identifying opportunities for sustainable practices.

The third role identified as a key structural element is the "framework setters", particularly public authorities. According to 27% of the studies, governmental bodies serve as the main driver for implementing sustainable practices in industries, since they drive most regulations, policies, and incentives. In doing so, they facilitate or make more difficult the shift towards a more sustainable paths and provide a clear direction for the rest of the actors involved in the innovation process. In the asphalt paving sector, the framework setters, especially road authorities, play the most significant role in the overall process, in the sense that they develop sustainable policies and issue targets that shape all the stages in the process. The frameworks setters' actions can help levelling the playing field, encouraging the sector to adopt sustainable innovations and reducing the competitive disadvantage faced by early adopters.

Another key role is the "evaluators", who play a crucial role in monitoring and assessing the implementation of sustainable innovations. Evaluators as a role were only identified in 8% of the studies. However, one of its main functions "monitoring" was mentioned in 31% of them. Evaluators are responsible for creating new metrics and tools to measure the impact of innovation on the performance of systems. Through their monitoring and evaluation activities, they provide the necessary data that systems need to adapt and reorient themselves toward sustainability paths. In the asphalt paving sector, the evaluator is one of the main roles along with frameworks setters and managers, as they are the ones assessing the potential of sustainable innovations. Basically, they determine which innovations move to further steps in the innovation process. Evaluators help identify gaps and potential areas of improvement in sustainable innovation implementation, and their feedback is essential to achieve the targets.

The last key role is the "coordinators", which was mentioned in 12% of the studies. According to the literature, coordinators act as a facilitator in bringing together diverse actors such as governments, contractors, and communities to collaborate toward achieving common sustainability goals. They help build trust and communication channels among actors, create a shared understanding of challenges and opportunities, and coordinate joint actions. In the asphalt paving sector, the coordinators' role is mostly played by third-sector actors (e.g., the network for transport, infrastructure, and public spaces and research institutions), who are mostly involved in the testing and validation stage. Coordinators should take part in the entire process, connecting different actors to proactive and collaborative platforms and making a coherent combination of local and national action plans.

Other

The final category includes three elements that could not be grouped into one single category but were consistently highlighted in the literature. The first element is "financial benefits", which were mentioned in 62% of the studies reviewed. It was consistently mentioned that sustainable innovations often require high investments, and the benefits are hard to monetize or only noticeable in the long term. In the asphalt paving sector, profit always plays a role when making decisions in the innovation process. For example, an innovation with great potential of contributing to emissions reduction is not considered for further development if it does not bring profit for the companies.

Another element identified is "large-scale implementation", which was associated with market creation. This element was mentioned in 54% of the studies reviewed, highlighting that to ensure the success of sustainable innovations, it is essential to create a favourable market environment. The literature highlights that this can be done by signing agreements among different industries and creating a temporarily protected niche market. In the Dutch asphalt paving sector, the sustainable innovation process is considered successful when the innovation is implemented in multiple large-scale projects. An innovation that is implemented at that scale can guarantee high-quality products and ensure profits, which further incentivizes the contractors.

The last element is "accessibility of testing locations", which refers to the ease of locating and accessing sites where sustainable innovations can be tested and demonstrated. It allows researchers and innovators to assess the effectiveness and feasibility of their solutions and to directly analyse structural elements in the context of the innovation process. Around 35% of the studies highlighted challenges related to accessibility to testing locations, such as the difficulty in finding suitable locations for research as well as an insufficient number of trials and demonstration projects. According to the empirical patterns, this is because in the asphalt paving sector, access to testing locations can only be ensured through collaboration among public, private, and third sectors, which can be challenging due to conflicts of interest. being the key interaction in the process.

Table 1: Pattern matching- Empirical elements contrasted with theoretical elements.

Category	Empirical elements	Literature review
Institutions	Sustainability targets	3, 5, 8, 15, 19, 21, 26 (27%)
	Lack of harmonization in policies and procedures	1-5, 7-10, 13-15, 17, 18, 20 (58%)
	Conservative assessment criteria	4, 5, 7, 10, 13, 19, 20 (27%)
	Project perspective in decision-making	15, 19, 22, 25, 26 (19%)
	Legal and policy factors	1-6, 8-16, 18, 19, 21, 22, 23 (77%)
	Misalignments among levels in the system	3, 5-7, 9, 17, 19, 22, 23 (35%)
	Mindset (trust, fear, willingness)	1,2, 5-7, 8-11, 13,14, 16, 18, 19, 21-23 (62%)
Interactions	Collaboration	3, 6, 7, 10, 14, 18, 22 (27%)
	Best practices exchange	5, 12, 15, 17, 18, 22 (23%)
	Communication initiatives	1,4, 7, 10, 15, 17, 22, 25 (31%)
	Inter-organizational interactions	4, 7, 17, 20, 22, 25 (23%)
	Hierarchical relationships (Operational and strategic level)	3,6, 7, 11, 16, 17, 22, 25, 26 (35%)
	Competition for steering innovation	2, 6, 8, 9, 11 (19%)
Actors' roles	Public sector as a framework setter	2, 5, 7, 9, 11, 22, 25 (27%)
	Public sector as a client	3, 6, 11, 19 (15%)
	Public sector as evaluator	3, 8 (8%)
	Third parties as evaluators	0%
	Managers	3, 4, 6-8, 10, 11, 14-16, 18, 19, 22, 23, 25, 26 (62%)
	Association/ groups as coordinators	17, 22, 23 (12%)
	Specialized staff	2-7, 9, 11, 14-16, 18, 24, 26 (54%)
	Monitoring (actor's role)	5-7, 13, 14, 22, 25, 26 (31%)
Other	Accessibility to testing locations	5, 9, 13, 15, 21-25 (35%)
	Large scale implementation/ market acceptance	3-6, 9, 10, 12, 13, 20, 21, 23-26 (54%)
	Financial benefits	2-6, 9-13, 16, 18, 20, 21, 23, 24 (62%)

Note: 1=(Aktas and Ozorhon, 2015); 2=(Alsanad, 2015); 3=(Atafo-Adabre *et al.*, 2020); 4=(Cardoso *et al.*, 2023); 5=(Chan *et al.*, 2016); 6=(Dhull and Narwal, 2016); 7=(Ershadi *et al.*, 2021); 8=(Giunipero *et al.*, 2012); 9=(Gordon *et al.*, 2023); 10=(Hill *et al.*, 2023); 11=(Hinrichs and Wettlin, 2019); 12=(Hoicka *et al.*, 2022); 13=(Hübel and Schaltegger, 2022); 14=(Hussain *et al.*, 2016); 15=(Kanda *et al.*, 2022); 16=(Karji *et al.*, 2020); 17=(Manny, 2023); 18=(Mathivathanan *et al.*, 2021); 19=(McMurray *et al.*, 2014); 20=(Munyasya and Chileshe, 2018); 21=(Nemoto *et al.*, 2023); 22=(Organisation for Economic Co-opertaion and Development OECD, 2015); 23=(Oeij *et al.*, 2019); 24=(Pizzol *et al.*, 2022); 25=(Wang *et al.*, 2018); 26=(Wesseling *et al.*, 2022).

CONCLUSIONS.

This study aimed to identify the elements that influence the implementation of sustainable innovations in the asphalt paving sector, an integral part of the construction industry, in the Netherlands. Our study offers insights into socio-technical elements shaping the innovation process in the asphalt paving sector, an integral part of the construction industry. We focused on the testing and validation and scaling-up stages of the process, as they involve complex interactions among different actors and levels of the system. Based on the pattern-matching process, we identified 15 elements that play a critical role in the innovation process, which were classified in four categories: (1) institutions, which include legal and policy factors, mindset, conservative assessment criteria, and harmonization; (2) interactions, consisting of collaboration, inter-organizational, and intra-organizational interactions; (3) actors' roles, specifically, the roles of managers, specialized staff, evaluators, framework setters, and coordinators; and (4) other, which include financial benefits, large-scale implementation, and accessibility to testing locations. Overall, the findings highlight the need for systemic approaches for redistributing organizational functions and actors' roles to facilitate and improve the efficiency of the implementation of sustainable innovations. This aligns with the findings of Lee *et al.* (2021) who identified the lack of defined roles and responsibilities among actors as a main cause of limiting guidance in implementing sustainability strategies in projects.

Our study contributes to the understanding of the socio-technical elements that influence the implementation of sustainable innovations in the construction sector and other project-based industries that provide public services. It highlights the importance of analysing the institutions, interactions, and actors' roles. Specifically, the findings underline the need of a proper understanding of roles among actors at distinct levels of the system to improve effectiveness of sustainable innovations and ensure that the systems continue to meet their intended goals over time. Furthermore, our findings can help policy and decision makers, particularly in the asphalt paving sector, to identify the key structural elements that may hinder the implementation of sustainable innovations. By doing so, the transportation infrastructure sector is in a better position to design and construct infrastructure systems that can respond and adapt to changing social and environmental contexts, thereby leading to more sustainable and resilient solutions.

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INVESTIGATING THE ROLE OF DIGITAL TWIN AND 5G TECHNOLOGY IN ENHANCING SMART ENERGY MANAGEMENT

Shashwat S[1], Kumar Vishal[2] and Kishor Zingre[3]

[1&3] Department of Architecture and Built Environment, Northumbria University, Newcastle upon Tyne, NE1 8ST, UK

[2] School of Built Environment, Massey University, Auckland, Private Bag 102904, North Shore, New Zealand

Smart Energy Management (SEM) backed by IoT devices and AI/ML algorithms is crucial for achieving energy reduction goals and meeting global sustainability targets such as COP 26. A Digital Twin (DT) allows for rapid analysis and real-time decisions made through accurate analytics for SEM. Furthermore, for urban-scale DT; the next generation of network connectivity can support a high volume of data transfer in real-time. Therefore, this paper analyses trends; technological readiness; and challenges and proposes mitigation strategies for applying DT in the SEM domain. The research status quo is objectively portrayed using scientometric analysis (e.g., clusters using the VOSviewer tool); and the research trends and challenges were identified using a thematic review. The number of publications has grown exponentially in the past four years; with China followed by the UK producing the most publications. Three distinctive trends are observed that are "real-time data analysis"(26%); "optimisation"(34%) and "operation/maintenance"(14%). Furthermore, it highlights the role of the 5G network in transformation and pushing the DT adoption in SEM, which can aid in decision-making and strategic planning in the construction sector.

Keywords: 5g network; digital twin; smart; AI; machine learning; sustainability

INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) identified in its 2018 report the need to reduce global emissions to net zero levels by 2050 (Masson-Delmotte *et al.,* 2018). Furthermore, the United Nations Climate Change Conference (COP 26) 2021 aimed to limit increased global temperature to 1.5 °C above pre-industrial levels (COP 26, 2021). It aimed to gain sustainable practices on climate change as agreed in Paris Agreement and UN framework convention. Such a transition towards net zero requires industrial, social, economic (corporations) and governmental interventions and moving towards technological innovations (Miller, 2022). Recent advancements in using digital technologies powered by Machine Learning (ML), Artificial Intelligence (AI), high-speed networks like 5G, cloud computing, and edge computing invoke a potential to deliver sustainable solutions that can help achieve net zero goals

[1] s.shashwat@northumbria.ac.uk

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and reduced carbon emissions (Chew *et al.,* 2020; George *et al.,* 2021; Kumar and Teo, 2019). EU's Service Oriented Grid for the Network of the Future (SOGNO) initiative is one such large-scale project that aims to minimise customer outages due to storms and other events damaging overhead power lines, which can result in financial penalties for lost customer service minutes using 5G network that supports real-time data-driven monitoring and control, promoting cost-efficient solution (Ericsson, 2019).

Most energy consumption happens due to rapid urbanisation and consumption, resulting in increasing demand for cities to be a more thoughtful and significant push to reduce greenhouse gas emissions and carbon footprint (Pierce and Andersson, 2017). In cities, buildings account for most of the energy consumption, and therefore, we see increased demand for using intelligent technologies in energy management. Additionally, there is a more significant push to refurbish and retrofit existing buildings to achieve operational improvements and implement smart technologies to gain better energy management (Harrison and Donnelly, 2011; Le *et al.,* 2021).

Digital Twin

The demand for higher energy efficiency in buildings resulted in increased usage of real-time intelligent planning and energy management (Hastak and Koo, 2017). A recent endeavour in this sense is the increased interest in Digital Twin (DT) applications in various applications ranging from individual buildings to building complexes to urban/city level. Digital Twin (Figure 1) is a digital replica of physical space aimed at cloning the physical environment in the digital arena and supporting real-time linked data to improve monitoring, control and decision-making through automation and informed actions (Deren *et al.,* 2021). Figure 1 shows three support pillars of DT, i.e., a digital replica of the building/City/infrastructure (3D Information model), sensors providing real-time data using fast network connections and a Common Data Environment (CDE) acting as a single source of truth in terms of data. Boje *et al.,* (2020) proposed that three generations of digital twins will exist. The first generation (generation #1) DT will be monitoring platforms, the second generation (generation #2) will be intelligent semantic platforms, and the third generation (generation #3) will be agent-driven socio-technical platforms.

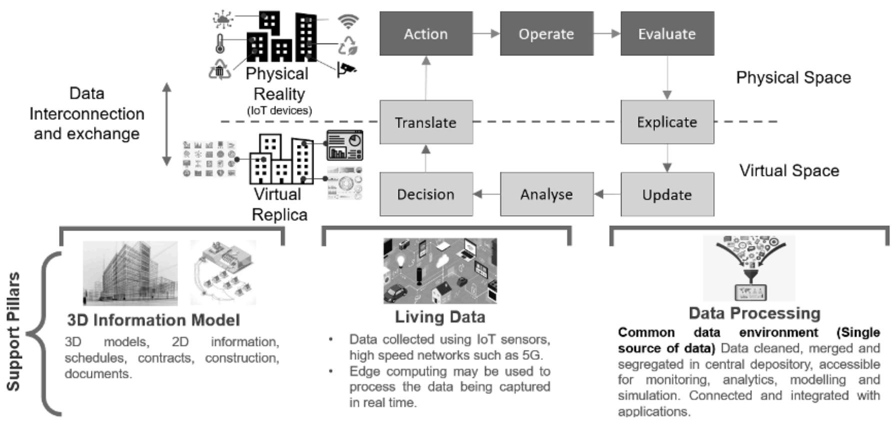

Figure 1: Digital Twin and Supporting its supporting Pillars

Smart city and its component digital twins' purpose is to make Facilities Management (FM) easier through better real-time data capture and devising automation algorithms to optimise the usage without human interventions reducing dependence on humans to make complex decisions in real-time (Smart FM). Figure 2 shows an example of DT architecture, whereby data from various physical equipment and Internet of Things (IoT) devices provide data to a CDE using a high-speed network (5G), leading to a broader 3D information model-based DT. Various algorithms using ML/AI can be developed that can perform automated tasks. One of the most significant parts of FM is Energy Management (EM). EM will get smarter, coined as Smart Energy Management (SEM), with DT due to recent advancements in network connectivity with the advent of 5G technology, AI and ML algorithms. While AI and ML help process the data faster, 5G ensures data migrates from the cloud to IoT devices in real-time.

5G Network

5G is the 5th generation of mobile networks. It is designed to connect virtually everyone with everything, such as machines, objects, and devices. 5G network aims to provide high bandwidth data (up to 20 Gbps speed), ultra-low latency, better reliability, high cybersecurity, and connection to a high number of devices per square kilometre. It also aims to provide a much better, consistent user experience (Qualcomm, 2020). To reduce interference, 5G is based on OFDM (Orthogonal frequency-division multiplexing) that modulates digital signals across different channels (Wild *et al.,* 2014). 5G also uses broader bandwidth technologies such as sub-6 GHz and mmWave (Bhushan *et al.,* 2017). This means more people will have access to 5G for various use cases like gaming, VR/AR, video streaming, and analytics. The flexibility to operate in both bands, i.e., a lower band (e.g., sub-6 GHz) and mmWave (e.g., 24 GHz and up), gives 5G more capacity for high throughput and low latency (Qualcomm, 2020).5G is designed to support all kinds of spectrums, such as licensed, shared, or unlicensed and multiple bands. Furthermore, it will provide new ways to interconnect, such as device-to-device and multi-hop mesh (Qualcomm, 2020).

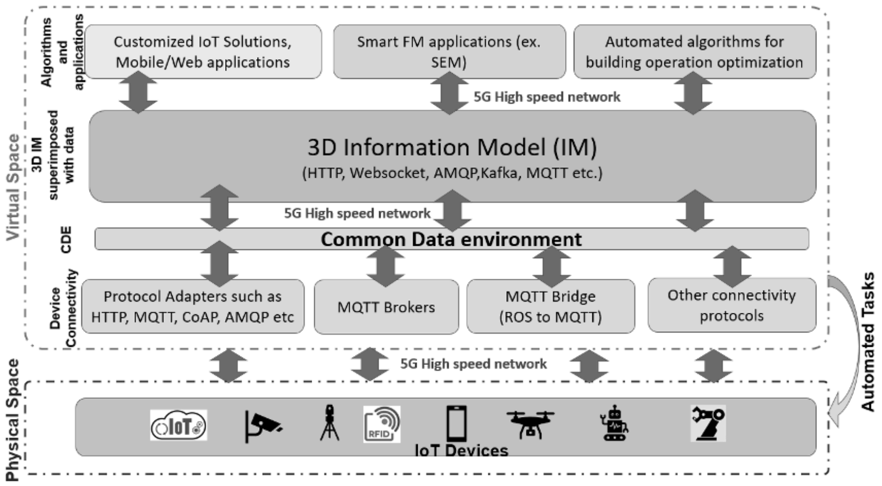

Figure 2: Digital Twin Architecture using a 3D information model

This paper, therefore, explores the current research in SEM and the usage of DT and 5G network application in the domain of SEM through a literature review. The review identifies the progress made in applying DT and 5G network in SEM, the challenges and possible mitigation strategies.

METHOD

A systematic literature review methodology is adopted for analysing DT's application in SEM research. The literature search was conducted using the SCOPUS database, one of the largest online scientific literature databases (Martín *et al.,* 2021). The search string and Boolean operators which were used for searching is "(TITLE-ABS-KEY (Smart energy management AND digital twin))". The search resulted in 133 documents after removing 11 papers published in other than the English language. Conference review (21 nos.), which commonly consists of entire conference proceedings and book chapters (6 nos.), was also excluded, resulting in 106 documents. This preliminary screening was conducted using the SCOPUS database filter features. The initial investigation was performed using the analysis feature provided by the SCOPUS database itself. It was followed by analysing the co-occurrence network of all keywords using VOSviewer, a visualisation tool.

Further processing by screening the title and abstract was conducted to identify the relevant literature for the building and construction sector. The available research for the application of DT in SEM focuses on various fields such as grids (19 nos.), energy storage and distribution (7 nos.), power plants (including renewable) (13 nos.), manufacturing (11 nos.), transport (11 nos.), communications (3 nos.), agriculture (2 nos.), water utilities (3 nos.), equipment management (2 nos.). A sizable of 35 documents published for the building and construction sector till early March 2023 were filtered for detailed investigation. Additionally, nine papers were added to the list, obtained through multiple searches in google scholar and found relevant to the topic. The final number of documents is 44, adequate to draw meaningful thematic insight from the literature and is reported in this article.

FINDINGS

Technological readiness

The research on the application of DT in SEM has been exponentially growing for the last four years (refer to Figure 3a).

Figure 3: A) Documents published per year, b) Documents published Sectors wise, c) Documents published country wise, and d) Top five source of publication of documents for digital twin and smart energy management.

As mentioned in the previous method section, the application of DT in SEM happens in various sectors, with the most dominant in the building construction section (refer to Figure 3b). China, followed by the United Kingdom, Italy and the United States, lead the research (refer to Figure 3c). The top 5 publication sources are highlighted in Figure 3d, with Solar Energy with the highest number of around ten documents.

a) Scientometric analysis of DT in SEM

Keyword co-occurrence analysis can help to identify the cluster that constitute the theoretical blocks or foundational topics for the current and future topic. Three clusters are identified with the network visualisation graph (refer to Figure 4) of the co-occurrence of the keywords. The first cluster (Cluster 1 in Figure 4) focuses on data analysis and advance technologies for improving security, and reliability. The cluster that can be identified include digitalisation and data-driven decision-making techniques (blockchain, digital storage, cyber-physical systems, and embedded systems), energy systems and smart grids. The second cluster (Cluster 2 in Figure 4) focuses on real-time data analysis, automation and machine learning and similar techniques to optimise energy management and infrastructure, including energy storage, microgrids, renewable energies, and intelligent buildings. The third cluster (Cluster 3 in Figure 4) focuses on applying digital technology to improve energy efficiency, sustainability, industrial research, and information management.

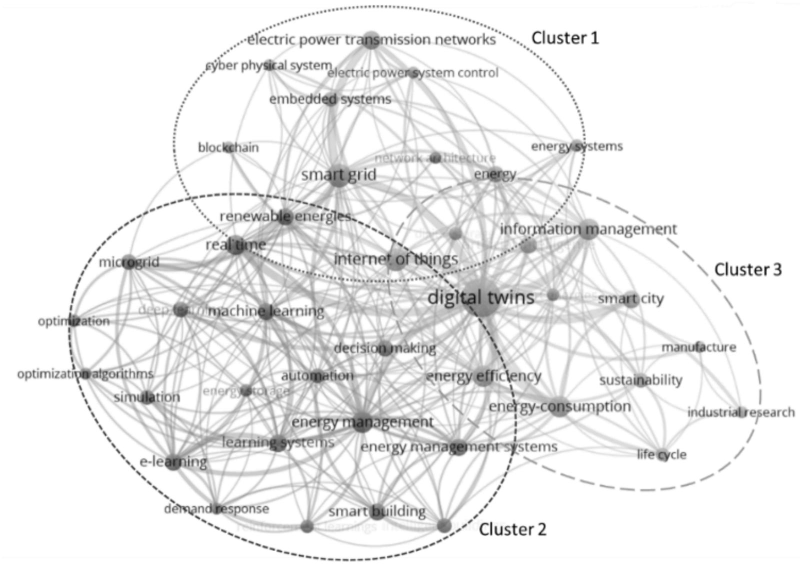

Figure 4: Network visualisation of co-occurrence of all keywords (minimum five occurrences) using the VOSviwer tool combining similar keywords using the thesaurus feature of the tool

The clustering presented by the VOSviewer was essential in providing visually a holistic and logical classification for ongoing and future trends. Subsequently, a rigorous systematic review for applying DT in SEM was conducted on 44 documents selected in the final stage (as mentioned in the Method Section) to identify the themes focused on by the researchers. These are mainly focused on three themes, i.e., operation and maintenance, optimisation, and real-time data analysing and decision. These studies are conducted at various scales, such as building, campus and urban levels. Academicians are also interested in other research topics, though less frequently, such as energy storage, study advancement, and construction facilities.

Operation and maintenance

The end users of a building are the most critical stakeholder in ensuring facility performance following design criteria, which necessitates technology-task fit, particularly for DT applications in the case of SFM (Wong *et al.,* 2022). The application of technologies such as extended reality are being explored for DT in SEM to improve the maintenance process; however, the use of DT in SEM for operation and maintenance is limited in the construction industry as compared to other sectors such as manufacturing, the energy industry and aerospace (Coupry *et al.,* 2021). The research also emphasizes the relevance of user acceptability as well as the impact on return on investment for the feasibility of such advanced technologies. The occupant's behaviour (or building's behaviour, such as operation faults or change in an energy storage device) also impact the use of SEM system, especially the way they interact with the control mechanism in DT, which affects the indoor environment conditions such as heating, ventilation, and Air-conditioning (Englezos *et al.,* 2022).

Optimisation
Improving the performance without impacting the occupant's comfort is complex due to the co-existence of multiple systems in a building sector. A multi-layer DT architecture to mimic the SEM and an edge-based reinforcement learning technique are developed to decrease energy costs in residential sectors while increasing user comfort. Experiments on synthetic and real-world smart home datasets reveal that the suggested strategy efficiently lowers the dispersion of the collective diurnal energy demand by 20.9% and 20.4%, respectively, and reduces the energy cost per family by 10.7% and 17.7% (Fathy *et al.,* 2021). A similar % energy-saving contribution of 20.5% was also observed through the optimisation of equipment energy-saving mode (Xiong *et al.,* 2021). The optimisation based on the temperature modulation has also been conducted by developing a three-layered architecture framework (data processing, building classification models, and high-end analysis) using data collection through IoT, simulation and experiments and gathering (Zakharov *et al.,* 2019). Moreover, O'Dwyer *et al.,* (2020) have developed a theoretical modular framework for city applications which uses machine learning techniques for forecast generation and model predictive control systems to manage the energy for maintaining the coordination between numerous sub-systems.

Real-time data analysis and decisions
To create optimal and decentralised choices for household devices, Huang *et al.,* (2023) proposed an hour-ahead demand response algorithm for energy management in homes. It uses a multi-agent reinforcement learning approach and an artificial neural network approach. The findings demonstrate the effectiveness of the suggested algorithm in managing the energy consumption of various devices, lowering customer electricity costs and discomfort levels, and lowering energy costs compared to a benchmark with no demand response. However, Francisco *et al.,* (2020) propose using smart metering data analytics to create daily building energy benchmarks segmented by strategic periods. The findings suggest that temporally segmented energy benchmarks can offer a more precise and detailed measurement of building efficiency, enabling the identification of building retrofit strategies and near-real-time efficiency in the context of an entire building portfolio and supporting the development of digital twin-enabled urban energy management platforms.

b) 5G technology in SEM

5G networks have four major application scenarios in smart energy management. These are control services, collection services, mobile application services and multi-station integration (Deloitte, 2021). In control services, 5G will help in precise load control and differential protection for the distribution network by suitable algorithms that disconnect the switch and isolate the faulty distribution network. For the collection services, 5G will help in real-time electricity consumption data to perform various analyses such as metering anomaly monitoring, consumption analysis and so on (Zeinali *et al.,* 2017). Similarly, mobile application services aim to monitor the safety and environmental data to reduce the manual inspection workload and improve efficiency. The fourth application scenario is multi-station integration aimed at resource sharing, such as a smart grid (Ericsson, 2019, Ahmadzadeh *et al.,* 2021). Among many, two recent examples of 5G applications in SEM are EU's SOGNO initiative and the Smart5Grid project. SOGNO aims to minimise fault detection in real-time and reconfigure the network to minimise the electricity outage due to adverse weather conditions, besides increasing network monitoring through remote optimisation (Ericsson, 2019). Smart5grid is another EU-funded project that aims to support the energy sector evolution with high bandwidth, low latency, high-density network architecture (i.e., 5G network) that can provide digital layers and help use edge computing and cloud-native applications to support high-end processing and real-time monitoring (smart5grid, 2021).

Challenges and Mitigation Strategies

Multiple researchers have laid the foundation for implementing Digital Twin in Smart Energy management and using a 5G network to support this cause. Though the relevant technologies seem to provide an excellent solution to energy optimisation, enhanced operation and maintenance, and real-time data analysis and decision, implementing these technologies to the bottom of the pyramid (user level), multiple roadblocks need to be addressed (Table 1).

Table 1: Current challenges and Mitigation strategies for DT implementation in SEM

Key parameter	Current Challenges	Mitigation Strategies
Network Speed	High bandwidth, low latency network speed is required to support DT based on edge and cloud computing (Ericsson, 2019).	5G promises to provide low latency, high bandwidth network with network slicing options for customised configuration and real-time data processing capabilities.
Scalability	Scaling DT at an urban scale level to handle large number of buildings can be challenging.	Adopting a modular approach in the implementation of DT leveraging cloud-based scalable and flexible solutions and utilising edge computing for distributing the processing load (Castelli *et al.,* 2019).
Cyber-security	High digitalisation needs a secure environment to perform efficiently. Though 5G network can be tailored to various security protection mechanisms, the development in this direction is still nascent (Deloitte, 2021).	Different entities must work together to clarify the boundaries. Such boundaries and their respective security development must develop in parallel. Industry-specific security protocols must be designed for DT and 5G network utilisation as both technologies are new.
Open-source platforms	Proprietary systems, though they perform efficiently in their own environment, the major challenge faced by the AECO industry is the interoperability of these systems. Interoperability hinders performing cross-platform simulations, analyses, and decision-making (Chew *et al.,* 2020).	Government-led initiatives such as SOGNO and SMART5Ggird or others should promote open-source development that can help the industry to develop their own customised, innovative application on top of it and learn from the innovation. Closed systems will be a hinderance to faster adoption of such energy saving technologies.
Infrastructure and workforce development cost.	High digitalisation efforts like DT and using the 5G network have new investment requirements, which is a big challenge to MSMEs (Micro, small and medium enterprises). Additionally, continuous workforce development will be required to catch up with the pace of technological advancement (Ahmadzadeh *et al.,* 2021).	Top to bottom approach is needed to tackle such investment. Singapore has been leading in such an approach whereby government use multiple channels to fund the industry for adopting various new digital technologies such 5G network (5G innovation grant total to 30 million SGD) or their Skills future workforce development programs whereby government give subsidies to companies to enrol their staffs to get upgraded with technical skills. (IMDA,2021)

CONCLUSIONS

To achieve sustainability goals and reduce overall carbon emissions, the use of digital twins for smart energy management is gaining popularity in the last four years. The use of 5G technology, which provides high-speed data transfer, low latency, improved reliability, and the ability to connect a significant number of IoT devices, will push the digitalisation and real-time analytics in SEM and accelerate the implementation of DT. Therefore, this scientometric and thematic review analysed the trend and development, especially in the context. Furthermore, the trials of 5G networks in the SEM domain have shown some complex use cases for SEM being undertaken using IoT, edge and cloud computing to enhance real-time optimisation, maintenance, and remote monitoring. This review used the SCOPUS database as the literature source, resulting in 106 journals, conferences, and review articles. Numerous scholars from different sectors have investigated the use of the digital twin in smart energy management, such as manufacturing, transport, communication, energy storage/distribution/generation/ consumption, operation and maintenance, optimisation and building and urban infrastructure. Three broad themes in the application of DT in SEM, i.e., operation and maintenance, optimisation and real-time data analysis and decision, emerged from this Scientometric analysis. However, broader issues highlighted in the reviewed literature should be resolved to gain wider implementation in the Sem domain. These issues, such as the expense of hardware, software, network speed, cybersecurity, open-source platforms, support funding, and their possible mitigation strategies, are discussed briefly. To fully utilise new technologies and optimise, the construction sector must adopt them more quickly.

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INSTRUMENTALITY OF PROCUREMENT LAWS TO IMPLEMENT SOCIAL SUSTAINABILITY IN NIGERIA

Joshua S Mangvwat[1], John P Spillane and James G Bradley

Irish Construction Management Research Centre (ICMRC), School of Engineering, University of Limerick, Limerick, V94 T9PX, Ireland

Construction projects can achieve social sustainability when anchored on relevant statutory instruments that support the procurement process. However, the absence of provision for social sustainability in procurement laws in Nigeria presents a significant challenge to the sector. Hence, this study documents the challenges site workers and host community face, as two key stakeholders in social sustainability. The aim is to explore how the absence of social sustainability in public procurement law affects implementation of the social agenda. Semi-structured interviews are conducted with six senior management staff with experience in public procurement in tertiary institutions. A thematic analysis of the result shows the prevalence of casualisation of labour as a major impediment. Other factors are the contractors' profiteering, community belief systems that restrict employing women as site labour and client's drive to evade additional cost associated with implementing social factors. The study recommends advocacy by pressure groups for legislation to amend and update the Procurement Act to capture social factors. This will develop and integrate the social agenda alongside existing procurement objectives, for implementation, in Nigeria, and internationally.

Keywords: legal instruments; procurement; social factors; sustainability

INTRODUCTION

While the planet is central to environmental sustainability, profit is fundamental to economic sustainability, health and wellbeing of people is to the core of social sustainability (Gurmu *et al.,* 2022). While sustainability broadly represents various responses to climatic threats, social sustainability's domain is the human needs and community issues, that enhance the quality of life (Andrecka 2017). People live and work in communities to earn a living and enhance their quality of life. It is this "life-enhancing condition" that depicts social sustainability, which is continually evolving within communities into processes within the communities that can achieve that condition" (Valdes-Vasquez and Klotz 2013). Life-enhancing attributes like health, safety, human rights, labour issues, community initiatives, employment benefits, and ethical issues are indicators commonly accepted within the social sustainability sphere (Andrecka 2017). As a people-oriented concept, social sustainability is argued to have the capacity to stand on its own merits (Littig and Griessler 2005). The concept of social sustainability is increasingly gaining focus in the construction industry, partly because the criteria for procurement of projects are moving from the traditional

[1] joshua.mangvwat@ul.ie

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emphasis on quality and price, to the secondary issues of social and environmental objectives (Ruparathna and Hewage 2015). From a public procurement perspective, the concept of social sustainability and corporate social responsibility are connected (Andrecka 2017). Consequently, sustainability deploys procurement to support the wider social, economic, and environmental objectives in ways that offer long-term benefits (Sims 2006). The role that public procurement plays to promote sustainability parameters remains key in transforming the construction sector towards sustainability. Hence the need to contextualise public procurement laws in Nigeria as instruments in implementing social sustainability in constructing for the future.

Contextual Perspectives

The literature review puts social sustainability and procurement laws in a perspective that enables an understanding of the context within which the study is carried out. It reviews sustainable construction, before narrowing to the legal imperative. It then reviews previous research to identify social factors before focusing on existing sustainability policies in establishing the social gap in the Nigerian context.

A Perspective on Sustainable Construction

Sustainable Development Commission (2016) allows for diverse interpretations of the concept of sustainable development. However, at its core is an approach to development that looks to balance different, and often competing needs against an awareness of the environmental, social, and economic limitations society faces. This makes sustainability a continuous process or an iterative development depending on the building practices that embrace the environmental, social, and economic aspect of the society (Doan *et al.,* 2017). Building on this, sustainable construction has been viewed from different perspectives. The three that stand prominent in literature are the environmentally, economically, and socially sustainable construction (Doan *et al.,* 2017). These together form the Triple Bottom Line (TBL) that make up the founding elements of sustainability (Elkington 1997). On its own, construction is an economic activity that deploys public and private resources through procurement for developmental purposes (Zhu *et al.,* 2013; World Bank 2014). Achieving a balance among the TBL remains the ideal scenario in the context of sustainability and must be an inevitable consideration in the drive for constructing for the future (Elkington, 2004). Whereas construction in the private sector is driven by profit, the public sector procures using public resources for societal good. This activity in both sectors places an onus on accountability on the construction industry to society, in the judicious use of resources (Ndimele *et al.,* 2018). Marrakech Task Force (2011) in Romodina and Silin (2016) aptly captures the accountability requirement by defining sustainable public procurement as a process where organisations meet their needs in ways that are beneficial not only to them, but also to society and the economy, while minimising damage to the environment. This aligns with the three broad ways that every economic activity impact on society. First is the notable impact on the workforce; followed by impact on the host community where such economic activities take place and, the third, being the impact on the wider global community (Ndimele *et al.,* 2018). Since social sustainability is about minimising the negative impacts that developmental activities have on people and society, while maximising the positives; the need for accountability through sustainability in construction cannot be overemphasised. Abdel-Raheem and Ramsbottom (2016) aptly reflects constructing for the future by viewing sustainability as fulfilling the needs of the present, without compromising the ability of future generations to meet their own needs.

Sustainability Policies in Nigeria

One of the main challenges of sustainability, is to balance the triple bottom line in decision-making process and implementation (Elkington 2004). Achieving environmental and economic sustainability without a corresponding social sustainability is an imbalance. The constraint in getting procurement professionals and clients to focus on social issues requires redress; specifically, on addressing social sustainability in construction. The public sector, being the single largest client of that sector in Nigeria (Manu *et al.,* 2019) is therefore in the best position to address the social agenda through its procurement process (CIPS and NIGP, 2012). The notable sustainability policies in Nigeria focus more on the environment and less on the economic and social aspects. This is despite the relationship between the construction sector and GDP (Gross Domestic Product). For instance, emphasis of Section 20 of the 1999 constitution is to "protect and improve the environment and safeguard the water, air, land, forest, and wildlife of Nigeria". Other environmental protection provisions include the Harmful Waste (special Criminal Provisions) Act Cap 165, which is a response to the illegal dumping of toxic waste in Nigeria in 1988 (Adewumi *et al.,* 2012), while the Environmental Impact Assessment (EIA) Decree 86 of 1992 which was a by-product of the provision of Principle 17 of Rio Declaration (Anago 2002). Most prominent is the National Energy Policy (NEP), enacted in 2003. This is the most direct national legal framework on sustainability designed to articulate the sustainable exploitation and utilisation of all energy resources. Ikediashi *et al. (*2014) identifies health and safety, waste management and flexible working environment, as the three main sustainability policy directions in that order. It is noteworthy to argue that while Ikediashi et al.'s (2014) findings are limited to facility management, all the policy directions are on environmental sustainability. While Nigeria is making consistent improvements towards enacting and implementing policies on sustainability, more needs to be done. Infrastructural and building projects must extend beyond being only environmentally sustainable. They should accommodate attributes that make them socially sustainable as well. Since it has been shown that social sustainability can stand alone (Littig and Griessler 2005), health and safety, as aspects of sustainability need to be policy driven. It is therefore a misplacement to put health and safety as a facility management concern under the environment, as done in Ikediashi *et al. (*2014).

The Legal Imperative

It could be inferred from Murtagh and Brooks (2019) that enforceable regulations in public procurement place a demand for accountability. In a qualitative assessment of practitioners' experiences with the drivers and practices for implementing sustainable construction in Nigeria, Tunji-Olayeni *et al. (*2020) found that the most appropriate policies for implementing sustainable construction include government regulations, tax relief and subsidies, and public awareness. This implies that to facilitate sustainability transformations in the construction industry, regulations must first be in place, before market-based policies and voluntary participation of stakeholders. Manu *et al. (*2019) studied the infrastructure procurement capacity gaps in Nigerian public sector institutions, concluding that the current procurement practice in Nigeria, which is based on the Public Procurement Act 2007, has failed to attain its stated objectives. Thus, implying that unless backed up by enforcement, having the Procurement Act is not a guarantee of success. Implementation coupled with enforcement is critical. There is paucity of evidence to suggest the contribution of public sector procurement to social sustainability in the construction sector (Fuentes-Bargues *et al.,* 2021).

There has also not been a reformation of the procurement laws to address this gap in Nigeria. Since sustainability is about realising that every decision we make, or fail to make, impacts society (Elkington, 2004); the construction industry needs to operate sustainably during the procurement process. The failure in Nigerian practices therefore calls for a change in what is crafted in procurement policy decisions, and how to implement them accountably. Tunji-Olayeni *et al. (*2020) argues that there is no better place to start than in the context of addressing the policies that underpin procurement. Therefore, addressing the absence of social factors is a starting point. This is because social outcomes must be intentionally created (by laws) either directly, for example by employing disadvantaged people, or indirectly, by requiring their supply chain to do so, thereby creating social value (Raiden *et al.,* 2019). The foregoing shows that when relevant law backs up the procurement process, it empowers and boosts the procuring entity's capacity to effectively discharge its responsibilities (Murtagh and Brooks 2019; Raiden *et al.,* 2019). Conversely, the absence of support of the law creates a barrier to and depletes that capacity (Young 2015). Although procurement laws provide the legal instrument that supports the attainment of procurement objectives for construction project through the tender process, a look into the legal, regulatory, policy framework and tender documents in Nigeria, highlights an absence of social sustainability in procurement practice (Manu *et al.,* 2019; Ejohwomu and Oshodi 2014). This non-inclusion of social sustainability in procurement laws in Nigeria could explain the assertion by the World Bank (2013), which links challenges to meeting sustainability objectives, to the inadequate capacity of procurement entities, to effectively manage the procurement processes.

Justification for Public Procurement.

Hughes *et al. (*2006) compares and conclude that public procurement is more complex than its private sector counterpart. The reason being that while the private sector is oriented towards generating money, the public sector spends in the provision of services for society. Although compatible in process, their fundamental difference lies in the limits of how far the public sector can be pushed towards commercialisation. Conversely, Thai *et al. (*2005) identifies procurement in private sector to be generally less regulated. Moreover, procurement in the private sector potentially varies from one organisation to another and from one jurisdiction to another. Another difference lies in their economic value. Although Fuentes-Bargues *et al. (*2021) shows the economic value of construction to represent approximately 10% of the GDP of the European Union and to employ 7% of its total labour force, it is the public procurement sector that accounts for the large volume of spending each year (Zhu *et al.,* 2013). Therefore, transforming public procurement is one way to improve the effectiveness of public expenditure (World Bank 2014). Hence, the complexities in public procurement, economic value, and proneness to regulation, justifies the emphasis on the need to reform laws in that sector.

Social Factors

Social sustainability covers a wide range of factors that reflect the needs of society (Hidayat *et al.,* 2020; Karji *et al.,* 2019; Li *et al.,* 2018; Xiahou *et al.,* 2018; Kordi *et al.,* 2021; and Jafari *et al.,* 2019). For reason of scope and time, this study focuses on some of these needs, as they affect the construction site worker and community where projects are sited (Sloan 2010). Table 1 aggregates the factors into 4 needs with a breakdown of 13 descriptions, as identified in the literature.

Social Gap in Procurement

The literature shows public procurement as a prominent tool to achieve sustainability when used (Montalb an-Domingo *et al.,* 2019; Andrecka 2017; Murtagh and Brooks 2019; Karangizi and Ndahiro 2009). This explains why countries like Australia, Canada, and South Africa have implemented long-term policies targeted at indigenous people, to encourage the development of social sustainability principles through public procurement (Loosemore *et al.,* 2019; Iles and Ryall 2016). The reason for this is derived from the power to make and enforce policies, that promote and drive sustainable procurement throughout the acquisition and disposition process (CIPS and NIGP, 2012) which vests solely on the public sector. Apart from being the biggest construction client in Nigeria, the existing legal instruments reviewed, demonstrate that the public sector has not used its policy-making and regulatory powers to include, promote, and drive the social agenda, much less enforce compliance (Manu *et al.,* 2019; Ejohwomu and Oshodi 2014). This study therefore documents the challenges that are consequences of this failure, as they affect the site worker and community.

Table 1: Social sustainability factors in construction projects

Needs	Description	References
Labour issues	Casualisation of labour	Montalbán-Domingo et al. (2018), Petersen & Kadefors, 2016).
	Child/forced labour	Andrecka (2017), The Nigeria Labour Act (1971)
	Job security and equal opportunities	Gurmu, et al (2022), Hendiani & Bagherpour (2019); Murtagh & Brooks (2019)
	Training for skills development	Pocock et al. (2016), Popovic et al. (2018), UNEP (2009)
	Consistent wages and overtime	Popovic et al. (2018), Andrecka (2017)
	Maternity/sick leave, holidays, bonus, transport, insurance & lunch	Andrecka (2017), Hill & Bowen (1996), Karji et al. (2019)
Gender Inclusion	Equity in distribution by gender	Littig & Griessler (2005), Hill & Bowen (1996)
Engagements with host community	As stakeholders. Youth employment	Valdes-Vasquez & Klotz (2013), Woodcraft et al. (2011)
	Support for community needs	Hendiani & Bagherpour (2019), Li et al. (2018), Xiahou et al. (2018)
	Buying from community	Zuo et al., (2012) Loosemore (2016).
Health, safety, and wellbeing	Security, insurance, and pension requirements.	Kamas et al. (2019), Hill & Bowen (1996)
	Personal protective equipment	Popovic et al. (2018), Raheem et al. (2014), López-Valcárcel (2001)
	Provision of standard first aid	Hill & Bowen (1996)

METHOD

To document the challenges construction site workers and host community face due to the absence of social factors in procurement laws in Nigeria, a study of the procurement process in public tertiary institution is undertaken. Semi-structured interviews, each lasting an average of one hour, are conducted with six senior management construction professionals with experience in procurement ranging from 10 to 34 years. The interviews reveal first-hand responses from each interviewee on their experience in dealing with different sources of funding for projects, contractors, interactions with host community, supervisory roles on projects, and regulatory bodies on procurement, among other aspects. The anonymised interviews are transcribed, and themes identified from the transcripts that align with societal needs as identified in the literature, relative to the site worker and community stakeholders. The themes enabled the categorisation of the challenges, as stated in the interviews, in response to the semi-structured discussions.

FINDINGS

Table 2 shows a further breakdown of the 13 descriptions identified in the literature in Table 1 into 27 socially unsustainable practices. These emanate from analysis of responses from the six interviews conducted and align with the 4 broad needs categories which provided the themes for this empirical study. Table 2 is therefore a documentation of the challenges that are being faced by the two key stakeholders in social sustainability, namely the site workers and host community.

Table 2: Social sustainability challenges

	Current practice	Interviews					
		1	2	3	4	5	6
Labour issues	Casualisation of labours persists	X	X	X	X	X	X
	Skilled labours engage child labour	X		X		X	
	Workers hindered from joining labour unions		X	X		X	
	PPA2007 silent about sourcing site workers	X	X		X		
	Contractor interest prevail in employing workers		X				X
	Overtime avoided for profit maximisation	X	X	X			
	Bonus tied to speed/productivity	X				X	
	No policy on welfare of site workers		X	X		X	X
Gender inclusion	Strength, not gender, is criteria for employment		X	X	X	X	X
	Religious-cultural beliefs restrict women	X	X	X	X	X	X
	Women not engaged for lack of skills	X	X	X		X	X
Engagements with host community	Community ignorant of opportunities on projects		X		X		
	PPA 2007 does not address engagement	X	X	X			X
	Funding conditions limit community engagement	X	X		X		X
	Community welfare is at contractor's volition	X	X	X	X		X
	Lack of skills limits employment from members	X	X	X	X	X	
	Patronage of locally available building materials	X		X		X	
	Inhomogeneous community creates tension when engaging members		X				
	Non-engagement is loss of benefits to community		X				X
	No incentives for contractors to engage	X		X	X		X
	Client engages community only when need arises	X	X	X	X	X	
	Sites vulnerable to theft due to non-engagement	X					
	Institution's CSR not tied to construction projects	X	X	X		X	X
Health, safety, and wellbeing	No qualified personnel to administer first aid					X	
	Inducement of client site agents compromise enforcement		X				X
	Contractors profit from partial/non implementation of provisions	X	X	X	X	X	X
	Falsification of reports and documentations	X	X			X	

All six respondents referenced the challenges that emerge under each of the respective need categories shown as themes on Table 2. The challenge that emerges under each of the four themes is discussed. Findings on the theme of labour issues, for instance, shows the prevalence of casualisation of labour. This practice of casualisation of labour contrasts with the expectations that employment should contribute to new opportunities for the employee, job stability, and to the employment of the vulnerable population (Montalb an-Domingo *et al.,* 2019). It therefore goes against the International Labour Organisation's provisions that requires respect for labour standards, as set out in ILO Conventions and national legislation (ILO 2001). Such practices contravene the "core" labour standards of the ILO - the United Nations agency with global responsibility for work, employment, and labour issues. There is therefore the need to develop a strategy and action plan for improving implementation of labour standards in construction projects, as well as promoting productive employment in construction through socially sustainable practices in procurement.

Gender inclusion unveils a community belief system that restrict employment of women as site labour. Littig and Griessler (2005) advocates that it is necessary to pay special attention to the situation of women. This is not because gender mainstreaming demands for the equal treatment of both genders in social, economic, and legal matters. They cited Chapter 24 of Agenda 21, cf. United Nations (1992) to substantiate their argument that it is because gender mainstreaming is listed as one of the key goals in official sustainability documents. The health, safety, and wellbeing as a theme reveals contractors as profiting from either partial or non-implementation of contract provisions for health, safety, and wellbeing of the site worker, and of the community. Loosemore *et al. (*2019) associates the avoidance of costs of complying with new social procurement requirements to the highly competitive nature of the construction supply chain and market and therefore concluded that is not surprising.

However, five out of the six respondents variedly referenced four of the challenges associated with the theme "engagements with the host community". And by this, the four challenges referenced stand at par with each other with none being prominent over the other. The four varied challenges referenced by the five out of six interviewees are the community welfare being at the volition of contractors, lack of skills being a factor that limits employment from the community, the client engages the community only when the need arises, and the institution's corporate social responsibility (CSR) not being tied to construction projects. Interviewee No.1 specifically mentioned that the practice of allowing the community welfare to be at contractor's volition is a deliberate action taken by the client. This enables the client to achieve project delivery while evading additional cost associated with implementing social factors for the site worker and community. Ogunsanya *et al. (*2019) attributes this to the perceived high cost of adopting sustainable solutions. In contrast, Boyd and Schweber (2012) identify and deemed stakeholder engagement as the first out of four key factors that are crucial for the mainstreaming of sustainability. It is therefore imperative to engage the community as stakeholders in the decision-making process to achieve sustainability objectives in construction projects. Failure to do this will heighten the barrier to the integration of social issues by industry practitioners and impact negatively on the drive for social sustainability, with the target of employee health and safety, impacts on societies, and goodness of life (Kamas *et al.,* 2019) will remain elusive.

The other challenges that emerge are as presented on Table 2. These reflect the responses obtained from the interview process. They are therefore documented, not in any order of preference, but based on the lived experiences of the respondents. These align with the aim the study set to achieve. Furthermore, a comparison by Khojastehpour and Jamali (2021) shows that social needs in developing countries considerably vary from those in developed countries. This reflects in the narrow focus on employment, infrastructure development and income generation in developing countries as against the giant strides achieved in developed countries. Another contrast is in regulatory complexities. This is evidenced by instability, inconsistency, and lack of capacity for enforcement in developing countries, which led to wastefulness due to institutional and regulatory voids and lack of regulatory compliance (Gupta and Wang, 2004). And despite projections of prominence of public procurement as an instrument for achieving developmental objectives (Montalb an-Domingo *et al.,* 2019; Andrecka 2017; Murtagh and Brooks 2019); it is the efficiency in the process in modern economies that is instrumental to ensuring a reduction in wasteful activities (World Bank 2014). Therefore, the role that public procurement plays in terms of regulatory laws, strong institutions, and the capacity for enforcement in developed practices could provide a model for the developing countries to follow (Brown and Knudsen, 2015). This could enable the later to navigate through current institutional voids, thereby eliminating wastes in the drive for constructing for the future.

Ejohwomu and Oshodi (2014) argue that there is a need to examine the extent to which current policies and activities pertaining to sustainability in the construction industry, are being integrated into built environment projects in terms of their planning and development. A frequent problem in many project-based organisations is that central policies and initiatives fail to filter down to the project level and get transferred across projects (Loosemore 2014; Widen 2006). Hence, this study unveils Nigeria as a strategic case of a developing construction sector whose practices are at variance with those in the developed economies. And despite its ranking as first among the Economic Community of West Africa (ECOWAS) countries by territorial size, population, military spending, GDP per Capita, Nigeria is termed a regional power without followers (Scholvin, 2014). Therefore, constructing for the future in developing countries would require the instrumentality of public procurement in achieving social sustainability that is akin to those in the developed systems. And a focus on Nigeria's construction sector as a microcosm of developing countries in the sub-Saharan Africa region suffices.

CONCLUSIONS

The paper explores the absence of social sustainability in public procurement laws. This is with the aim of documenting the challenges that site workers and host community face as key stakeholders in the social agenda. Since the study set out to explore and not to generalise or compare for representativeness, the response from each interview counted towards identifying issues that should be addressed for social sustainability. However, one finding stood out prominently under each of three out of the four themes studied as basic needs. These are the casualisation of labour (labour issues), community belief system that restricts employment of women as site labour (gender inclusion), and contractors profiting from either partial or non-implementation of contract provisions for health, safety, and wellbeing of the site worker (health, safety, and wellbeing). The findings further confirm the absence of enforceable laws for social sustainability thereby resulting in the challenges which unveils a disconnect between the current practice and the basic needs. This study suggests that a review in existing procurement policies pertaining to social sustainability would be necessary to influence practice in the construction industry. This could curb wastefulness and contribute positively towards the drive for constructing for the future. The legal imperative therefore becomes inevitable if the social agenda is to be implemented in the construction industry in Nigeria through public procurement, hence the instrumentality of the law. This places an onus on academia to be proactive in developing a framework that enables the implementation of social sustainability if the legal imperative is addressed. Hence a recommendation for future research to develop an implementation framework for social sustainability in the procurement of construction projects. Further research could also be carried out to establish the relative significance of the challenges documented in this study to prioritise and address each.

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THE INTEGRATION OF GREEN BUILDING TECHNOLOGIES INTO THE CONSTRUCTION SECTOR OF DEVELOPING COUNTRIES: THE CASE OF GHANA

Nana Genfi[1&3] and Serik Tokbolat[2&3]

[1] *GRAHAM Group, 11 Old Jewry, London, EC2R 8DU, UK*

[2] *Department of Civil Engineering, University of Nottingham, Nottingham, NG7 2RD, UK*

[3] *School of Architecture, Design and the Built Environment, Nottingham Trent University, 50 Shakespeare Street, Nottingham, NG1 4FQ, UK*

Emerging climate change crisis, resources scarcity and global sustainability agenda are putting pressures on developing nations and demanding actions. This study aimed to examine the significance of introducing green building technologies (GBTs) in construction projects in Ghana by conducting a literature review and identify key drivers, barriers, and promotion strategies for their implementation based on a survey conducted among stakeholders relevant to the Ghana's construction sector. The research revealed that (1) government-linked barriers are critical barriers to GBTs adoption, (2) environmental and health-related drivers have a significant impact on the implementation of GBTs and (3) effective communication strategies and public support from the government through the introduction of regulations and standards were established as essential promotion strategies to the effective integration of GBTs in Ghana. All participating stakeholders would prefer to see GBTs integrated into the construction industry.

Keywords: barriers; drivers; green building; sustainable construction; Ghana

INTRODUCTION

The growing population and increased urbanization have triggered a steady growth in the construction sector (Anaman and Osei-Amponsah, 2007). The expansion of the worldwide economy thrives on the extraction and consumption of natural resources which generate waste and emissions that threaten the environment (Cotgrave and Riley, 2013). Pachauri and Meyer (2014) asserted that developed countries have immensely benefitted from fossil fuels, however, the end products of these fossil fuels such as greenhouse gases endanger the environment. The built environment is responsible for about 40% of worldwide energy consumption and use of resources which, in turn, negatively affect the well-being of the environment and humans (Yates *et al.,* 2015; Mawat *et al.,* 2019; Masia *et al.,* 2020). Common views are shared by Twumasi-Ampofo *et al.,* (2012) and Djokoto *et al.,* (2014) on the nature of processes

[2] serik.tokbolat@nottingham.ac.uk

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adopted in the construction environment in developing countries contributing to high energy use, environmental pollution, etc. At present, green technologies are widely discussed across various industries as viable solutions to the issues and can be applicable in construction projects.

GBTs are concerned with the use of efficient building materials and construction practices to ensure the minimal use of energy and apply sound management practices to promote waste and water efficiency which are also among the main GB principles (Richardson and Lynes, 2007; Glavinich, 2008). Integration of GBTs lead to the optimum consumption of energy and water and their application in construction promotes the efficient use of natural resources. To meet the sustainability goals the integration of green technologies is the way forward due to technologies such as efficient water heating, energy-efficient HVAC systems, solar technologies, building orientation optimisation technologies, etc. which allow designers to achieve minimal energy use. To improve sustainable construction within the industry, newer technologies and methods have emerged such as Building Information Modelling, lean construction, value engineering, life-cycle assessment, etc. which impact project design and collaboration (Oke *et al.,* 2018).

There is the need for cooperation from all stakeholders across different stages of construction, who should make environmentally friendly decisions and choose energy efficient solutions and practices. If stakeholders do not consider aligning with green construction policies and processes, the consequences could be negative to the ecosystem (Sharma, 2018).

This study aimed to examine the significance of introducing green technologies in construction projects in Ghana and identify key drivers, barriers, and strategies for their implementation. This was carried out by (1) assessing the views of stakeholders in Ghana on aspects hindering the adoption of GBTs as well as drivers of their successful integration; (2) examining the availability of a legal basis for integration of green buildings and GBTs in Ghana, and (3) evaluate the effects of various strategies to promote the integration of such technologies.

LITERATURE REVIEW

The construction industry of Ghana is in the process of addressing the growing demand for residential, industrial as well as commercial spaces, while still preserving the physical environment of the country and social welfare by adopting principles of sustainable development (Ahmed *et al.,* 2014). Ghana is a slow, upcoming market in Africa. The progress of the country is partly supported by the outputs of the construction industry (Assibey-Mensah,2009; Ahmed *et al.,* 2014). Recently, the construction has been one of the fastest-advancing business directions in Ghana and it was found to be the key contributor to economic growth (Osabutey *et al.,* 2013).

There was also no specific government legislation found to support GBTs implementation in Ghana, so the concept of GBTs is seen to be down to the stakeholders' option. Anzagari *et al.,* (2019) reported that, the industry is burdened with planning challenges and a lack of sustainability standards, despite the current regulations in the industry meant to manage the practices of the construction stakeholders. Thus, there is a need to integrate the concept of sustainability to improve the industry and reduce the negative environmental impacts.

In the Ghanaian construction market, the demand for innovative construction has been low which creates an obstacle to the adoption of GBTs (Addy *et al.,* 2020).

According to Ahn *et al.,* (2013) and Chan *et al.,* (2017), among the top obstacles to green construction in the United States, for example, are lengthy payback times, the propensity to retain existing procedures, limited skills and experience of subcontractors, higher prices of renewable goods and resources, resistance to reform and the absence of government incentives. In Singapore, in turn, poor commitment and coordination among the project team, high costs of green tools and materials, indifference from clients and market demand, etc. were all established as barriers (Hwang and Tan, 2012).

A study in Hong Kong by Zhang *et al.,* (2012) described high maintenance costs, lack of incentives, limited knowledge, etc. as the most important hurdles to the integration of comprehensive GB systems. According to Winston (2010), insufficient construction legislation, as well as a lack of experience and skills, are obstacles to sustainable housing growth in Ireland. As other countries have different laws, a thorough comprehension of the obstacles to GBTs acceptance in specific countries is needed as it will aid in overcoming barriers and support the use of GBTs (Aktas and Ozorhon, 2015).

According to Agyekum *et al.,* (2020), among the drivers identified during interviews with some members of relevant professional bodies are observability of the advantages of green-certified buildings, incorporation into professional bodies' code of conduct, governmental commitment, public recognition, green building certification rewards, policies and legislation. Other critical considerations, such as "set rules and regulations" and "green design requirements and building specifications," were also evaluated in the results. Also, economic conditions continue to have a significant influence (Agyekum *et al.,* 2020).

According to Hwang *et al.,* (2017), some viable results to encourage the implementation of GBTs in business parks in Singapore are green growth strategies and respective legislation, government co-funding and incentives, and partnering with academic organizations to analyse the effects of GBTs integration in business parks. Hwang and Tan (2012) acknowledged the schemes which boost the GB acceptance, including the education of clients about GB benefits, expanding the scope of government incentives to include GBTs adoption, the use of construction tours as a form of education to the public and the development of a GB project management structure.

METHOD

A quantitative research strategy was adopted as an optimal approach in this study, requiring robust data to be collected from construction-related experts using a survey and assessing it applying statistical analysis (Johnson and Onwuegbuzie, 2004; Fellows and Liu, 2015). This research implemented a non-probability sampling approach in determining the sample size as there is no data on the availability of sustainability-related experts in Ghana and it was deemed to be difficult to assess the population size. A similar methodology was used by Owusu-Manu *et al.,* (2018) where the use of this technique helped to obtain an effective sample size and minimise bias often linked with the sampling technique.

The survey questionnaire was used as it was seen as the best tool to gather the opinions of many construction stakeholders and to ensure objectivity (Tan, 2011). The questionnaire has been formulated to evaluate the themes discussed above and comprised the following sections shown in Table 1.

Table 1: Sections of the questionnaire survey

Sr. No	Sections under the Questionnaire
1	Letter to Participants
2	Background Information of Participant including their organisational position and profession
3	Perception About the Benefits of GBTs in the construction Industry of Ghana
4	Barriers to GBT implementation
5	Drivers for GBT implementation
6	Promotional strategies for the implementation of GBTs

The questionnaire contained mostly close-ended questions with its length designed not to exceed 15-minute engagement time, with straightforward answers in some sections and some answers structured into categories and values for evaluation using 5-point Likert scale where respondents are asked to evaluate the level of agreement on the defined parameters. Zhang *et al.,* (2011) emphasised the use of the Likert scale for evaluating the comparative relevance of distinct factors based on the views of survey participants. In this study, the Likert scale was used to denote "1" as "Not important" to "5" as "Very important".

Prior to distributing the questionnaire, a pilot study was undertaken to wholly assess this approach regarding the design of the questionnaire, ensuring all relevant themes are captured in the survey research as well as tweaking the content to incorporate the use of five options which will be evaluated using the 5-point Likert scale. This pilot study was achieved with the aid of an experienced professor and a knowledgeable researcher in the subject of sustainability to undertake a content validity assessment of the draft questionnaire ensuring all terminologies are easily understood and the appropriate technical words are included.

Data Collection

Due to COVID-19 Pandemic limitations, the drop-and-pick method was not feasible so only the web-based survey via google forms was used. The link was shared with survey respondents through e-mails, referrals, and social networks using a snowball sampling approach due to limited access to a sampling frame as well as their knowledge and willingness to partake in the study (Owusu-Manu *et al.,* 2018). The target population for this research was the construction stakeholders within Ghana.

56 responses were received when the survey concluded. A review of the survey feedback showed six were incomplete and hence, omitted leaving 50 responses. Out of the targeted 114 respondents, only 50 responses were used indicating a response rate of 43.9%. The slow integration of sustainability in the Ghana also contributed to the participation of a few experienced professionals in the survey. According to Ott and Longnecker (2010), the response rate is higher than the recommended value of 30% which implies that this sample size is considered valid for the central limit theorem. Also, Nulty (2008) asserted the difficulty in ensuring the participation of survey respondents, as well as their reluctance, could result in lower response rates from online surveys.

Data Analysis

From the questionnaire, the feedback from the respondents was entered into Microsoft Excel spreadsheets, other analytical tools employed for this study were descriptive analysis and mean score ranking approach.

FINDINGS

From the survey, in terms of educational background, 4% of participants have a PhD, 62% have a master's degree, 32% with a bachelor's degree with just 2% with elementary school background. There is a fair representation of different construction stakeholder types as evidenced by 60% as consultants, 26% as contractors, 10% as developers with 2% in government and the same in urban water supply which shows diversification in survey research. Based on their professional designations, there was higher participation by engineers with 58%, 14% being architects, 14% being project managers, 2% participation each by clients, construction managers and quantity surveyors and 8% being site supervisors.

72% of the respondents are aware of green technology with 16% unfamiliar with this concept. Only 14% have just over 6 years of experience in green buildings with the majority having lesser years of experience in this concept as shown by 54% with no experience in green buildings. This explains why GBT adoption has been extremely slow in Ghana. Also, it is worth noting from the survey analysis that 94% of the respondents are keen to see the implementation of GBTs in this construction environment, due to a few green developments in Ghana recently and this aspect of the survey aided in improving the reliability of the obtained results.

In ranking the theme variables of barriers, driving forces and strategies, the most popular descriptive statistics of mean and standard deviation were used to rate them in order of importance as seen by the participants (Mao *et al.,* 2015). According to Mao *et al.,* (2015), where two or more variables share the same mean score, the higher score is assigned to the variable with the least standard deviation value. This was used in evaluating the research data for the theme variables to the implementation of GBTs. The rankings established based on the statistical analysis using mean and standard deviation are subjective based on the feedback expressed by the survey respondents and their understanding of the sustainable themes used in the questionnaire.

Barriers

Based on the 17 barriers used in the questionnaire, the responses for each barrier as evaluated by the Likert scale. The mean and standard deviation were established for each barrier and ranked using the mean score ranking approach. As all the mean scores for the barriers exceeded 3, it implies all the barriers have significant importance and mitigation measures must be employed to improve the adoption of GBTs. The top-ranked barriers, as identified by the respondents, were the absence of policies and regulations for green building, unfamiliarity of GBTs and their benefits, lack of initial capital to support GBTs, lack of political commitment, non-existence of GBTs database as well as the absence of GB training programmes for project staff. The respondents felt the top barriers are linked to government, economic and knowledge related elements which imply sustainable construction is obstructed due to a combination of factors such as the accessibility of information and the readiness of the market. Darko *et al.,* (2018) affirmed the importance of government-linked barriers as they hinder the implementation of GBTs and this is also emphasised by Djokoto *et al.,* (2014), who reported the absence of government backing has affected the integration of sustainable construction. The interventions from government can improve stakeholder motivation and encourage GBT implementation through incentives and provision of GB policies and regulations. Also, effective communication strategies such as heightened public awareness and GB workshops can lead to successful integration of GBTs in Ghana. These results of cost and knowledge-linked barriers may be because the survey respondents felt the strategies of financial support and training programmes can aid in the successful adoption of GBTs and address the barriers.

Drivers

The drivers in the questionnaire were identified as a result of extensive literature review as well as professional opinion and the effectiveness of the drivers are evaluated based on the feedback from the respondents using descriptive statistical analysis.

It can be established from the analysis that the top-ranked drivers from the survey are minimal environmental impact, enhanced indoor environmental quality, the conservation of non-renewable resources, enhanced occupancy comfort, devising a standard for innovative construction as well as minimal consumption of materials in construction. The respondents agreed the top drivers are environmental and social related elements but that notwithstanding, all the drivers in the questionnaire are significant as their mean score values exceeded 3 which is the middle value on the Likert scale.

The results from this study may be because sustainable construction in Ghana is at its inception stage and has not been fully accepted by all and there is still a general unawareness about the benefits GBTs offer. The essence of environmental and health-related drivers stems from the fact that the respondents feel there is a gradual depletion of natural resources due to unsustainable construction practices and feel a change in the methodology of construction will mitigate the adverse environmental impact and promote efficiency in the use of resources.

Strategies for promotion

In supporting the implementation of GBTs, the effectiveness of the strategies identified in the questionnaire have been evaluated based on the feedback of the survey participants and these strategies may include resources and platforms which are essential to improve the adoption of GBTs on a national level.

The top-ranked strategies from the analysis are media publicity, the use of workshops and seminars for public environmental awareness, proper enforcement of GB policies once developed, the introduction of green rating and labelling programs as well as public acknowledgement and rewarding schemes for GBT adopting companies. With an overall mean score higher than 4, it implies all the strategies listed are rated ‘important’ and must be considered for the promotion of GBTs. The essence of evaluating these strategies in order of importance allows stakeholders to appreciate which ones require more focus towards GBTs implementation. The respondents felt effective communication strategies, in conjunction with, public support from government through the introduction of regulations and policies, will activate the drive towards sustainable construction and nullify the identified key barriers from the survey. This reflects the consistency in their feedback and contributes to the reliability of the survey. Table 2 illustrates the highly ranked barriers, drivers and promotion strategies.

CONCLUSIONS

GBT implementation in Ghana is influenced by knowledge, cost and risk-related factors which have a major adverse effect on its application. This research aimed at investigating the themes involved in the GBT adoption and the use of the questionnaire survey allowed the collection and analysis of data using mean score ranking technique as well as statistical analysis to evaluate the level of awareness and how GBTs can be adopted.

Table 2: Highly ranked barriers, drivers, and promotion strategies to the adoption of GBTs

Rank	Barriers to GBTs Adoption
1	Absence of policies and regulations for green building
2	Unfamiliarity of GBTs and their benefits
3	Lack of initial capital to support GBTs
4	Lack of political commitment
5	Non-existence of database and information about GBTs
6	Absence of GB training programmes for project staff
7	Absence of rating systems and labelling programs for green buildings
8	Inadequate local institutes and facilities to support GBTs
9	Reluctance to switch from the use of traditional technologies
10	No backing from senior management on the use of GBTs
Rank	Drivers for GBT Integration
1	Minimal environmental impact
2	Enhanced indoor environmental quality
3	Conservation of non-renewable resources
4	Enhanced occupancy comfort
5	Devising a standard for innovative construction
6	Minimal consumption of materials in construction
7	Advancement in the efficiency of GBTs
8	Increased building value
9	Reduced whole lifecycle costs
10	New technology and information systems
Rank	Strategies to Promote GBTs Integration
1	Media publicity (e.g., print media, audio-visual media, social media campaign)
2	The use of workshops and seminars to create public environmental awareness
3	Proper enforcement of green building policies
4	The introduction of green rating and labelling programs
5	Public acknowledgement and rewarding schemes for companies that use GBTs
6	Training programmes on GBTs for project stakeholders
7	Accessibility of corporate framework for effective adoption of GBTs
8	Support from public institutions such as Environmental Protection Agency on the use of GBTs
9	Accessibility of adequate information on the importance of GBTs
10	Strict GB regulations and guidelines

This research evaluates the survey results on the variations in themes to GBT adoption in Ghana where the criticalities of the identified drivers, barriers and strategies have been assessed from the perspective of the local construction stakeholders. From the survey results, it was deduced (1) government-linked barriers are significant barriers to GBTs adoption, (2) environmental and health-related drivers will contribute immensely to the implementation of GBTs in Ghana and (3) effective communication strategies through the use of workshops and media publicity and public support from government were established as major promotion strategies to the integration of GBTs in Ghana.

It is imperative for academic and professional bodies who are among the key stakeholders and are required to play a vital part in terms of promoting environmental awareness and insight on green building technologies. Besides, a conducive environment offered by the government demonstrating a commitment to sustainability through the provision of guidelines and incentives to admonish local firms to be innovative and achieve GBT expectations. Notwithstanding the achievement of the research goals, some of the research limitations were the inadequate sample size, limited experts on sustainability, and the low response rate of the construction stakeholders to the questionnaire survey as a higher response rate could have enhanced the credibility and reliability of the findings collected. Another limitation of the study is related to the fact that the term GBTs is rather too generic encompassing a wide range of technologies and principles. The further studies should consider specific technologies or sustainable construction measures and associated aspects driving or hindering their implementation.

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