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Proceedings of the CIB World Building Congress 2016

Volume III

Building up business operations and their
logic

Shaping materials and technologies

Edited by
Arto Saari
Pekka Huovinen



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WBC16 Proceedings : Volume III

Building Up Business Operations and Their Logic
Shaping Materials and Technologies

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Preface

This volume III of the WBC16 proceedings is focusing on the building-up and shaping of intelligence into our built environment for life. In total, the 61 papers with the 735 pages are advancing such intelligence in diversified contexts across the globe.

In Section I, firms, business operations and knowledge embedded within the building and construction sector are being built up in terms of business development, market creation, strategic differentiation, competitiveness, knowledge, organisational learning and social responsibility.

In Section II, life-cycles and sustainability within the built environment are being built up in terms of building adaptability, life-cycle maintenance, virtuous and economic sustainability, green business modelling, performance based building, manufactured green buildings, concrete facades renovation, construction materials stewardship, live energy and urban water management.

In Section III, building information modelling (BIM) is being shaped in terms of business value delivery, BIM with Lean Construction, BIM with GIS, data-driven projects, perceptions among clients and users, overcoming barriers, meeting challenges, implementation, predictive semantic inferences and knowledge acquisition.

In Section IV, many novel solutions based on information and communication technologies (ICT) are being shaped in terms of Big Data, integrated and quasi-automated procurement, augmented reality onsite, text mining, virtual reality headsets and smart safety vests.

In Section V, contracting forms, risks and legal issues are being shaped in terms of a “Next Step”, highly economic alliancing, organisational economics, PPPs, risk sharing, extra contractual, context-specific concerns, the concurrency and analysis of delays as well as the adjudication of payment claim disputes.

In Section VI, construction project management (CPM) is being shaped in terms of PM design, stakeholder management, safety design and constructability, time management and space charts as well as cost control via Kaizen and contingencies.

Arto Saari

Tampere University of Technology
May 2016

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May 2016

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The Business Development Management Function: Processes at the Front of the Front End of the Management of Projects

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Abstract

The strategic front-end of the management of projects is where the construction is scoped, defined and designed client-side prior to engagement with main contractors on the supply side through procurement. At the front of the front end on the supply side is the business development management (BDM) function, the euphemism for sales. BDM is claimed to be isolated from other processes along the project lifecycle. Applying marketing theorization around securing work and delivering value for the analysis, this paper addresses BDM in ten major contractors to examine the extent of integration. Marketing offers three theoretical lenses: the transactional marketing mix, the more transformational relationship marketing and the current emergence of the service-dominant logic. Each lens facilitates conceptual evaluation of BDM in terms of current practice at the front of the front end, the extent of integration in the project lifecycle from its own theoretical position, and the rigor of value propositions and delivery. This is complemented at a detailed BDM level by an interaction sales approach. The findings show elements of all theories across the main contractors and in BDM processes in each contractor. A lack of integration is evident using all three analytical lenses and value propositions and delivery are constrained as a result. Management awareness of theory and applied configurations in BDM are thin and provide an explanation for the low integration, resulting in firms constraining their ability to effectively articulate and differentiate value propositions, deliver value propositions to clients and constrain growth in a competitive market.

Keywords: Business Development Management, Marketing Mix, Relationship Marketing, Service-Dominant Logic, Value Propositions

1. Introduction

The strategic front-end of projects is where construction is scoped, defined and designed client-side prior to main contractor engagement. At the front of the front end on the contractor side is the business development management (BDM) function, the euphemism for sales. Projects are specific assets, where selling occurs prior to production to contract. A long period of selling is typical whereby BDM is engaged with selling prior to a specific project and then BDM is injected into the project front end once the specific project is identifiable.

The sales function includes securing sales and delivering value. The emphasis between the two varies conceptually according to the underpinning marketing theorization. There is broadly one transactional approach, the *marketing mix*, and two transformational approaches, *relationship marketing* and the *service-dominant logic*. The transformational approaches place more emphasis on value. The sales function has been neglected in the extant management and marketing literature, especially in regard to value (e.g. Jones et al, 2005; Haas et al, 2012). Sales or BDM has received minimal attention in construction (Smyth, 2000). Marketing and BDM are claimed to be isolated in the project domain (Pinto and Covin, 1992; Turner, 1995). This paper tries to address BDM operations. It investigates: (i) range of activities conducted within the function and related to this (ii) the extent of integration with other functions along the project lifecycle. Applying marketing theorization around securing work and delivering value for the analysis. At a detailed level of BDM an *interaction sales approach* is employed (Haas et al, 2012).

Methodology and methods are interpretative and qualitative. The empirical evidence is drawn from 10 main contractors to examine the way selling is conducted and how value is addressed for delivery and realization. The findings show elements of all three theorizations underpinning BDM processes across the contractors, yet selling is largely conducted without strategic and tactical guidance. Integration is minimal, affecting value propositions, relationship management and practices of co-creation of value. Contractors therefore constrain their service provision from the outset of the project lifecycle. The paper concludes that management lack awareness of theory and a systematic approach to BDM. This constrains selling capabilities, configuring valuable propositions and value realization by clients post-completion. Construction firms therefore curtail potential market growth.

Structure of the paper is traditional: a literature review, methodology and methods, findings and analysis followed by the conclusions and recommendations on BDM in construction.

2. Literature Review

2.1 Marketing Theorization and the Strategic Project Front-End

The management literature has emphasized the business model concept in recent years (e.g. Zott and Armit, 2008). Business models embody strategy, structure and processes with an associated earning logic of revenue and profit. The marketing strategy, of which selling forms a part, is part of the model, even though the mainstream management and marketing literature have few overt connections. Marketing and sales has two main components: securing work and delivering value in order to grown and sustain a reputable business. Although the theoretical approach to marketing affects the emphasis between selling and value, both are necessary to secure new and repeat business, especially project markets (Smyth, 2015).

Marketing has developed three main theoretical lenses: the transactional *marketing mix* (MM) (Borden, 1964), the more transformational *relationship marketing* (RM) (Berry, 1983) and the

current evolution of the *service-dominant logic* (S-DL) (Vargo and Lusch, 2004). There are other important contributions, for example entrepreneurial marketing (Morris et al, 2002) and the RM variant of project marketing (Hadjikani, 1996). The lens applied will be largely limited to the three mainstream theorizations. Entrepreneurial marketing has hardly been addressed for projects and in construction, while the status of project marketing has been addressed elsewhere, including the extent to which it is a theorization (Smyth, 2015), yet it will be referred to where relevant.

The marketing mix or MM arose from economics around the exchange process and was founded in reference to mass market consumer goods. The emphasis is upon key inputs (McCarthy, 1964) on the assumption suppliers know what they want and choose from predetermined offers on the market. The customer is largely passive until active at the point of exchange. The emphasis is upon selling products and services, value being largely determined from the inputs. In construction, application is conceptually limited because main contractors have few controls over the key inputs apart from price. Additionally, sales occur ahead of production and the exchange occurs over the project lifecycle. However, it was used extensively within the conceptual limits as means to secure work based upon past inputs, that is track record by sector and building type (Smyth, 2000).

Relationship marketing or RM was founded in the market for intangible business-to-business (B2B) services (e.g. Grönroos, 2000). The emphasis is on process. Selling is conducted through organizational and network relationships, supported by systems and procedures to manage the process. The customer or client and other stakeholders are active and relationship management extends into operations in support (e.g. Ford et al, 2003). Relationships are conceived as delivering value and content is negotiated and customized. RM conceptually aligns with construction. Clients are to be managed as much as projects and between projects to manage the sleeping relationship (Hadjikani, 1996), for example through a key account management (KAM) function (Smyth and Fitch, 2007). RM adoption in construction is partial and has lagged many sectors, commitment being incremental (Smyth, 2015).

The service-dominant logic or S-DL emerged a decade ago (Vargo and Lusch, 2004). The emphasis is on value outcomes. Customers are most active, conceived through the axiom of the *co-creation of value* (Vargo and Lusch, 2015). Value is co-created through organizational resources being combined. In projects informs the configuration of value propositions that can optimize value realization in use and in context (Akaka et al, 2013, 2015). Theoretical development has identified co-creation occurring through dialogue (Ballantyne and Varey, 2006) and interaction (Edvardsson et al, 2011). Interaction brings forward some the RM tenets again. In projects, value in context and use echoes the renewed call for a focus upon benefits delivery and impact (Morris, 2013). In construction, the S-DL implies a medium-to-long term view, which is at odds with the short-term incentive structures of management, financial and stock markets (cf. Smyth and Lecoivre, 2015). It accords with addressing client organizational problems or servicing the core business for which valuable projects are the solution. It also addresses total asset management, facilities, whole life cost and potentially responding to climate change issues. Marketing theorization can both articulate the current state (Vargo and Lusch, 2004) and carry normative content (cf. Prahalad and Ramaswamy, 2004). The S-DL has yet to be picked up prescriptively in construction practice.

Changing theorization has shifted the approach to value. From the tangible input focus pre-determined by the supplier to a perceptual primary outcome focus realized value in use and context, marketing has increasingly been decoupled from the exchange with price as the measure of value. Yet the emphasis upon price through competitive bidding for construction, the bidding process is also largely decoupled because the bid price typically has little to do with the incurred cost at the time of the final account when the exchange process is complete.

BDM involvement occurs prior to any project. This is part of client management or KAM and operates at a programme management level of the contractor to maintain the relationship, manage service consistency and workload continuity (Smyth, 2000). This is particularly the case where potential and repeat business clients are perceived as valuable to the supplier in terms of growth and profit. The *client lifetime value* derived the project value of work over, say, 7-10 years is significant to project businesses although many contractors retain the transactional focus upon projects as the main unit of financial consideration (Smyth, 2015).

BDM engages with projects at the front-end where the investigation of client needs and configuring solutions is explored in the main contractor. Previous research has pointed out that marketing occupies an isolated position in regard to project management (Pinto and Covin, 1992; Turner, 1995). Yet somewhat paradoxical, there is an argument claiming BDM is a subset of project management, for example applying a funnel approach to link them (Cooper and Budd, 2007). This raises analysis of BDM at a more detailed level.

2.2 Business Development Management in Construction

Selling in the extant management and marketing literature has been neglected (Jones et al, 2005; Haas et al, 20102). The sales literature is generally presented as linear, for example: production → sales → marketing → partnering (e.g. Weitz and Bradford, 1999). For projects selling occurs prior to production. While there has been research into the BDM at general level (e.g. Preece et al, 2003), the detailed analysis of the function has been neglected, especially around configuring value propositions in preparation for and in bid management. It requires firm support to align the inputs, develop the relationships and understand the potential value in use. It requires different degrees of organizational and marketing capabilities to conduct this with effect (Möller, 2006).

Selling is a prime emphasis under MM. Selling and delivering value through relationships have similar weighting under RM. S-DL has focused upon conceptual development and refinement with little or no consideration of selling in the role of service provision and value realization. A recent exception is an *interaction sales approach* for the co-creation of value (Haas et al, 2012). The approach develops the line of argument that BDM becomes part of value co-creation through face-to-face interaction. Thus selling and value creation become intertwined. It re-introduces RM tenets through a relational value creating process to the sales function: *the sales function reflects a role of sales as creator of relationship value* (Haas et al, 2012, p. 95), which becomes part of the service value and thus contributes to the ability to sell too. Haas et al (2012) brings forward 4 conceptual categories to understand the sales process:

1. *Jointness value* – resources are combined dyadically and in the network, in the case of projects at the project front-end as well as during construction (cf. Ballantyne et al, 2011). BDM initiates i) identification of the key relations and relational processes, ii) configuration of the value proposition and service delivery, iii) the co-creation of value.
2. *Balanced initiative* – customers are active (e.g. Levitt, 1983), providing preconditions for innovation, collaboration and combining resources to co-create value (e.g. Tuli et al, 2007). In construction, the client is active and the contractor reactive, for example in developing procurement routes and other innovation (Smyth, 2006). This implies support from organizational capabilities and programme management to guide BDM action.
3. *Interacted value* – relationships provide a means to identify and configure value propositions, which hold potential for the client and end-users to optimize value realization in use (Haas et al, 2012). Win strategies emerge from creative dialogue and by committing to reciprocal promises (Ballantyne and Vary, 2006). BDM initiates the process, implying functional integration (Smyth, 2015).
4. *Socio-cognitive construction* – value is phenomenologically and subjectively realized from the functional and symbolic content in use (Vargo and Lusch, 2015). Thus value is

as much behaviourally derived from the specific assets, following the idea that action shapes interpretations (Weick et al, 2005). In construction, BDM has focused upon value as past performance through track record and current execution regarding time, cost, quality and scope, underplaying benefits delivery and impact (cf. Morris, 2013) and educating clients accordingly (Smyth, 2000) – see Figure 1 for further details.

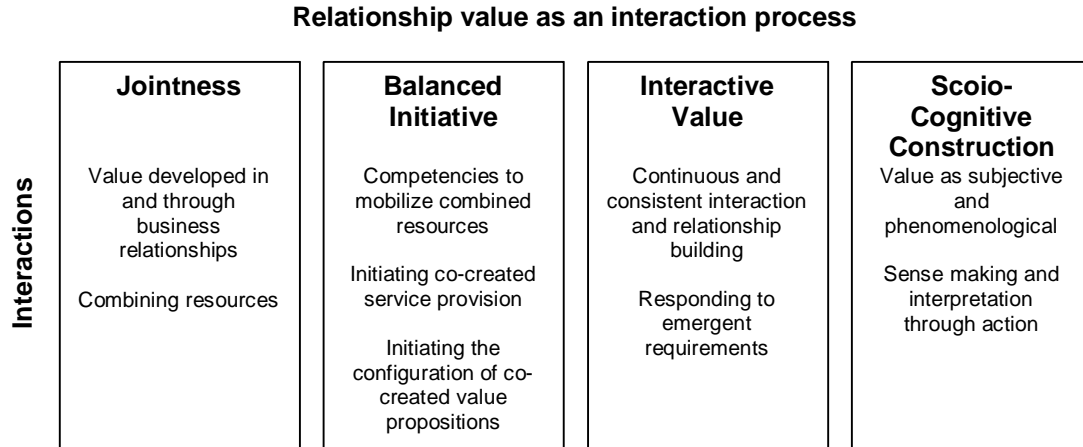


Figure 1: An Interaction-based Framework of Sales' Value Creating Tasks in Projects (developed from Haas et al, 2012)

BDM has a pivotal role at the front of the front-end, connecting the contractor with the client and forming the interface with the project. It has been argued that successful outcomes are dependent upon strategically addressing the front end on the client side (Morris, 1994, 2013) and on the supply side (Smyth, 2015). There are two implications that arise for BDM. First, the interaction sales approach brought forward by Haas et al (2012) has to be conceptually subdivided into the strategic and tactical sales levels of operation to reflect the contractor-project interface and the front end, and the project lifecycle from the front end to the realization of value in use. Second, the long exchange period in construction from post tender negotiations, through the stage payments to the final account mean that value in use clearly becomes twofold: a) the execution experience as service provision over the entire project lifecycle from the front of the front end to the final account, b) the project content value in use post-completion for the client and end-users. These provide a theoretical contribution to be evaluated through the empirical analysis.

In order to apply the interaction sales approach in detail, the BDM effort to *understand client needs* in order to sell the service and configure value propositions involves a number of potential levels: (i) collecting information on the project and requirements, (ii) knowing the motivations and considerations of the key decision-makers, (iii) understanding client business solutions or organisational purposes the project is addressing, (iv) understanding the client's own core business to get to the bottom of what they perceive as valuable. The MM approach only requires the first level. RM requires the second and third levels. S-DL requires all levels to secure a comprehensive understanding of use value.

3. Methodology and Methods

An interpretative methodology was applied to respect value judgments, subjectivity and information provided in context (Denzin, 2002). Respecting key actors perceptions enriches understanding of attitudes present, the strengths and weaknesses of organizational artifacts, processes and behaviour, yielding meaning to generate patterns of events, draw out experiences, draw attention to outcomes of significance (Smyth and Morris, 2007). The

researcher is also interpreting evidence, producing a layered approach (see Table 1). In this research the data comes from 30 semi-structured interviews with those in business development management roles (BDMs) across 10 main contractors. Ownership varied: 4 UK-owned contractors, 4 mainland EU-owned contractors, 1 other European contractor and 1 Antipodean-owned contractor. Sectors of operation included civil engineering and infrastructure, building, refurbishment and fit out, although sector activities did not appear material in how BDM practices were conducted. The period covered is the constrained European market from 2009.

Table 1: Interpretation Levels in Qualitative Research (adapted from Wells and Smyth, 2015)

Levels of Interpretation	Agent	Stage of Interpretation
1.	Interviewee in the main contractor organization	Interviewee interprets events (including processes) as they occur – a sense-making activity
2.	Interviewee in the main contractor organization	Interviewee with other actors moderate their interpretation – an iterative sense-making activity
3.	Interviewee in the main contractor organization	A degree of post-rationalisation as a result of subsequent events, also moderated by social and other contextual factors
4.	Interviewee as informant	Recall moderation in context of interview – interpretative selectivity
5.	Interviewee as informant	Responsiveness to the perceived research agenda and selectivity as to what the actor perceives the researcher wants to hear
6.	Researcher as data collector	Selectivity of information according to values and research context in note-taking and analysis post-interview
7.	Researcher as analyst	Researcher interprets events as perceived in the analysis – a sense-making activity

4. Findings and Analysis

The findings and analysis are presented from the strategy level through the project lifecycle.

4.1 Marketing and Sales Strategy in the Main Contractors

The marketing strategy was variably developed across the firms. It was arguably the most developed in BranCo, applying RM, yet some BDM practices were rooted in MM pipeline selling. Across all the contractors with marketing plans other functions were largely unaware of the content, for example EuroCo's procurement department was both unaware of the plan and had no dialogue with BDM to coordinate value propositions in the supply chain. In BritCo marketing was cut post-2008. Marketing" was consigned to a backroom function of processing market information and BDM was absorbed into bid management. UKCo did not have an explicit marketing strategy, seeing BDM as a pipeline of information collection and response – it was reported as *marketing on the run*. EUCo put in place its first marketing plan in 2008 and subsequently developed strategies for key customers, which were presented to board level. Primary content was a strong emphasis on forward work planning. EuroCo customer plans were frequently out of date and not referred to at functional levels (cf. Smyth, 2013). A KAM capability has been introduced for consistent client management. It was poorly resourced and largely operated at project rather than programme management levels.

A strategic intent of jointness to combine resources was absent, despite client demands for collaborative practices in the infrastructure sectors. Contractor perceptions around competitive advantage and intellectual property were constraints to jointness for the co-creation of value through knowledge sharing, innovation and collaborative working. RhoCo and BudCo particularly emphasized these points, but these two organizations were among the most focused on transactional and operational cost. They were defensive rather than transformative to drive dynamic and incremental performance improvement around value.

Procedures to guide BDMs for relationship building and understanding client needs were absent, affecting balanced initiative and interactive value. This represents a lack of strategic support for the tactical BDM operations. BudCo operated a transactional pipeline approach with a strong input-price connection maintained throughout. ElecCo, FinCo and BritCo were also highly transactional and closely adhered to MM practices. Value was perceived as technology and expertise. In EuroCo, management capabilities for innovation and service provision were not recognized. Yet many clients, especially in the public sector were reported to have lost capabilities post-2008 and thus need more strategic support and advice. This was recognized and presented relationship building and co-creation opportunities for FinCo and EuCo, although the latter was better placed and selectively took the opportunity as a type of balanced initiative and interactive value creation.

Overall, strategy development for BDM has improved over the last 15 years (cf. Smyth, 2000), yet remains weak against the theoretical lenses apart from MM.

4.2 BDM at the Strategic Project Front-end

The BDMs sought a mix of high value and high profile clients, with some trade margin offs if the client profile was thought to reinforce sector track record and the ability to secure other new work. This was particularly found in FinCo for public sector and for BranCo for some private sector work. Mid-recession, trade-offs challenged the RM strategy in BranCo. New clients were difficult to secure, especially in new sectors. There was around 10% experimentation in BDM activity for entering new markets and anticipating new markets – an important substitute for market research because contractors reside near the top of the ‘food chain’ (cf. Smyth, 2000). BranCo followed this strategy. One BDM in EuroCo reported that it was difficult to secure resources to prime new sectors even where tasked with the objective. EUCo and BranCo admitted that they were weaker on value than selling. EuCo was the only company that drilled down to all five levels of to *understand client needs*, albeit sporadically and not always succeed in injecting the understanding to value propositions. Initiatives were not always balanced (cf. Haas et al, 2012). BranCo was the only company to employ a *client lifetime value* as a measure, which helped to reinforce interactive value in selling.

Mapping of the key decision-makers helps understand client need as part of RM, namely knowing the motivations and considerations of the key decision-makers.. BranCo was the most effective case company, yet inconsistent practices were also present. Some BDMs conducted formal mapping for their own purposes at organisational, programme and project levels among clients and their representatives, while a few logged their maps on the CRM system, Salesforce®. Engagement with CRM was low across the companies. A number relied on informal processes, mentally mapping people by role and influence. Mapping competencies support interactive value in interaction selling (cf. Haas et al, 2012).

There was a lack of strategic resource commitment and criteria. AntCo tactically committed resources based upon time and effort at project level. Finance management and commercial directors were said to be predominantly transactional. It restricted client engagement and combining resources through jointness.

Customers frequently seek high interaction levels, for example to have a large say in the members of the project teams (Haas et al, 2012; Smyth, 2015). Management awareness of theory and applied configurations are thin with the consequence of low levels of resourced interaction and integration. Practices were uneven and varied. The lack of strategic support was tactically echoed as a lack of guiding procedures.

4.3 BDM Tactics at the Front-end

In the general absence prescribed systems and procedures, routines and action were left to individual responsibility (cf. Smyth, 2015). In FinCo client interaction was cut back following 2008 with reliance upon telephone contact to solicit information to feed the work pipeline, and employing a highly transactional around the bid and contract process: *We tend to be office based. We don't go out and meet the clients.* BudCo are predominantly transactional, claiming to be good at managing high-level relationships yet weak down the hierarchy and into operations. There were similar procedures for internally qualifying project opportunities. These were generally qualified against resource inputs rather than the potential of combined resources to manage risk and create value, that is, through jointness. For example, UKCo classified project opportunities as follows:

1. Platinum – must win;
2. Gold – resources committed to investigation, but the decision to proceed taken;
3. Silver – interesting but no resources committed;
4. Bronze – promising yet too early to know.

In EuroCo opportunities over a threshold cost went to the main board for risk assessment.

Some RM tenets had been absorbed by the BDMs, who were building relationships even if these were left unrecorded CRM IT software. An EUCo BDM summed it up: *its all about people and relationships*; and, *it boils down to some trusted relationships* according to an AntCo BDM. Some BDMs built relationships to improve pipeline information quality and processing. This sales approach overlooked value delivered through relationships or co-creation, including in BranCo. To progress relationships, BranCo made resource commitments against key clients, yet to configure value, non-contractual promises could not be made as the procedures did not exist to deliver against these. Imbalanced initiatives and interactive value were compromised. Cost and risk management mainly drove out value. Even when value was addressed, it was seen in terms of cost, RhoCo pursuing this for efficiency using Six Sigma. Some clients reinforced the transactional approach. However, one client set BDMs “homework” to gauge commitment, offering opportunity to co-created value at the front end. Overall, configuring aligned value propositions proved to be a tactical challenge due to the lack of strategic support.

Some EUCo BDMs perceived value as inputs determined at prequalification. Value was perceived as standard inputs. Prequalification and bidding documents were put together on a cut and paste basis rather than being tailored to context. Many BDMS had no involvement in bid management. FinCo, BritCo and BranCo did, the former two from an MM perspective and the latter from an RM perspective. Yet, BranCo BDMs tended to hand over prospects after pre-qualification. BDM lifecycle involvement, even through a “watching brief” was widely cited as important: *they need a common link* and the *willingness to partake in dialogue*, yet implementation was inconsistent. BranCo was more effective at developing “win strategies” during bid management, influenced by BDM yet not derived from promises due to the lack of integration. BudCo claimed to have an effective link between BDM and bid management, which fed into value propositions. BranCo BDMs were most vocal on this point and it is summed up in EUCo as the challenge of *getting the theme running through*. Bid managers and project managers were largely left unaware of understanding about value or were not required account for this. BDM remains isolated in relation to project management (cf. Turner, 1995).

ElecCo has a different approach, predefining specialist inputs supported by breadth and depth of expertise. This was offered as exchange value in the knowledge of a high degree of client dependency even though there may be customized solutions to context. Realized value in use could be quite high, but it not was not directly co-created. Overall value propositions were high value yet transactional.

Collaboration, early contractor involvement and open dialogue are formal mechanisms for combining resources in joint problem solving that can feed into balanced initiative and interactive value delivery. These measures were mentioned by a number of BDMs across the cases and especially in UKCo. Collaboration was present in infrastructure, driven by clients with service and value in mind.

A lack of integration was evident, despite interactions, and value propositions were suboptimal. Evidential patterns were mostly identified in terms of a lack of systems and procedure for BDM.

4.4 BDM Tactics in Execution and Post-completion

Delivery is constrained by low integration both in service provision for execution and realizing potentially valuable propositions post-completion. Sporadic involvement of BDMs was reported during execution. This was across two types of contact for value delivery: externally the client contact and internally the project team contact. The internal relationship includes key performance indicators and lessons learned fed into configuring future value propositions. BudCo reported limited knowledge feedback to tweak “win themes”. EUCo BDMs were charged with making contact twice with site during execution. Where feedback occurred, it was inconsistent and intermittent, and described by one UKCo BDM as being managed “quite randomly”. Summing this up, a BDMs reported feedback as important, yet, *in practice it never happens*.

The BDMs were contributing to the function being isolated (cf. Turner, 1995), belying any conceptual argument that BDM is part of project management (cf. Cooper and Budd, 2007).

BDMs, indeed the companies, were disengaged from monitoring value alignment and value realization post-completion, even though the final account is closed long after practical completion on site. Benefits delivery and impact was neglected by BDMs and by the case study firms. Overall, sales interaction falls away and the monitoring of and support for the co-creation of value is low – low jointness, balanced initiative and failure to understand socio-cognitive construction.

5. Conclusions and Recommendations

The sales function has been neglected in the extant management literature, especially in regard to value (e.g. Jones et al, 2005; Haas et al, 2012). BDM has received little attention in projects and construction (Smyth, 2000). The paper set out to review BDM practices on the ground. It investigated the range of activities conducted within the function and related to this the extent of integration with other functions along the project lifecycle. Low integration was prevalent, confirming previous findings (Smyth, 2015). Marketing and BDM have been claimed to be isolated from other processes in the project domain (Pinto and Covin, 1992; Turner, 1995). This is still the case to an extent but there are more touch points and interactions than might be expected from past research, especially at the front end. The notion that marketing is to be subsumed into project management has no current basis, the future aim being to integrate rather than for either function to absorb another.

The informal BDM activities were diverse and inconsistent in supporting a single theoretical lens or the interaction sales approach (cf. Haas et al, 2012). This was the consequence of low strategic investment and commitment for BDM rather than the development and delivery of differentiated value propositions. BDM strategic support in the firm hierarchy was an underdeveloped, including programme management to support BDM prior to any project and

at the front end of construction projects. Overall, the transactional *marketing mix* or MM was still prevalent despite the ill-theoretical fit. *Relationship marketing* or RM principles were applied piecemeal, and aspects of the *service-dominant logic* or S-DL were present by implication rather than strategic design. The activity to *understand client needs* only served MM. Selling dominated value within marketing and BDM, and risk and cost dominated value. In summary, selling is largely conducted through BDM without any conceptual underpinning and strategic guidance.

The paper has made a contribution by analyzing BDM using the interaction sales approach conceptually and conceptually added the strategic and tactical analysis. It also investigated BDM at a more detailed level of activity. There is scope to dig down further in future.

The recommendations for practice could be numerous at the level of activity, but the big picture for management at senior level and for marketing and BDM is that there needs to be increased awareness of theory and a systematic approach to BDM. Implementation needs resourcing and commitment with a transformational emphasis upon growth the market.

Research recommendations show clearly that asset specific markets and project businesses in particular require mainstream marketing concepts to be translated into context for these to have use value. Thus care is needed in appropriating and applying marketing theorization in construction.

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New Market Creation in Urban Area Development: An Ecosystemic Business Model Approach

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Abstract

The primary tool to bridge innovations and the market is the business model concept, i.e., the logic of creating and capturing value. Although business model is regarded as a boundary-spanning unit of analysis, most of modern business model frameworks are firm-centric and less suited for analyzing the interdependent nature of organizations residing and evolving in same innovation ecosystems. Through the business model approach, also urban ecosystems are able to build sustainable competitive advantage. However, an ecosystem can cross a variety of industries and encompass a variety of organizations, which makes the identification of its exact boundaries both theoretically and practically difficult. Hence, contributing to ecosystem level business model discussion, this study applies a business model approach to analyze how an ecosystem may innovate and build competitive advantage as a whole.

In particular, this paper focuses on how business model approach can be viewed as the way for leveraging value from innovations in the urban area development context, and explores how urban area development may contribute to new market creation. The Finnish spatial planning system, spanning from strategic spatial planning to physical land-use planning, provides a context for researching innovative opportunity and advantage exploration and exploitation behaviors. Particularly, contributing to the opportunity exploration for new market creation is called for within Finnish urban area development practices. Drawing from Activity Theory and business model literature, in the context of ecosystems, we suggest an ecosystemic business model approach in urban area development. The corresponding analysis of three urban area development cases show how new unofficial spatial planning practices relate to ecosystemic business model approach and new market creation.

Keywords: business model approach, innovation ecosystem, large-scale project, market creation, spatial planning

1. Introduction

Today's business environment incorporates a diversity of innovation stakeholders, ranging from public organizations, research institutes, large and small firms onto individual users and citizens (Lappalainen et al. 2015, Gobble 2014). Hence, the concept of innovation has spread from the internal parameters of corporations to include also the wider ecosystem (Durst & Poutanen 2013, Ahokangas et al. 2015). Relying on open innovation (Chesbrough et al. 2014), also cities have started to utilize e.g., public-private-people partnerships (Lappalainen et al. 2015). Innovation ecosystem thinking is therefore useful in seeking to understand the dynamic relationships between different industries, private and public organizations and governments (Lappalainen et al. 2015, Papaioannou et al. 2009, Durst & Poutanen 2013) when they are building new markets.

The primary tool to bridge innovations and new market creation is the business model concept, i.e., the logic of creating and capturing value (Chesbrough 2010, Teece 2010). The business model is a boundary-spanning unit of analysis (Zott et al. 2011) that connects an organization with its environment, customers, competitors and larger society (Teece 2010). In ecosystemic contexts value creation and capture are embedded within the whole ecosystem of players, meaning that value is co-created and co-captured (Ahokangas et al. 2015, Lehto et al. 2013). The business model concept serves as an open innovation platform, connecting focal organization with other organizations, communities and individuals for joint development of innovations (Saebi & Foss 2015). Through the business model concept, also urban ecosystems can be seen to be able to build sustainable competitive advantage (Lappalainen et al. 2015).

However, most of modern business model frameworks are firm-centric and less suited for analyzing the interdependent nature of organizations residing and evolving in a same innovation ecosystem (Iivari et al. 2015). Therefore, business model research needs to consider also ecosystem level business models (van der Borgh et al. 2012). Contributing to this view, this study regards the business model as a tool to build synergy among the ecosystem members for determining how the ecosystem innovates and builds competitive advantage as a whole (Jansson et al. 2014, Iivari et al. 2015).

Specifically, this paper explores how business model approach can be viewed as the way for leveraging value in the urban area development context. Urban development agencies may provide opportunity exploration scenes (Oosterlynck et al. 2011, Hirvonen-Kantola et al. 2015). Particularly, enhancing the opportunity exploration for new market creation is called for within Finnish urban planning and development practices. Thus, this research enquires *how business model approach can contribute to new market creation in urban area development?*

Now, we will introduce the concepts of innovation ecosystem and ecosystemic business model. Then, we suggest an ecosystemic business model approach to be applied in our analysis on urban area development. We also show how urban planning and development practices relate to the innovation ecosystems' business model approaches and their life cycle, in three urban area development cases.

2. Theoretical framework

2.1 The emergence of innovation ecosystems

The notion of ecosystems has gained increasing attention in academic literature as a concept to understand and explain the complexity and the interconnected nature of modern business environment (Durst & Poutanen 2013). The ecosystemic perspective is considered to reflect a fundamental change in the way we think of business in general, particularly in relation to innovations (Gobble, 2014). The term business ecosystem was first introduced by James Moore (1993) who calls a business ecosystem an economic community supported by a foundation of interacting organizations and individuals—the organisms of the business world (Gobble 2014). Ecosystems are focused on commonly created value, renewal, and constant innovation in order to achieve a sustainable competitive advantage in their business environment (Ahokangas et al. 2015, Lehto et al. 2013).

Ecosystems are partly intentionally formed and partly a result of accidental emergence (Moore 1993). Business ecosystems are hence characterized with high complexity, interdependence, co-operation, competition and coevolution (Iansiti & Levien 2004, Jansson et al. 2015). Moore (1993) states that firms create a new business ecosystem based on four evolutionary stages from birth, expansion, leadership, and self-renewal. At the birth stage, it is essential for the ecosystem members to go beyond just satisfying their immediate customers. At the expansion stage the scale-up potential of the business concept of an ecosystem is tested. At the leadership stage the business ecosystem reaches stability and profitability. The final stage, self-renewal or death, is caused by the threat of rising new ecosystems. Hence, there is a continuous life-cycle process of the ecosystem members taking place within an ecosystem (Hirvonen-Kantola et al. 2015).

The underlying thought behind ecosystemic perspective is to expand the capabilities of one actor beyond its own boundaries and transfer knowledge into innovation through collaborating with others (Adner 2006). The joint utilization of complementary capabilities in pursuit of new innovations is hence highlighted within ecosystems, and in this way, ecosystemic thinking closely relates to open innovation (Chesbrough et al. 2014). Although open innovation originates from corporate R&D, its application has expanded beyond inter-firm collaboration (Chesbrough et al. 2014). Also cities and regions have started to seek the benefits of openness and ecosystemic thinking through public-private-people partnerships based on quadruple helix model (Lappalainen et al. 2015).

The ecosystemic thinking is particularly relevant for the smart city concept, which refers to cities themselves acting as innovation drivers (Schaffers et al. 2012). A city can be considered ‘smart’ when investments in human and social capital and traditional and modern ICT-based infrastructure fuel sustainable economic growth, high quality of life and wise management of natural resources through participatory government (Schaffers et al. 2012). Test-beds, living labs, collaborative platforms and testing environments provide good development opportunities for innovation creators and help them to bring their solutions to the market (Launonen & Viitanen 2011). Launonen and Viitanen (2011) stress that innovations need to be designed for

real life situations in order to have commercial value. However, urban area development in this context is still bound to traditional land-use planning based on zoning, which makes fast responding to changes and the free development of new markets challenging.

2.2 The concept of ecosystemic business model

The business model is the primary tool for leveraging value from innovations (Chesbrough 2010). The business model bridges innovations and new market creation, i.e., the logic of creating, capturing, delivering and sharing value (Teece 2010, Amit & Zott 2015). Value creation and capture are based on opportunities that require business models for the successful exploration and exploitation of those opportunities and the subsequent competitive advantage (Ahokangas & Atkova 2015, Teece 2010). In ecosystemic contexts value creation and capture are embedded within the whole ecosystem of players, meaning that value is co-created and co-captured (Ahokangas et al. 2015, Lehto et al. 2013). Collaboration of the focal firm with its ecosystem is one of the defining factors of business model openness (Frankenberger et al. 2014). However, the ecosystemic business model can also be regarded as the business model of an ecosystem with mutually connected opportunities. Thus, in an ecosystemic context, the business model functions as an open innovation platform that connects an organization with other organizations, firms, communities, individuals and larger society for joint development of innovations (Saebi & Foss 2015). Therefore, the business model is a boundary-spanning unit of analysis (Zott et al. 2011).

Casadesus-Masanell and Llanes (2011) discuss open source, open core, open edge and proprietary business models. Within ecosystemic smart city contexts this categorization can be interpreted to concern the roles of the city as the focal player of the ecosystem with the rest of the ecosystem when innovating new offerings and creating new markets. With an open source business model the ecosystem jointly co-creates value for its customers whereas in proprietary mode the focal player tries to control value or market creation activities of the ecosystem. In open core business model the focal player remains open whereas the rest of the ecosystem players run their activities independently. In the open edge mode the city as the focal player defines the rules of collaboration allowing the rest of the ecosystem act within the established rules.

Through the utilization of the business model concept, urban ecosystems are capable of building sustainable competitive advantages (Lappalainen et al. 2015). The business model is a tool to build synergy among the ecosystem stakeholders in order to determine how the ecosystem innovates as a whole (Jansson et al. 2014, Iivari et al. 2015). Most importantly, however, within the ecosystemic business model approach, cities may thrive for new market creation by enabling the innovation ecosystem to shift from an evolutionary stage to another (Moore 1993). In addition, cities may allow for the logic of creating, sharing, delivering, and capturing value to develop freely or in a defined manner. Hence, the ecosystemic business model approach needs to consider also business model's viability, evolution and its place in the product or service lifecycle, which in this research refers to spatial planning practices (see also Demil & Lecocq 2010). With the emergence of the idea that the built environment is a source of competitive

advantages for urban regions (Hirvonen-Kantola et al. 2015), the question of how business models may boost new market creation is particularly relevant for innovation ecosystems that are nowadays being catalyzed in different cities in Finland, in the urban area development context.

3. Research strategy and methodology

3.1 The context of urban area development

The urban area development takes place within the Finnish spatial planning system, spanning from strategic spatial planning to physical land-use planning, and provides a context for researching innovative opportunity and advantage exploration and exploitation behaviors (Hirvonen-Kantola et al. 2015). However, our spatial planning system is a normative and multilevel system based on land-use planning. Although, the attention has been paid to the European discussion on urban policy as creating prerequisites for urban development (Jauhainen & Niemenmaa 2006).

In Finland, local planning authorities have been granted an independent role, and the system has offered opportunities for strategically active municipalities. As the ecosystem's facilitator we may thus identify at least the municipality with active land policy and local planning monopoly, as these are portals to opportunities. Here, the most important mechanism of control is the Land Use and Building Act (LBA, Maankäyttö- ja rakennuslaki 1999/132). The land-use planning system is a functionalist and rationalist hierarchical system in which general planning ideally guides detailed planning, and which aims to produce legally binding plans that enable development and implementation.

Municipalities draft their own master and detailed plans, and the powers of approval and ratification are given to the local municipal councils, which makes the local government central stakeholder in the ecosystem. Detailed plans regulate development by defining building rights, efficiencies, dimensions and functions in detail, attached to land-owning information. Plans can be initiated and paid for by both landowners and municipalities, that is, by diverse ecosystem stakeholders. Indeed, the planning practice seldom conforms to formal planning hierarchy, since landowner rights are well protected in the LBA. In addition, investors and the Ministry of the Environment expect speedy preparation of detailed plans, although business considers urban planning slow.

Diverse Public-Private-People partnerships are applied in urban planning and implementation, and any interested party participation is emphasized. The planning authority must publicize planning information so that interested parties are able to follow and influence the planning process (LBA 62 §). Here, openness is a competitive advantage to the innovation ecosystem reaching for new market creation. When launching the preparation of a new plan a Participation and Assessment Scheme has to be drawn up and publicized. It should cover participation and interaction procedures as well as processes for assessing the plan's impacts (LBA 63 §).

However, the business impact assessment with value propositions and competitive advantage identifications is typically neglected, and the content of ecosystemic business model unformed.

In recent years, planning has advanced from top-down government to negotiations with developer-contractors, setting common goals and tying in the ecosystem stakeholders at the beginning of planning projects. The implementation of plans has been integrated with planning, and the detailed plan has become a type of project plan. In order to plan in neo-liberal conditions some cities have developed unofficial practices, which are central instruments in spatial planning. In fact, the three urban area development cases that we will study next, point out the role of unofficial urban planning and development practices, in approaching new market creation as the business opportunity for the ecosystem with mutually connected opportunities arising from the urban area development context.

3.2 Ecosystemic business model approach

Building on the literature review, we will apply a business model approach in exploring how urban area development may contribute to new market creation. Drawing from Activity Theory (Engeström 1987, 2001) and business model literature, in the context of ecosystems, we first suggest a new ecosystemic business model approach in urban area development (Figure 1), to be applied in our analysis.

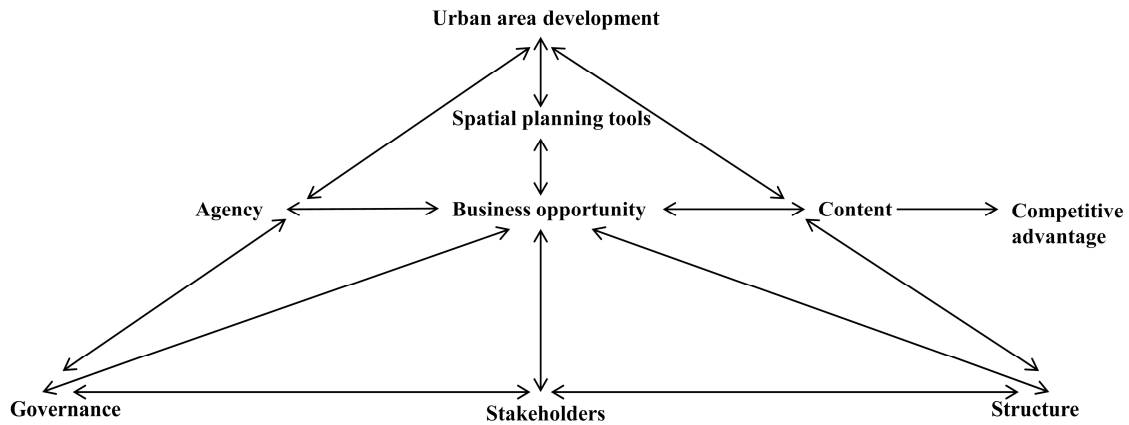


Figure 1: Ecosystemic business model approach in urban development.

In our model, a business opportunity is set as the focal sense—meaning—which affects directly all the other key factors. These are the subject, object, outcome, rules, community, division of labor, and tools included in the human activity system (Engeström 1987). Hereby the structure is transformed into a business model framework. As opposed to the human activity system just mentioned, we consider the urban area development as context to define business opportunities, and thus we add context on top of the model. We also regard spatial planning tools as mediating artefacts.

The model covers the opportunity, stakeholders, content, context, structure and governance of the ecosystem. Starting with agency, it can be seen as the subject of the ecosystem, holding a

portal to opportunities, or being responsible for facilitating the activities and interaction within the urban ecosystem. The other side of the coin, the stakeholders including government, industrial/business, academia and citizens form together with the city the community of the ecosystem. Second, the context of the ecosystem can be viewed from innovation perspective as renewal and new market creation can be seen as the key co-creation activities of the ecosystem players. The structure, i.e., the configuration of the ecosystem then defines and delimits the scale and scope, plus division of labour of the units involved. Third, the governance and mechanisms of control as rules relate to the openness of the ecosystem business model, varying from open source to proprietary. This can also be seen in the content of the ecosystem activities that form the basis for the value proposition as the object of the ecosystem as well as its competitive advantages as outcome.

In this paper, three urban area development cases in progress are noted as the hot spots (Gratton 2007) applying the ecosystemic business model approach for new market creation. These cases utilize different types of urban planning and development practices, and they are regarded as one of the most important strategic urban development projects (Salet & Gualini 2006, Oosterlynck et al. 2011) in their cities as they are set to integrate the aims of the local land-use planning, and business and industrial policy. The data concerning the cases was gathered through various forms of primary, participatory (Wallerstein & Duran 2003) data collection methods, e.g. following up the urban area development processes, participating in quadruple collaboration, workshops and meetings, as well as follow-up interviews with focal actors.

All the elements included in the ecosystemic business model framework were identified in the three urban area development cases, and depicted in Figures 2–4. Then, it was analyzed if any of the elements had risked the innovation ecosystems' openness and evolution, in search for new market creation.

4. Analysis

4.1 New market creation in urban area development

Cities may strive for new market creation by enabling the innovation ecosystem's evolution. Moore (1993) states that firms create a new business ecosystem based on four evolutionary stages: birth, expansion, leadership, and self-renewal. At birth, the ecosystem members go beyond just satisfying their immediate customers. At expansion, the scaling up potential of the business concept of an ecosystem is tested. At leadership, the business ecosystem reaches stability and profitability. Finally, rising new ecosystems results in self-renewal or death.

The following analysis on three urban area development cases in progress—the development of the Hiukkavaara Arctic smart city, urban regeneration of the Karjasilta school area in Oulu, and the future Vehkala business and enterprise area in Vantaa—show how urban planning and development practices relate to the innovation ecosystems' business model approach and the ecosystems' life cycle. To start with, INURDECO-SWC quadruple collaboration project aimed at creating the Hiukkavaara Arctic smart city innovation ecosystem (Figure 2), and a detailed

plan for Hiukkavaara center, energy efficient block concepts, plus an operational model for Hiukkavaara living laboratory including innovative real property conveyance for threshold projects testing energy-efficient solutions.

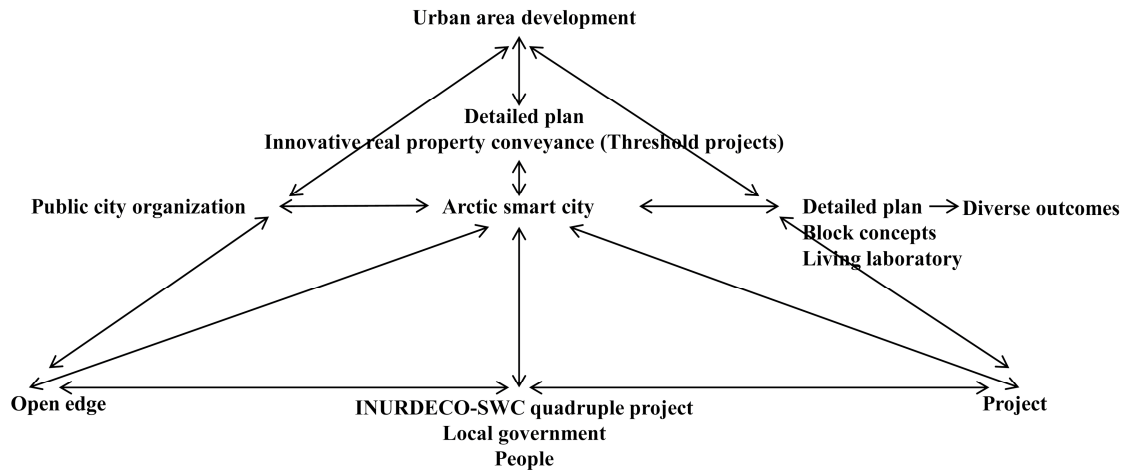


Figure 2: Ecosystemic business model approach in the Hiukkavaara Arctic smart city.

Ideally the ecosystem would have had a business model approach with an open source, in which the ecosystem jointly co-creates value for its customers (Casadesus-Masanell & Llanes 2011). In practice, it had open edge governance with detailed planning channeling the ecosystem's interaction process. However, with multiple content and diverse scales and scopes, the innovation ecosystem lost synergy, which derives from insufficiently identified business opportunities. In the end, the Arctic smart city living laboratory sustains a test-bed by a continuous innovative real property conveyance process, with motive for knowledge. For the capability for self-renewal of the ecosystem's remaining part, the ability to update the threshold project parameters is vital. As such, the life cycle of the innovation ecosystem in the Hiukkavaara Arctic smart city ceased along with the finalized detailed planning project.

Whereas in the Karjasilta school area regeneration related innovation ecosystem, the sight for the expansion stage was built-in the innovative real property conveyance practice. Here, the city sought for unforeseeable prospects including a business lab. In the lab, smart city modules meant for mass customization have been developed, which indicates a will for scaling up. However, in this business model approach (Figure 3) the innovation ecosystem risks sustainable competitive advantage with structure tailored for the current development and construction project, which forms the core for the developer-led ecosystem's governance.

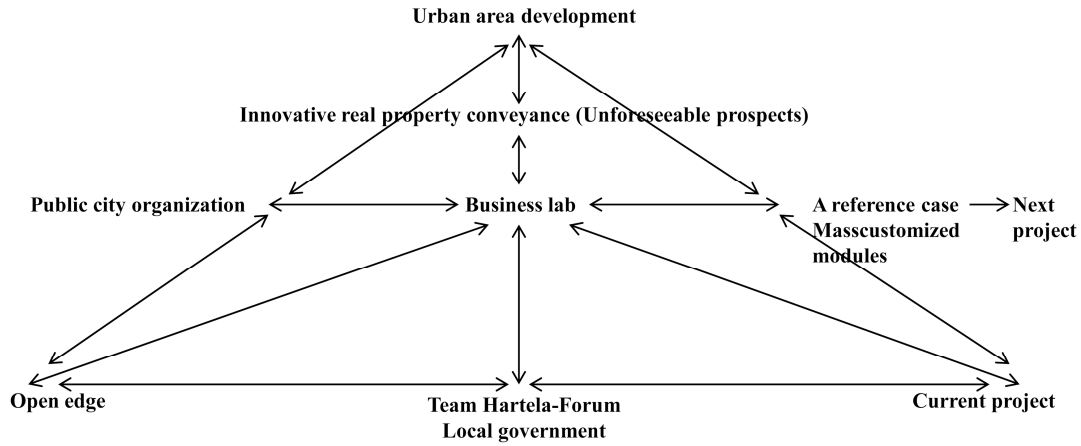


Figure 3: Ecosystemic business model approach in the Karjasilta school area regeneration.

The most future-oriented ecosystemic business model approach (Figure 4) can be found from the Vehkala business and enterprise area. Even though this is an ecosystemic business model approach with open edge, urban area profiling as the core—and mediating artefact—aims at creating a specialized, co-creating ecosystem permanently located in the Vehkala business and enterprise area. There will be a district with diverse stakeholders supporting the selected profile of the area. For its regional scale and scope, the ecosystemic business model approach will possibly be able to scale up to modify the local market. This ecosystemic business model approach will be challenged at the leadership stage, whether it can reach stability and profitability, and finally self-renewal.

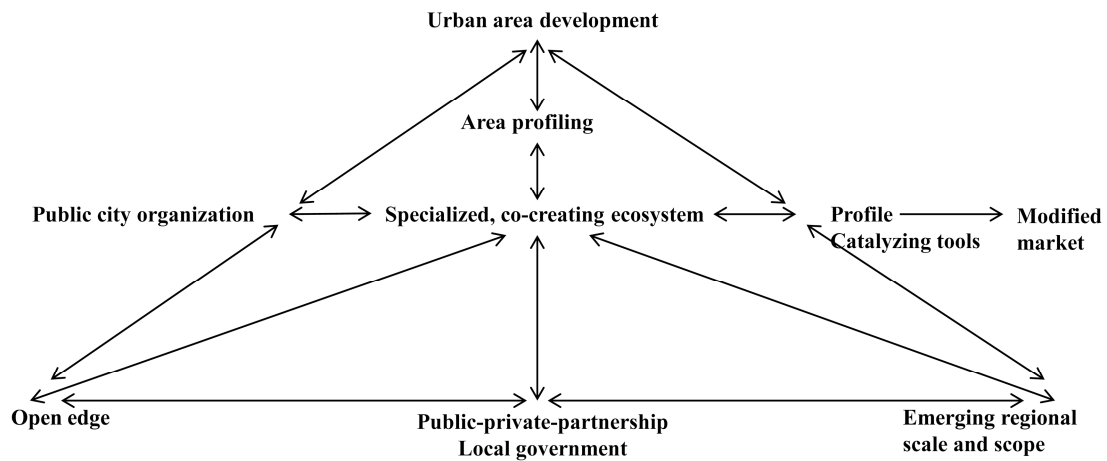


Figure 4: Ecosystemic business model approach in the Vehkala business and enterprise area.

5. Conclusions

We have studied in this article, how business model approach can be applied to analyze new market creation in urban area development. Our contribution is the suggested ecosystemic business model approach, and the analysis on how urban planning and development practices have embraced the ecosystemic business model approach and contributed to new market

creation. Hence, this study contributes to business model literature from ecosystem perspective, as well as to the procedural theory of spatial planning utilizing large-scale urban projects as open innovation platforms. We illustrated the applicability of the ecosystemic business model approach through three urban area development cases.

In the ecosystemic business model approach, the city may strive for new market creation by catalyzing ecosystems by offering them an urban area development platform, enabling the innovation ecosystem shift from an evolutionary stage to another, and allowing openness—the ecosystem’s natural logic of creating, sharing, delivering, and capturing value. Even though the analyzed ecosystemic business model approaches were with open edge, they had a core facilitated by the city organization. However, our analysis revealed that the nature of this core—a mediating artifact—is decisive in targeting the ecosystems’ expansion, leadership, and self-renewal. Here, for instance innovative real property conveyance and area profiling, with more open cores, serve emerging ecosystems better than detailed planning, a normative project.

The ecosystem also needs a clear focus on the opportunities at its birth stage. Possibilities for scaling up need to be similarly considered at the start for the pursuit of new opportunities. We argue that the key for successful exploration and exploitation of opportunities is to have a future-oriented perspective on the ecosystem’s life-cycle with a long-term aim. Our analysis shows that all the elements of the business model approach; agency, stakeholders, context, content, structure and governance, need to be continuously reflected during the ecosystem’s evolution in order to secure synergy. As the first two cases reveal, the lack of such perspective may result in the cease of the ecosystem’s sustainability and risk of its full potential in new market creation. We conclude that the ecosystemic business model approach in urban area development can contribute to new market creation, when there is a clearly defined opportunity and content. This secures the ecosystem’s evolutionary path and enables full potential for new market creation.

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A Technique for Developing Strategic Differentiation for Small Architectural Firms

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Abstract

Since the crash in 2007, the number of small architectural firms has risen dramatically as both recently graduated and recently laid off architects decide to go out on their own. In such a crowded market firms will need to find some way to distinguish themselves from their many competitors. Arguing from the Resource Based Strategy theory the authors assert that to be successful architectural firms must build and promote competences which are both scarce and in demand in order to compete successfully. This should especially be the case in a 'buyers' market'. Architect starting their own firms must provide something more than standard package of architectural services will not be enough to permit new firms to gain clients. A series of case studies was used to compare this theoretical proposition with the experience of recently established architectural firms (+5 years). The case studies gathered firm histories including the original goals of the principle architect(s), their entrance strategies and marketing approaches, their client list and portfolios of acquired and completed projects. This permitted a comparison to be made between the firm profile the architects originally desired to establish, and the profiles eventually realized. In particular, the perceived selling points which the principle architects believed would provide them with the ability to acquire projects with the services they eventually were able to sell. The case studies supported the assertion that a clear differentiation strategy is one means of successfully launching a firm and gaining a client base.

Keywords: Architectural Firm, Strategy, Differentiation, Competences

1. Introduction

This paper described the results of a preliminary study of the use of the Personal Construct Theory (PCT) and the Repertory Grid Technique (RGT) (Kelly, 1955) to elicit values which characterise a small architectural firm and can be used to guide a strategy of differentiation. The tool has two uses: as a research tool the Repertory Grid is intended as a standardised means of eliciting differentiating values from small firms and establishing a field of values within which small firms typically position themselves. Establishing this field of values would be helpful to principals of small firms in determining their own position, and to researchers in achieving a better understanding of the strategic context in which small architectural firms operate. The second use for the tool is as a consulting or diagnostic tool for individual small firms. The tool is intended not only to elicit characteristic values, but also to contrast the firm with its nearest competitors in terms of these values and thus enable a clearer differentiation of the firm.

2. Small fish in a big market

2.1 The problem facing the many small firms in a very competitive market

The architectural field is characterized by a very large number of very small firms chasing relatively few commissions. Ironically, the crash in 2007 has led to a significant increase in the number of these very small firms. Massive layoffs amounting to as much as 40% of the architectural workforce in countries such as the UK, and the Netherlands, although the impact of the global financial crises (GFC) was to a lesser impact in Australia the number of staff turnover increased considerably moving across practices or contractual amendments – ie. work-week of four days instead of five. In the Netherlands, for example, between layoffs and a pattern of continued newly minted architectural graduates has meant that for many architects the only way to practice has been to freelance or attempt to set up their own firm. This has resulted in a 9% increase in the number of boutique firms and a 47% increase in the number of freelancers between 2007 and 2014 (Consultancy.nl, 2014). All of these new firms fiercely compete with existing and well-established architectural firms for what until very recently has been in most countries a declining amount of architectural work on offer. To be successful in such a hostile market environment one might expect that a firm would need a carefully considered strategy – one in which the firm is carefully positioned in the market between potential clients and their competitors.

2.1.1 The Coxe strategy

What might be considered the standard approach to strategy for architectural firms was developed by the Coxe Group in the 1980s and focuses on conformance to six viable architectural firm types (Coxe, 1987). However, we would like to argue that this approach is no longer adequate to the needs of architectural firms (Heintz, 2012). While the Coxe Groups' fundamental point of knowing who and what a firm is, helps firms to structure themselves well and remains valid, the current situation calls for more. Specifically, the current situation calls for a method for architectural firms to differentiate themselves from their nearest competitor firms, normally firms of the same Coxe type.

The architectural market, especially at the small end, is an unusual market in the sense that there are comparatively many sellers and comparatively few buyers. Clients enjoy a relatively strong position in

the architectural market; there are always many architectural firms ready to compete for any commission offered. In terms of the types developed by the Coxe Group, the majority of an architectural firm's competition will be firms of the same type. The vast majority of small firms still offer a "wide range" of design services, claiming competence in all types of building and for all types of clients. These will most commonly be type C Strong Service business-centred-practices (Coxe, 1987). Hence, while the Coxe type strategy may be very helpful in ensuring that a firm is well structured, it is of little use in differentiating a firm from its nearest competitors. For that a firm needs to discover how it can stand out from those most similar to it.

Heintz & Aranda-Mena (2012) concluded in a previous paper (Montreal paper) that more appropriate methods should be used to investigate the topic of business strategies for architectural firms, especially those start-ups or in transition from small to medium or medium to large. Many of the practices would begin with a design agenda or design-oriented, growth and transition would require a business mindset. Moments of crises emerge when the core value systems might seem compromised by the principals. In other words, to trade the design or artistic values for commercial values, pride in architecture often emerges when a project is 'not compromised' when moving into the Resource Based View (RBV) or similar model. At the conclusion of their earlier paper the authors identified a lack of real-world and empirical evidence on the models of Business for architectural firms and concluding with their paper suggested a more psychological approach to the research in order to better understand the views and values held by a range of practices suggesting then reading on Personal Construct Psychology and the Repertory Grid Technique (Kelly, 1955).

2.1.2 The need for differentiation

The *Resource Based View* [RBV] of firm strategy may offer us a helpful lens through which to understand strategy in this more competitive environment. The principle conclusion of the RBV was that to be successful a firm had to find a unique resource or competence to which their competitors did not have access (Penrose, 1959; Barney, 2001). This unique potential was then the source of a competitive advantage.

Seen from this point of view, the general problem solving and design competences that form the core of architectural training and of traditional architectural practice are anything but scarce. Signature styles, or at least the ambition to display a signature style, are also relatively common. And to portray a specific 'signature' as a scarce resource seems a bit sycophantic.

2.2 What counts as a unique resource?

If RBV strategy relies on unique resources, what count as a resource for a small architectural firm? And are any of them unique? As architecture does not require a heavy investment in plant or costly materials, the resources in question are the firm's competences to deliver specific services to their clients. However, it is difficult to imagine a truly unique architectural competence, aside, that is from the architect's signature style, which is not relevant to the majority of clients. We therefore argue that strategy for small firms will be a matter of a scarce combination of scarce competences, rather than of truly unique competences. Architectural firms, small or large, must strive to identify one or more scarce competences to which they have access and build their firms around them.

Competition in architecture takes place on a project-by-project basis – in the selection processes of clients. While clients for large projects will often have relatively robust, transparent selection processes based on pre-established criteria, clients for smaller projects, and therefore smaller firms will have more improvised selection processes. For these clients the two most important selection factors will be price and ‘click’ – the feeling that they can work with this particular architect. Click is a mix of personality, values and interaction style. This will typically be assessed on the basis of a presentation based on the firm’s portfolio and how it proposes to carry out the design of the project. We therefore propose that the relevant competences are:

- Values
- Competencies required to realize values
- Portfolio as evidence of realized values.

The method we propose here will elicit the value system of the principals of firms interviewed. It is at the level of values that a firm can best determine its potential to differentiate itself from its competitors. Once the value system is determined, the firm can then perform an assessment of its competencies and determine which ones to foreground or to invest in developing further. Finally, the firm can determine how to present its portfolio to best exemplify its chosen values.

3. Personal Construct Psychology (PCP)

The overarching theoretical foundation of this paper and approach is that of Personal Construct Psychology (PCP) also known as Personal Construct Theory (PCT) first published by George Kelly in 1955. The theory has a strong psychological foundation but has also been applied in more pragmatic domains. The over all contribution of the paper is to validate RGT as a briefing method for unearthing of tacit knowledge by firm principals. Results overtime are to inform the authors on emerging business strategies applied by architectural firms, clients and designers. For this, the authors are into determining how well RPT - in conjunction with cluster analysis – is able to reveal:

- (1) Architects’ visions on attributes of practice differentiation and business development strategies.

Psychology aims to predict behaviour. Similar to other psychological theories PCP is founded on a set of assumptions about man and his relation to the world (Kelly 1955). In this way, through the PCP lens the authors draw on respondents experience to plan for their future. PCP only help to expose those plans or predictions and thus the researchers would have a possibility to provide guidance - and the respondent to see and compare their own practice over time.

This study embraces a pragmatic approach towards its validity in which at this point it only seeks to *make-sense* from the respondent view point, thus internally valid. That is, if the grids make sense to those involved in the study the model is internally valid. This is supported by the epistemological framework of Personal Construct Psychology (PCP) (Kelly, 1955). Kelly suggests, that the sorting scenarios proposed to the client are representative of those with which he must deal in structuring his life role. No such thing as general representativeness can be achieved in the same way that there is no general validity of a test. The problems of representativeness in constructs and element where measured in relation to each hypotheses or client under test (Kelly 1955).

PCP offers a framework for understanding human behaviour and decision-making. PCP works on the premise that people spend a lifetime testing personal predictions or hypotheses. In other words, every

person is viewed as a scientist who seeks to apply definitions, concepts and constructs (constructs as attributes attached to concepts) to each of his or her actions. By adopting such a view, PCP provides a framework where subjects think and reflect on their decision-making, attitudes, knowledge and as well as actions taken by individuals and collective groups. One of the research techniques to elicit such knowledge and information is the repertory grid technique RGT (Gaines, 1999).

3.1 The Repertory Grid Technique [RGT]

The repertory grid technique falls under the principles of Personal Construct Psychology. The technique has been applied on a wide range of fields spanning from psychology to management. To begin an RGT session on a particular topic the client (or interviewee) and the researcher (in this case software designer) begins with discussions around given scenarios known as '*elements*'. Such elements could also be situations, people, objects or any chosen scenario under investigation and in the case of this paper they may refer to different software applications that planners are asked to consider. As part of such discussions, the technique requires the client to compare elements thus generating a list of *bi-polar* attributes or *constructs*.

RGT requires respondents to compare and contrast a number of elements, objects or scenarios. For instance, the focus of a grid session could be on the assessment of the interface of a number of planning software applications. This will require comparing and contrasting across all ten elements such as software tools - organised in pairs or triads - thus generating *distinctions* also known as *bi-polar constructs*. When the approach is by triads, this comparison takes place by randomly bringing up three scenarios at a time. Then each respondent needs to identify an aspect that is similar to two scenarios and which makes a difference to a third thus generating grids with elements and bi-polar constructs. Grids are generated implying conscious reflections. Grid validation takes place by individual respondents who follow up discussions, thus respondents have the choice to change the grid. A more detailed account of how constructs are elicited will be presented in the next section of this paper.

3.2 Applying RGT to differentiation of architectural firms

In the context of business strategies for design firms, the application of RGT would involve subjects considering subsets of *competing design firms* as *elements* with the purpose of generating a number of constructs and rating them. The first step is to select a number of architectural firms from the environment of the interviewee. Each participant was asked identify 9 architectural firms which exemplified a set of roles and which served in some way as an example to them. Originally, the authors chose a series of roles which were defined in terms of the characteristics of the firms to be named, however during the interviews it emerged that the interviewees were more able to think of relevant firms when triggered to think of firms in terms of their meaning to the interviewee. In all cases the final two firms were the interviewees own practice as it was then, and as the interviewee would ideally see it develop.

Table 1: Original and Emergent Reference Firm Roles

<i>Original</i>	<i>Emergent</i>
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1	<i>Traditional architecture practice</i>	1	<i>Former Employer</i>
2	<i>Alternative architecture practice</i>	2	<i>Mentor</i>
3	<i>Avant-gard practice</i>	3	<i>Ideal Model (Firms which the subject would like to imitate)</i>
4	<i>Small start-up</i>	4	<i>Negative Model (Firms which the subject would definitely not like to imitate)</i>
5	<i>Small established</i>	5	<i>Competitor</i>
6	<i>Design driven practice</i>	6	<i>Ally</i>
7	<i>Process driven practice</i>	7	
8	<i>My own practice</i>	8	<i>Subject's own practice</i>
9	<i>My ideal practice</i>	9	<i>Subject's ideal practice</i>

The way the interviews were structured was by organizing triads, consisting of three of the element architectural firms, and asking the respondent to identify a commonality amongst two practices which makes a difference to the third. For instance, if the triad consisted of elements 1, 4, & 6 (traditional, small start-up, design driven firms). The respondents might then group 1 and 6 together and differentiates them to 4 yielding the construct *Experience*, and the contrast *Lack of negotiation skills*. This means that for the respondents a traditional practice and even a design driven practice are better fit to negotiate with clients. This implies that a small start-up is less prepare with such an important business skill.

The process is repeated with as many practice combinations as felt exhaustive to cover the topic and subtopics of the paper. This could be developed over on-off session or over a number of sessions.

4. Interviews

The study consists of a series of 5 interviews (4 in the Netherlands, and 1 in Switzerland) of principals of small architectural firms using the PCT/RGT technique. The Interviews were conducted according to the protocol described below. Each interview resulted in a completed Repertory Grid comprising of between 7 and 10 constructs consisting of values and their contrasting 'opposite'. These in turn provide a characterisation of each firm individually, and of the strategic context collectively which will be presented in a follow up paper to this one.

4.1 Firms Interviewed

This section reports on emerging constructs on five interviews as a scoping qualitative study.

4.1.1 Frim PN1 A&R10

In going so far as to include the word 'renovation' in the name of the firm the owner-architect signals to potential clients that their problem is not a second choice selection for the firm – not a poor substitute for a new building. By focusing the practice on renovation, the firm has been able to assemble

experience in the problems specific to the renovation and repurposing (transformation) of older buildings. The firm supplies advice during the initiative phase, including assistance in obtaining renovation subsidies for listed buildings. The owner-architect started the firm on a part time bases, and have been working fulltime for 3 years by the time of the interview. The firm had 3 contract workers in addition to the principal.

4.1.2 Firm PN2 (Urbmath)

The sole owner-architect started Firm N1 immediately upon graduation from architectural school. Indeed the firm's approach is directly taken from the architect's graduation project – a center for Rotterdam Contemporary Youth Culture. What sets Firm N1 apart from other young architectural firms is the architect's personal interest and facility in what he calls Youth Culture. In essence the architect is hip. He is a figure in the Rotterdam hip-hop scene, and is accepted as a credible speaker for youth culture by the municipality and by private clients. The firm was 3 years old at the time of the interview, and had grown to 5 contract workers.

4.1.3 Firm PN3 (ORGA Architect)

PN3 is specialized in sustainability, specifically “Bio-based Building”, and is active in research into bio-based architectural materials as well as design of sustainable buildings. In addition the firm has a strategic partnership with a small contracting firm, also specialised in bio-based building. The firm has received media attention, and the principal has received an award for entrepreneurship and achievement. The firm was 6 years old, and had 4 fulltime employees in addition to the principal.

4.1.4 Firm PN4 (SJO Architecten)

The 2 principals of SJO Architecten took over the firm on the retirement of their previous employers. The succession had been carefully structured by the previous employers, who hoped to leave a legacy and an imprint on the firm. The firm had changed its name less than a year before the interview. The firm had been healthy up to the crisis in 2008, and had continued with reduced staff since then.

4.1.5 Firm PS1 (OOS Architektur)

Firm motto/slogan: **Design is our passion**

PS1 is an architectural firm based in Zurich which was founded in Zurich in 2000 by the four architect-principals. In recent years it has grown into a larger commercial firm with corporate clients operating in Zurich and neighbouring areas. Besides office facilities, other projects also include housing projects and converting old factories into social-housing systems in the townships of Aathal, Flums and Schönaunear Zurich. The factory conversions has become one of their trademarks their own office being in an old factory in Zurich's industrial suburb Haltestelle.

“We create space in all scales, and design it comprehensively. Our team is made up of specialists in architecture, interior design, urban planning, spatial development, scenography and branding. They transform the requirements, subjects and values of users and clients into a customized spatial environment. In addition to our wide experience, we continually observe new trends and developments

and ensure that the knowledge gained flows into the projects. A trans-disciplinary approach and holistic methods characterize the development process and the results of our work.”

The practice was 13 years old at time of interview and had approximately 20 employees and two principals, both interviewed.

4.2 Interview Results

The method generated both a wide spectrum of constructs, and therefore of values, reflecting the variety of firms interviewed. Yet it was also possible to group the constructs in clear clusters around three themes: Design & Ideology, Process, and Business. The Design cluster was the least surprising. Architects traditionally attempt to distinguish themselves through their portfolio and signature or style. However, we saw some constructs, such as the Flexible-Specific construct that contrasted sharply with the traditional architectural interest in specificity and idiosyncrasy. The Process cluster contained constructs that were both internally focussed and externally focussed.

Table 2: Clustering of constructs, clusters, subclusters and example constructs

<i>Cluster</i>	<i>Subcluster</i>	<i>Construct</i>	<i>Contrast</i>
<i>Design & Ideology</i>	<i>Design</i>	<i>Elegant Design</i>	<i>Mediocre Design</i>
		<i>Flexible, Impersonal</i>	<i>Specific, Personal</i>
	<i>Ideology</i>	<i>Official Culture</i>	<i>Subculture</i>
		<i>Design Driven</i>	<i>Social Impact Driven</i>
<i>Process</i>	<i>Process</i>	<i>Joy/Fun</i>	<i>Professional/Corporate</i>
		<i>Openness to share knowledge</i>	<i>Won't share knowledge</i>
<i>Business</i>	<i>Internationalisation</i>	<i>Swiss Market</i>	<i>International market</i>
	<i>Specialisation</i>	<i>(Social) Housing</i>	<i>Divers portfolio</i>
		<i>Sustainability</i>	<i>General Services</i>
	<i>Services</i>	<i>Architect</i>	<i>Architect Developer</i>
	<i>Size</i>	<i>Big projects</i>	<i>Only small projects</i>
	<i>Marketing</i>	<i>Waits for work to come in</i>	<i>Creates work</i>
	<i>Business</i>	<i>Business as usual</i>	<i>Business innovation</i>
		<i>Want to make money</i>	<i>Careless of money</i>

The process cluster is a combination of current and desirable attributes to the practice - inwards to the firm. Theses align with the practice culture and also technical skills such as ability to share knowledge and problem solving.

The business cluster is outwards to the firm - with constructs such as business growth, national or international expansion, business size, client base and marketing strategies just to mention some.

The overall appraisal is been a positive one in the sense that grid process and results gives instant feedback articulated by the interviewer. In this way, participant and researcher can discuss results and modify them if necessarily. Amongst the graphics for date analyses are: structured repertory grids, cluster analysis, dendograms, principal component analysis and socio maps which are beyond the scope of this paper but previously studied in depth by one of the authors over a PhD investigation (Aranda-Mena, 2003). Grid analytical work will follow up to this paper.

4.3 Feedback on the tool

The authors have asked two of the respondents to provide some comments or feedback on actual Repertory Grid Technique. Here below some of the feedback. In general the interviewees responded positively, e.g. “Extremely Interesting” -- PN4.

4.3.1 Feedback from PN4

“Extremely interesting.”

Thinking about help to the specifics of the firm.

“This is very nice because then you start to think of how you want to position yourself.”

Forced choice is what makes you start thinking.

Each different set requires that you make a switch, either positive or negative.

4.3.2 Feedback from OOS

The Repertory Grid Technique was perceived as good and effective method but it was pointed out that in order to drilldown into more understanding of differentiation across the element organisations more information from the competitors would be required other than the more superficial perception. Follow up *zoom-in* sessions would be required.

Perhaps a follow up session purely focused on internal resources including human resources, skills and assets. It will be then easier to also compare with competitors. This was referred as a *360° degree pan-view*.

Other topics such as organizational maturity were discusses. Especially in relation to architecture which tends to be a “highly-controlled” culture where principal architects tend to keep the knowledge to themselves and run their studios on a top-down approach. Swiss example of Peter Zumthor, Mario Bota came to the discussion as highly personalized practices which must likely will die when their funding members are gone.

A world-view that still prevails in architecture culture is that of the architect at the top of the pyramid above investors and above society. In the view of the interviewees *design* is a core business attribute which has to be a must but from there a number of skills and competencies have to be develop.

The triad technique works well however, the perception is that the discussion is too superficial as the tendency is to generate an *outside-view* instead of “drilling-into”.

A recommendation (for the follow up interview) is to have/provide more information (or allow time to research) the particular elements (architecture practices) in order to have a more informed/factual discussion.

The two respondents much liked the triad interviewing technique and are looking forward to follow up discussions and engagement with our research paper/topic of much value to them!

5. Discussion

Past present and future.

Many of the constructs generated are similar to the questions the Coxe group used in their typological approach. On the one hand this suggests that few new values were disclosed. On the other hand it does make it possible to cycle between discussions of typological consistency and points of differentiation within the type.

However, the results do suggest that where the Coxe typologies suggest that few Strong Idea firms would have an interest in profitability, this may no longer be true. Indeed, the firms interviewed, although generally successful, did not fit easily into the Coxe typologies, particularly the distinction between practice-centred-business and business-centred-practice.

Developing tactics, bottom up.

During the interviews a more interviewee centred approach, e.g. the emergent elements, was found to elicit more productive conversation around the constructs. This sets the goals of research and consulting against each other, as mapping the range of strategic values would require using a consistent set of elements and constructs in order to build up a body of data that could be analysed with the statistical tools from the RGT.

The brevity of interviews, and the dependency on perceptions of the element firms, means that the interviews are limited to an exploration of values. The element firms serve as devices with which to prod the interviewees to reveal their values. The results, therefore, are not a complete analysis of capabilities of the interviewee's and element firms, but rather an analysis of the values by which the interviewee would like to differentiate their firm from the element firms. Further work would be required to determine the degree to which the interviewee's firm possessed the desired capabilities or needed to invest in developing them.

All of the firms interviewed expressed a clear desire to distinguish themselves from what they saw as the way the previous generation did business. Whether it was in terms of authenticity, design innovation and research, corporatism or business innovation. Interestingly, while there was a clear interest expressed by all the firms interviewed in profitability, most also wanted to contrast themselves from what they perceived as the conservative ‘corporate’ firms which are normally associated with profitability.

Customer orientation. [Actually, the strategy of differentiation of firms implies a similar differentiation of clients. The scarce competences will not be of interest to every client; otherwise they would not be scarce.]

6. Conclusions

On the validity of the current data collected the authors maintain that the paper is of qualitative nature and no further validation other than that of the respondents is required. In other words, internal and not external validity is expected at this point. However, it is envisioned that over a series of interviews eliciting constructs and elements will sum up of statistical analysis with external validity (Wright, 2006). At this point the authors are expecting to provide generic templates to assist industry with various entry points into PCT based mentorship sessions.

Results at this stage indicate wide range of emerging constructs, which have been categorised into a more specific number of clusters. A hierarchy of clusters are discussed such as (1) Design Oriented, (2) Ideology, (3) Process and (4) Business are amongst the most crucial discussion themes.

To conclude, this paper is argumentative in nature and as the abstract and introduction states, it aims to position the Repertory Grid Technique as a method to assist architectural firms with their growth. The RGT has proven to be a flexible, engaging methods that begins from the view-point of the respondents and not from a more traditional prescriptive approach such as the earlier investigated and tested techniques such as the RBV.

One aspect of RGT which could be better addressed in future sessions include *timing* control as it is easy to branch into a number of internal and external issues to the practice with some of the interviews taking 90 minutes or in the Zurich case over several sessions. It would be interesting to limit the agenda to more specific topics for discussion with the view to revisit the interviewee and expand from particular points. The other side to timing is that of discussing experiences or aspects to the practice in past, present or even future. The timing in this sense provides a way to compare a point of reference within the same practice as it grows, shrinks or experiences transitions points from stability to crisis and bouncing back (or not) to stability. This aspect of timing can be better managed during the interviews in order to encourage “reflections” and provide a retrospective history to particular clients or firms.

The final argument is that of the utilised terminology via the RGT for eliciting the constructs and thus developing the grids. RGT would provide a number of predefined elements, however the authors found that different respondents react differently to the same set of elements and in some cases better words would suit those same elements – ie. same meaning under different words and in other cases even cultural or language adaptation. This is an interesting development as the interviews took place across three different countries and although in English, the connotations of the elements and in some cases the actual literal translation into Dutch or German would provide a different meaning, in such cases, the element name would be refined to suit the client or respondent and not the interviewer. In this case the authors expect to see overtime a number of similar elements or constructs under different names or labels and possibly moving across different languages too.

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Enhancing Competitiveness of Construction Project Risk Management through Benchmarking of the IT Industry: Organizational Attitudes, Barriers and Solutions

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Abstract

Projects in the construction industry are accompanied by unique unforeseen threats to overall project goals and risk management (RM) reduces the detrimental effects to the project. However, risk provides a platform for opportunities if properly managed. Contrary to the slow pace of adoption in the construction sector of Singapore, the IT industry possesses a long history of properly managing risk. RM measure are redefined and improved by the IT industry from past projects failures. The demand for productivity gains, skill upgrade and sustainability drives a consistent investment of above S\$250 million by the Singapore government in the construction sector. It is therefore imperative to tackle the challenges facing the industry to enhance its long-term competitive edge and business sustainability. Hence, this paper seeks to: (1) to explore and understand the construction and IT industries' acceptance of RM and; (2) to recommend practices that could be adopted by the construction industry from the IT industry in order to increase implementation levels of RM. Attitudinal inclination towards RM was collected via questionnaire from IT and construction companies. The data was analysed using mean score ranking and examined with T-test for statistical significance differences among the different sectors. The results revealed that the barriers reported by the construction industry were significantly different from those experienced by the IT industry. Furthermore, the results established that IT industry practitioners tend to be risk takers who desire training in RM skills while construction industry practitioners tended to be risk avoiders who resisted the changes required to implement RM. Similarly, when compared to the IT industry, the construction industry respondents lack adequate understanding of RM benefits. The study concludes with recommendations for the construction industry to increase its awareness of the benefits of RM and provides recommendations to increase its implementation.

Keywords: Construction Industry, Information Technology, Risk Management, Singapore.

1. Introduction

In the construction industry, identification and analysis choice of risk is opined to improve business risk (Rostami et al., 2015). Failure to adequately envisage unforeseen risk is detrimental to any project. Where RM failure occurs, key stakeholders lay the root causes on implementation rather than on RM core principles (Gendron et al., 2015). The ability to assess and overcome risk provides fertile grounds for project investment growth (Yafai, et al., 2014). Singapore development ideals towards an advanced economy targets superior skills with the construction industry as a key sector. The sustainable growth to provide housing and infrastructure for the growing population requires a long-term strategic outlook. RM is a critical tool for managing projects and failure to manage risks leads to project failure. Construction project involves a large number of players. The Information Technology (IT) and the construction industries came into prominence under the initiatives of the Singapore Government to automate many work functions. IT industry records a long standing history in implementing project management (PM) (Larssen, 2006). Implementation of project and RM arose as a result of the industry's reputation for its many earlier failures. Because so many IT projects have failed, substantial research were conducted to improve their likelihood of success through the implementation of RM. Due to early developments and awareness, the industry has since enjoyed a higher success rate, decreasing overruns on budget and schedules (The Standish Group 1995). RM standards are devoid of basic principles in applying RM in Small and Medium Scale Enterprises (Rostami et al., 2015). Similarly, the anathematised state of RM use in small projects presents a negative trend to the ideals of total RM (Hwang et al., 2014). Oman construction industry places majority risk factors in government category (Yafai, et al., 2014). Companies that hire construction services on a recurring tenure systematically avoid applying RM procedures in projects (Serpella et al., 2014). The construction industry has a very poor reputation for managing risks with projects failure deadlines and cost (Mills, 2001). The construction industry is devoid of a good track record of coping with risks with poor reputations for dealing with risks that produce cost and schedule overruns (Smith et al., 2006; Azhar et al., 2008). In order to distinguish existing deficiencies in the implementation of RM in the construction industry, it would be prudent to perform comparative case studies with the IT industry. This process should stimulate the construction industry to recognize the importance of RM and to improve their capabilities to manage risks, ultimately helping to deliver more successful projects. Therefore, this study seeks to: (1) to identify organizational attitudes towards RM; (2) to recommend RM best practices in the construction industry.

2. Risk Management, Information Technology and Construction Review

2.1 Risk Management

Uncertainties provide a bedrock for discomfort to stakeholders in any project (Olsson, 2007; Serpell et al., 2014). Although inherent in this discomfort lies significant opportunities worth embarking on (Hillson, 2011; Serpell et al., 2014). Risk is defined as the possible occurrence of a detrimental event to a project (Hillson, 2011; Serpell et al., 2014). International Organization

for Standardization (2009) defines risk as a combination of the probability of the occurrence of a defined hazard and magnitude of consequences of the occurrence. Project Management Institute (2004) defines risk as an uncertain event or condition that, if it occurs, has a positive or a negative effect on project objective. Most concentration of project managers are directed towards the negative side (Hillson, 2011; Serpell et al., 2014). Hence, identifying, adequate examination and methodological application to risk reduction is key to any project (Tohidi, 2011; Serpell et al., 2014). RM process involves risk planning, identification, assessment, analysis, response, monitoring and recording and management process (ISO, 2009; Serpell et al., 2014). Risk identification and analysis are the most crucial elements in the process of RM (Mills, 2001; Hwang, Chua, 2011; Hwang et al. 2012). Ebrahimnejad et al. (2009) importance of risk identification are: (1) to avert possible events; and (2) relative importance on risks. Lyons and Skitmore (2004) and Hlaing et al. (2008) identified common risk identification techniques. The essence of risk analysis is to quantify the effects of major risks that are identified (Mills 2001). Hayes et al. (1986) stated that project risk analysis is often subjective affecting prospective benefits of RM from being realized. Effective risk analyses require a neutral and unbiased approach, though that is understandably difficult due to the potential for conflicts of interest. Techniques for risk analysis includes direct judgement, expert systems, code optimization, sensitivity analysis, probabilistic analysis, Monte Carlo simulation, kinetic tree analysis, expected monetary value, risk adjusted discount rate, and risk premium (Ahmed and Azhar, 2004; Lyons and Skitmore, 2004; Mills, 2001). RM is viewed from a negative domain rather than a neutral domain from the construction professionals' perspective in Indonesia (Hartono et al., 2014). Mills (2001) summarized that: (1) a cost-benefit assessment; (2) the removal of unnecessary contingency; (3) the clear recognition and acceptance of risk and; (4) realistic cost estimating.

2.2 Information Technology (IT) Industry and Risk Management

The evolving IT spheres provides several platforms for risk assessment. IT businesses provide project solutions that deliver new functionality for existing systems as well as create new systems for processing, storing and manipulating confidential data. To deliver products on time and at minimal cost, players in the industry have to be concerned with systematic invention, production and maintenance. Controlling and managing risks in this industry does not end with the completion of projects. RM to the IT environment is an essential management responsibility rather than a technical function carried out by the IT experts who create, operate and manage the IT system (IT Governance Institute, 2005). The Standish Group (1995) stated that formal managerial processes should be applied to the IT industry because when IT projects fail, it is usually due to the lack of management rather than technical mistakes. This aspect has triggered debates over the importance of RM in the IT industry (Mcmanus 2004). Taylor (2004) and Schwalbe (2009) stated that IT projects are usually linked to business processes and organizational systems that often involve a complex hierarchy of a large number of stakeholders. IT project managers tend to address RM as a standalone process and feed the results into their company integrated project management system (Marks, 2011). Many IT firms use integrated systems in order to balance the operational and economic cost of protective

measures. IT professionals are trained and educated in terms of skills, tools, software, and technical and managerial techniques that can be used for RM.

2.3 Construction Industry and Risk Management

The construction industry is characterised by large-scale, complex assembly of components on-site, often requiring significant coordination of project team members (Geddes 1996). Construction firms make business decisions relying more on intuition, personal judgment, and experience than from formal and systematic processes. The deficiency of RM implementation in Singapore construction industry is due to the lack of familiarity with techniques, concepts and methods of RM (Taroun & Yang, 2011). Construction professionals' possess natural inertia to adopt new systems of procedures which are not familiar to them (Enegbuma et al., 2014). Taylor (2004) and Han et al. (2006) proposed the use of intelligent RM system in the industry. Akintoye and MacLeod (1997) regarded cultural issues as one of the major barriers to RM adoption with negative attitudes and mistrust towards risk analysis. Akintoye and MacLeod (1997) summarized the causes as: (1) lack of expertise in the techniques; (2) lack of information and knowledge; (3) time constraints; (4) doubts on applicability; (5) reliance on experience; (6) doubts of its benefits; and (7) lack of client commitment. In risk mapping for cost estimation, ontology approach examines potential risk paths to project perceived future cost overruns for international projects (Yildiz et al., 2014). Knowledge based approach by learning from previous risk experienced from successive projects have been identified as a means to counter future risk (Serpell et al., 2014). Risk sharing between owners and contractors can be modelled by integration of fuzzy logic into systems dynamic modelling structure (Nasirzadeh et al., 2014). RM can be monitored and analysed using a risk evaluation system built on the maturity levels (Serpell et al., 2015). RM technique are not applicable for use in all project situations (Forbes et al., 2008; Serpell et al., 2014). RM and risk identification is better handled through continuous learning process by contractual parties to a project (Perera et al., 2009; Serpell et al., 2014). RM improvements to meet client quality, cost and time needs for small sized projects in Singapore are prominently affected by lack of time, budget and profit margins (Hwang et al., 2014). Lack of managerial skill and underlying knowledge in choice of RM tool presents a challenging factors for SMEs (Rostami et al., 2015). Low level of enterprise RM (ERM) maturity exists among firms in Singapore (Zhao et al., 2014a). Insufficient resources characterised by lack of time, money and people were most critical (Zhao et al., 2014b).

3. Research Methodology

To accomplish the research aim of exploring and understanding the construction and IT industries' acceptance of RM and recommending practices that could be adopted by the construction industry, an extensive literature review was carried out to gain insight into the existing research on RM in both IT and construction sectors. The research instrument for comparison of both the IT and construction sector was developed via a questionnaire (Creswell, 2014). The questionnaires consisted of three sections namely: profile of respondents, RM implementation and suggestions to improve risk implementation. The sampling were randomly carried out for both IT and construction sectors derived from two sources. IT sample

respondents were derived from the database of National Computer System (NCS) and Inland Revenue Authority of Singapore (IRAS) while construction was derived from the Contractor registry of Building Construction Authority (BCA). Each respondent was required to be assigned based on adequate knowledge and experience in the RM implementation processes in the firms. The responses were ranked using a five-point Likert scale from 1-Strongly Disagree to 5-Strongly Agree and analysed using mean score approach (Zhao et al., 2014a). The means score results was compared using a two-sample t-test to examine the statistical difference among the two sample respondents.

4. Data Analysis and Discussions

4.1 Information Technology and Construction Industry Demographics

The IT industry responses were 43 completed questionnaires. The work type in Table 1 revealed that PM and project managers made up for 72%. This points to the ability of the IT firms to competently carry out PM which forms the basis for this comparison. The number of employees showed that 93% of the sampled firms possessed over 500 staff strength. The larger the staff strength denotes adequacy in manpower and training in RM within the IT firms. The skill set and manpower is further enhanced by the interaction of the personnel with 70% clientele from both domestic and international. The years of experience in redefining and improving RM techniques is reflected by majority of 28% possessing 5-10 years. The high number of PM certification suggests that continuous professional development is encouraged within this sector.

Table1: Demographics of Respondents

		IT			Construction		
			<i>N</i>	<i>%</i>		<i>N</i>	<i>%</i>
Characteristics Company	Work Type	<i>PM</i>	31	72%	<i>PM</i>	13	40%
		<i>Development</i>	5	12%	<i>Development</i>	9	28%
		<i>Design</i>	7	16%	<i>Contractor</i>	6	19%
					<i>Sub-contractor</i>	4	13%
	Number of Employees	<i>350 - 500</i>	3	7%	<i>< 50</i>	9	28%
		<i>> 500</i>	40	93%	<i>50 - 150</i>	19	59%
					<i>151 - 250</i>	4	13%
	Client Type	<i>Domestic</i>	13	30%	<i>Domestic</i>	29	91%
		<i>International</i>	0	0%	<i>International</i>	0	0%
		<i>Both</i>	30	70%	<i>Both</i>	3	9%
Respondent	Job Title	<i>Project Manager</i>	31	72%	<i>Consultant</i>	3	9%
		<i>Developer</i>	5	12%	<i>Risk Manager</i>	4	13%
		<i>Designer</i>	7	16%	<i>Project Manager</i>	11	34%
					<i>Quantity Surveyor</i>	7	22%
	Years of Experience				<i>Architect</i>	7	22%
		<i>< 5</i>	10	23%	<i>< 5</i>	3	9%
		<i>5 - 10</i>	12	28%	<i>5 - 10</i>	15	47%
		<i>11 - 15</i>	10	23%	<i>11 - 15</i>	9	28%
		<i>> 15</i>	11	26%	<i>> 15</i>	5	16%
	PM Certification	<i>PMI</i>	27	62%	<i>PMI</i>	0	0%
		<i>Others</i>	8	19%	<i>Others</i>	2	6%
		<i>No</i>	8	19%	<i>No</i>	30	94%

On the contrast, the respondents from the construction industry revealed a 40% involvement in PM. This forms a wide difference of 32% when compared to the IT industry. Other work types

were developers, contractors and subcontractors. 60% of the firms were relatively small with staff strength of 50-150. Small companies might be limited in their ability to implement comprehensive RM systems due to the lack of financial capabilities and expertise. A total of 75% of the respondents have experience of between 5-15 years while 10% of them had less than 5 years of experience in the industry. In contrast to the IT industry, 94% of the construction respondents declared that they did not possess any PM-related certification whereas only 19% from IT had no such certification. This may imply that the respondents from the construction industry have not received formal training in management, possibly in preference to enhancing technical skills and knowledge.

4.2 Organizational Attitudes towards Risk Management

Subsequently, the respondents were asked about their companies towards risks that they faced in their business operations, processes and activities. An attempt was then made to assess their firm's attitude towards risks by asking if management could be regarded as risk takers, risk avoiders, or neutral to risk. Table 2 revealed that 67% respondents considered their firms to be risk takers. Those who identified their firms as risk takers were asked about the reason for their selection, most reported that because their organization had established organizational RM policies and processes, their firms were not afraid to take on risky projects. Majority of the IT firms reported that they had been implementing RM for a relatively long span of time (72% for greater than 5 years). Because the practice is well-established, it is likely one of the reasons that the firms were proactive on taking risks.

Table 2: Risk Management in Organisations

Organizational Attitudes Towards Risk Management (RM)		IT		Construction	
		N	%	N	%
Risk Attitude	Risk Taker	29	67%	9	28%
	Risk Avoider	8	19%	14	44%
	Neutral	6	14%	9	28%
Years of RM	< 1	0	0%	6	19%
	1 - 2	0	0%	24	75%
	3 - 5	12	28%	1	3%
	> 5	31	72%	0	0%
RM Implementation	Not at all	2	5%	21	66%
	All Projects	27	63%	1	3%
	Some Projects	14	33%	10	31%
RM Beneficial?	1 (Strongly Disagree)	0	0%	0	0%
	2 (Disagree)	6	14%	1	3%
	3 (Neutral)	5	12%	28	88%
	4 (Agree)	16	37%	3	9%
	5 (Strongly Agree)	16	37%	0	0%
Benefits of RM	Time Saving	10	23%	14	44%
	Cost Control	10	23%	14	44%
	Strategic Planning	3	7%	0	0%
	Increase of Stakeholders' Value	0	0%	1	3%
	Increase of Understanding of Risk	7	16%	0	0%
	Achievement of Project Goals	0	0%	1	3%
	Minimal Disruptions	5	12%	1	3%
	Utilization of Resources	8	19%	1	3%

Furthermore, as shown in Table 2, 63% of the IT firms stated that they implemented RM on all of their projects. Of course, for a firm that considers itself a risk taker, implementation of RM

would be a logical “must” on most of their projects. 74% of the respondents choose high ranks, indicating that the implementation of RM was perceived as beneficial to their firms. The survey questionnaire listed possible benefits that can be gained through RM implementation. Most respondents reported that time saving (23%) were the main benefits yielded by RM. Efficient RM allows organizations to develop contingency and mitigation plans that help them to manage potential risks and activate plans to address risks quickly when they occur. The regular review of contingency plans to monitor and control risks allows project managers to better predict cash flow and available budget for work to be completed. RM implementation prevents cost and time overruns and support more efficient utilization of available resources. Implementation of RM can be challenging due to various reasons. On the contract, Table 2 also shows that 28% of the respondents regarded their firms as neutral to risk and 44% reported being risk avoiders. It is noteworthy that respondents from development and contractor firms who encounter uncertainties in projects conform to a passive attitude of risk. However, this result may correspond with the research conducted by Smith et al. (2006), indicating that the lack of RM has persisted in the construction industry even though this industry is bound by a high degree of risk from complicated activities. In fact, 94% of the construction industry respondents reported that they had less than 3 years of experience implementing RM. The degree of implementation of RM is relatively low when compared to the IT industry with a total of 66% reporting that their firms did not implement RM at all on their projects. Although 31% of the firms indicated that they practiced RM on some of their projects, and 3% did so on all their projects, the benefits from RM implementation are apparently not well recognized. The majority, 88% were neutral about its benefits and 3% disagreed that there were benefits. Nonetheless, the survey respondents did indicate that proper implementation of RM may produce better identification and management of risks that affect cost and schedule performance (time saving–44%; better cost control–44%). The inference thus presents a scenario where firms from the construction industry are doubtful about the benefits of RM which invariably hinders implementation.

4.3 Barriers of Risk Management Implementation

Table 3 interestingly shows that more than 90% of the respondents believed that the benefits of RM were neither properly captured nor recognized by their companies (Lack of Belief in Benefits: $M=4.09$; one sample T-test $P\text{-value}=0.00$). On the other hand, none of the other barriers generated were identified as significant obstacles in their firms. The findings suggest that if an IT firm does not implement RM, it is more likely due to the lack of recognition of the benefits of RM rather than limitations of time and budget or resources such as tools and trained project managers and employees. This result may imply that most IT firms have policies, systems, and processes for RM, and their employees have been educated and trained in the area of RM. On the contrast, construction industry respondents believed that insufficient budget was one of the major obstacles hindering implementation of RM in their organizations ($M=3.94$; $P=0.00$). This may not be a surprise as the respondents originated from relatively small to medium-sized companies with limited financial capabilities for investment, development and implementation of RM. Furthermore, 78% of the respondents agreed that untrained staff ($M=3.63$; $P=0.00$) and project managers ($M=3.56$; $P=0.00$), as well as the lack of tools and systems ($M=3.56$; $P=0.00$) were barriers in their companies.

Table 3: Risk Management Barriers

Barriers	SD		D		N		A		SA		M		*One sample T-test		**Two sample T-test
	IT	C	IT	C	IT	C	IT	C	IT	C	IT	C	IT	C	
	%	%	%	%	%	%	%	%	%	%					
Lack of Belief in Benefits	0%	0%	2%	56%	5%	13%	74%	31%	19%	0%	4.09	2.75	0.00	0.13	0.00
Operations Comfort	14%	0%	79%	28%	7%	13%	0%	59%	0%	0%	1.93	3.31	0.00	0.06	0.00
Not Requested by the Client	0%	0%	93%	28%	5%	6%	2%	66%	0%	0%	2.10	3.38	0.00	0.03	0.00
Not Approved by the Client	0%	0%	74%	31%	7%	19%	19%	50%	0%	0%	2.44	3.19	0.00	0.25	0.00
Insufficient Budget	0%	0%	86%	0%	0%	6%	14%	94%	0%	0%	2.28	3.94	0.00	0.00	0.00
Time Constraint	0%	0%	93%	22%	7%	6%	0%	72%	0%	0%	2.07	3.50	0.00	0.00	0.00
Lack of Tools and Systems	0%	0%	100%	22%	0%	0%	0%	78%	0%	0%	2.00	3.56	0.00	0.00	0.00
PMs Not Trained	0%	0%	100%	22%	0%	0%	0%	78%	0%	0%	2.00	3.56	0.00	0.00	0.00
Staff Not Trained	0%	0%	100%	16%	0%	6%	0%	78%	0%	0%	2.00	3.63	0.00	0.00	0.00
No Culture in the Company	0%	0%	100%	34%	0%	25%	0%	41%	0%	0%	2.00	3.06	0.00	0.69	0.00
Not Much Risk Managed	3%	0%	95%	13%	3%	13%	0%	75%	0%	0%	2.00	3.63	0.00	0.00	0.00

This may imply that RM in Singapore construction industry remains in its infancy and the adaptation of key players to appropriate RM tools and systems is not yet common. It is also possible that insufficient financial support for RM discourages development and implementation of tools and systems, further contributing to the lack of opportunities for training project managers and other project players. This may also explain why the potential benefits from RM are not fully recognized. Considering that the mean scores of the listed barriers are statistically different between the IT and construction industries, it can be concluded that the firms from the construction industry face more barriers to RM than the IT industry. In other words, due to active implementation of RM, IT firms have likely overcome most of the listed obstacles while the firms from the construction industry have not. These results suggest that different strategies for increasing implementation in the two industries are required.

4.4 Improvement of Risk Management Implementation

Organisational culture and applicability of RM techniques are vital towards effective implementation and project success (Akintoye and MacLeod, 1997; Forbes et al., 2008; Serpell et al., 2014). As a result, the respondents were asked to select methods that could improve their current organizational environment towards adapting better RM. As summarized in Table 4, about 90% of the respondents agreed that RM implementation in IT firms can be improved by: (1) educating staff on the importance of RM ($M=4.12$; $P=0.00$) (2) conducting training sessions covering the knowledge, skills and tools of RM ($M=4.14$; $P=0.00$); and (3) enforcing the use of RM through appropriate measures ($M=4.02$; $P=0.00$). This may infer that IT firms have already established processes and systems for RM but they recognize that continuing opportunities for education and training should be given to their employees in order to maximize the positive impact of RM at their firms. As shown in Table 4, the results from the methods for improvement cited by the construction industry were significantly different from IT. These differences are discussed later in more detail. On the contrast, 72% of the respondents in the construction industry agreed that their firms should develop internal systems to improve the degree of RM implementation ($M=3.66$; $P=0.00$). This strategy was not recommended by the IT firms. $M=2.00$; $P=0.00$ suggests that such systems might already be in place. The mean

difference of the responses between the IT and construction industries was found to be statistically significant (two sample T-test P-value=0.000).

Table 4: Risk Management Improvements

<i>Methods for Improvement</i>	<i>SD</i>		<i>D</i>		<i>N</i>		<i>A</i>		<i>SA</i>		<i>M</i>		<i>*One sample T-test</i>		<i>*Two sample T-test</i>
	<i>IT</i>	<i>C</i>	<i>IT</i>	<i>C</i>	<i>IT</i>	<i>C</i>	<i>IT</i>	<i>C</i>	<i>IT</i>	<i>C</i>	<i>IT</i>	<i>C</i>			
	%	%	%	%	%	%	%	%	%	%					
<i>Develop Internal System</i>	0%	0%	100%	6%	0%	22%	0%	72%	0%	0%	2.00	3.66	0.00	0.00	0.00
<i>Educate Staff on the Importance</i>	0%	0%	0%	31%	2%	13%	84%	56%	14%	0%	4.12	3.25	0.00	0.13	0.00
<i>Conduct Training on Knowledge and Skill</i>	0%	0%	0%	44%	0%	6%	86%	50%	14%	0%	4.14	3.06	0.00	0.72	0.00
<i>Invite Relevant Experts</i>	0%	0%	98%	25%	2%	0%	0%	75%	0%	0%	2.02	3.50	0.00	0.00	0.00
<i>Enforce Use of RM</i>	0%	0%	0%	34%	2%	28%	93%	38%	5%	0%	4.02	3.03	0.00	0.84	0.00

Construction firms felt that bringing in relevant experts would be important to encouraging more implementation of RM ($M=3.50$; $P=0.00$) while this method was not one of the top priorities of the IT industry ($M=2.02$; $P=0.00$; two sample T-test $P=0.00$). The results imply that to increase implementation levels in the construction industry, proper internal tools and systems should first be deployed. Experts should be engaged with sufficient financial investment to support the effort. With a proper infrastructure, better implementation of RM can be established and intensive and training can be held to train employees.

5. Conclusions and Recommendations

RM continually plays a pivotal role for effective project delivery. This study examined and compared the status of RM performed by the IT and construction industries. The study observed contrasting differences in the educational level of the respondents where, IT possessed higher levels of training when compared to respondents from construction industry. However, educational training alone does not translate to high level of expertise in RM but relies on the respondents' ability to apply management skills effectively in any risk assessment situation. This buttresses the need for constant improvement in the practical knowledge on RM by construction sector. The findings also revealed that IT industry respondents took an affirmative stand on the values of their industry in propensity to take more risk and ensure adequate techniques are put in place to mitigate any unforeseen risk that may arise. This ensures higher competitive, productive and financial gains in the long run. This may reflect the flip positive opportunities inherent in risk. In retrospect, IT firms exhibiting the characteristics of risk takers may benefit from more opportunities to generate higher payoff. Caution is warranted here because the assertion is true only when highly productive and effective RM measures are in place such that risks are successfully mitigated or eliminated. IT industry has been implementing RM more and longer than the construction industry. Construction industry respondents took a more conservative standpoint as cautious risk takers. IT and construction firms surveyed for this study agreed that RM is beneficial and may produce better schedule and cost performances, more barriers were reported by the firms from the construction industry. Plausible methods recommended for the construction industry to improve RM implementation

were different from the IT industry. The firms from the IT industry reported that they have established systems and tools for RM and thus need to focus more on education and training. The construction firm indicated that proper systems needed to be deployed and used with the engagement of RM experts. It is imperative to educate and train staff on the importance and processes of RM, eventually enhancing the company's capability to mitigate risks and exploit opportunities. Construction firms can achieve long-term success via RM through more investment on a competent RM structure with proper IT solutions and training programs. Governmental and statutory requirements could also increase RM levels. It may be practical to develop a series of certifications focusing on RM and to devise a scheme for giving benefits to companies achieving such certifications. Due to the relatively small sample size, it may not be appropriate for the results of this study to be generalized for broader interpretation of the entire construction and IT industries. Another limitation is that the lack of RM implementation observed in the construction industry might be due partly to the small size of the firms that participated in the survey. It might be especially challenging for small firms to allocate sufficient resources to the development and implementation of rigorous RM.

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Changing Construction: Perspectives on Knowledge and Learning

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Abstract

The problem of knowledge in construction is not ‘just’ about knowledge, but about learning and about putting knowledge into action in order to change practices. This paper will use the Danish knowledge system as a case study in order to analyse where and why problems with regard to knowledge occur in construction. This analysis is based on a literature review of seminal studies on knowledge in general and a comprehensive documentary analysis of policy studies on the Danish knowledge system combined with qualitative research interviews of key persons. This paper starts out with a brief exploration of Danish policy studies and initiatives on knowledge and learning in construction. The paper then moves on to outline an analytical framework to understand knowledge and learning within construction. This paper suggests that an analytical framework should: 1) adopt a systemic perspective on construction and refurbishment, 2) highlight the absorptive capacity of firms as a crucial concept for adopting new knowledge, 3) be sensitive to the historicity and path-dependency of the individual construction project, 4) embrace communities of practice as the key framework for learning; and 5) manage the recurrent changes in knowledge types during construction projects, notably from tacit to explicit knowledge and vice versa. Based on this analytical framework, this paper has in broad terms analysed how the various Danish policy studies of the knowledge system have articulated the problem of knowledge in construction, identified how these articulations become controlling of the corresponding solutions, and pointed out some of the shortcomings as a result. With these insights in mind, it is the hope that future studies and public policies will adopt a more reflexive and reflective approach to the problem of knowledge in construction.

Keywords: Knowledge flows, bounded rationality, governance, social shaping, communities of practice

1. Introduction: A sticky problem

Knowledge or rather the lack of knowledge-sharing has frequently been evoked as a core problem with regard to improving the sustainability, performance and productivity of construction. Hence, a range of policy analyses along with development initiatives and research studies have been conducted over the years in Denmark. The policy analyses include for example the use of technological services in construction (Bang, 1997), a survey on learning and knowledge (Alsted Research, 2003), the characteristics of the communication landscape in construction as formulated by the development programme Project House (Christoffersen, 2000) and the repeated call for improved dissemination of building knowledge (see e.g. Carlsen et al., 2005). A number of other policy studies have focused on activities related to research and development in construction. These include among others an analysis by the Danish Building Development Council (abbreviated BUR) on production, use and dissemination of technical building knowledge (Dræbye, 1997) and several mappings of construction-related research and development activities (see e.g. Christoffersen and Bertelsen, 1990; Boligministeriet, 1993; Det Offentlige Forskningsudvalg for Byer og Byggeri (translation: The Public Research Committee on Cities and Construction), 2000; Haugbølle and Clausen, 2002). These have been followed by a number of public action plans like the programme ‘The Future of Construction: From tradition to innovation’ (By- og Boligministeriet & Erhvervsministeriet, 2000), the action plan on research and development activities (Udvalget vedrørende byggeforskning i Danmark (translation: Committee on Construction Research in Denmark), 2002), and a proposal for strengthening research and learning in construction issued jointly by the industry, government and knowledge institutions (Koordinations- og initiativgruppen for viden i byggeriet, 2009).

Along with the long line of policy studies a number of experiments and development activities have been carried out, which have pointed at possible ways to improve the dissemination and sharing of knowledge in particular with regard to the use of new information and communication technologies (ICT). These experiments and development activities include among others the Tele-byg project on the use of virtual communication in long-distance consultancy (Hansen et al., 2002) as well as the MELFO and Melfa projects on the use of handheld devices (PDA or smart phones) to support mobile e-learning for dyslexics. A number of initiatives like the BygSol programme (Christensen, 2008) and Bricklayers in Motion (see e.g. Bertelsen, 2011) have also been targeted at developing vocational training and improving the competences of craftsmen and unskilled labour. The construction-related research on knowledge include among others studies of morality and knowledge production among consulting engineers (Munch, 2005), the cultural organisation in construction and its role in knowledge application (Thuesen, 2006) and the constitution of partnering (Gottlieb, 2010). In recent years, extensive efforts have also been put into developing and applying Building Information Modelling (BIM) among Danish consultants in particular and more lately Virtual Design and Construction (VDC) among some of the major Danish contractors.

Despite all of these efforts, the “problem of knowledge” seems not only to be sticking around, but also to be accentuated by a general shift in most industrialised countries from new construction towards refurbishment activities. Refurbishment entails a different set of

challenges compared to new construction, which calls for new strategies, knowledge and development of practices among construction professionals, policy makers and knowledge institutions. Hence, a range of new initiatives are being launched to address these challenges in many countries like the UK Green Deal programme, the Belgian BrusselsRetrofitXL programme and the European roadmap for moving to a low-carbon economy by 2050 (European Commission, 2011).

Denmark is no exception to this general line of development. Thus, two large private foundations recently initiated and funded a think tank to develop a new comprehensive refurbishment strategy for the built environment. The think tank was composed of some 30 members representing all major parties of the built environment. Over the course of a year the think tank held a number of consultations with experts, professionals and policy makers to identify relevant challenges and formulate corresponding initiatives to address these. At the end of 2012, the think tank published its strategy with seven initiatives related among others to improving statistics on refurbishment, accelerating innovation, strengthening education and improving dissemination of knowledge (Tænketank for bygningsrenovering, 2013).

One of the ensuing initiatives encompassed a more substantial analysis of ‘the problem of knowledge’. This chapter will report on the results of this analysis and take a closer look at where and why problems occur with regard to knowledge within construction. It will take as its starting point that the problem of knowledge is not ‘just’ about knowledge, but about learning and about putting knowledge into action in order to transform practices. The chapter will identify different perspectives on knowledge and discuss how these understandings and metaphors of knowledge articulate knowledge differently as a problem and thus becomes controlling of the corresponding solutions.

2. Methodology

2.1 Ontological position

The analytical framework of this paper is developed on the basis of a number of seminal studies on knowledge in general. The ontological position is based on the following assumptions about knowledge in construction and refurbishment, more specifically:

- An analytical framework needs to address five levels to give a comprehensive understanding of the problem of knowledge in construction. These five levels are: 1) construction as a system, 2) firms as key players, 3) projects as the focal point, 4) communities of practice in groups and professions, and 5) individuals as bearers of skills.
- An analytical framework of knowledge in construction needs to be able to include both explicit and tacit knowledge as both forms are strongly prevalent among the different actors of construction.

- An analytical framework needs to acknowledge that knowledge-sharing among project participants and dissemination of knowledge from e.g. development projects takes place through many different means depending on the type of knowledge etc.
- An analytical framework needs to consider knowledge as functional rather than actor-centred, i.e. production, distribution and use of knowledge is not exclusively linked to the different type of actor, but all actors may to a varying degree over time and space act as producers, intermediaries and users of knowledge.
- An analytical framework needs to recognise that the formulation of knowledge problems and possible solutions to these problems of knowledge is largely dictated by how knowledge in construction is perceived and conceptualised.

2.2 Research design

The research design follows a case study design. Flyvbjerg (2006: 230) states that paradigmatic cases '*develop a metaphor or establish a school for the domain that the case concerns.*' Identifying a case as paradigmatic is particularly challenging as noted by Flyvbjerg (2006: 232) as paradigmatic cases by their very nature transcend any sort of rule-based criteria. The analysis of the Danish knowledge system on construction and refurbishment may be considered paradigmatic in the sense that it shares a number of characteristics and similarities with other industrialised countries e.g. with regard to the distribution of construction output as new built versus refurbishment, the application of the same European rules of procurement, and the use of a range of similar construction products as in many other countries due to the European internal market. However, there are a number of differences in national building codes, industrial structure etc. that makes it less likely to use the Danish knowledge system as an exemplar for construction knowledge systems in general.

The case also has elements of being a critical case, which makes it possible to draw conclusions or generalisations of the kind that '*if it is valid for this case, it is valid for all (or many) cases*' (Flyvbjerg, 2006: 230). These arguments relate to characteristics of the Danish construction industry like Danish construction professionals being generally considered as highly skilled and knowledgeable, a well-paid workforce with social status, high degree of digital literacy and extensive access to ICT solutions. Hence, if problems of knowledge exist in the Danish construction industry, the same kind of problems – and maybe even in an accentuated form – are likely to be found in other national construction industries.

2.3 Methods and data

The study is based on a documentary analysis combined with qualitative research interviews. The longitudinal documentary analysis is based on a comprehensive selection of written Danish sources covering the most prominent policy studies etc. over a period of over more than two decades. This longitudinal study has been combined with a cross-sectional study of the present situation and challenges through qualitative research interviews with seven key persons representing major actors of the construction industry. These include a representative from

educational institutions, information offices, research institutions, contractors, trade unions, wholesalers, and R&D funding offices.

3. The problem of knowledge in construction

3.1 A systemic perspective

Gann and Salter (2000) adopt a systemic perspective on construction, where innovation must be understood in the context of both the technological support infrastructure for producing knowledge and the regulatory and institutional environment. The individual elements of the system are connected to each other through flows of knowledge. Haugbølle et al. (2012) has developed Gann and Salter (2000) systemic perspective to also explicitly include the building users and suggest that links between the individual element can predominantly be understood as business processes between actors in three different types of markets, learning processes and policy processes (see Figure 1).

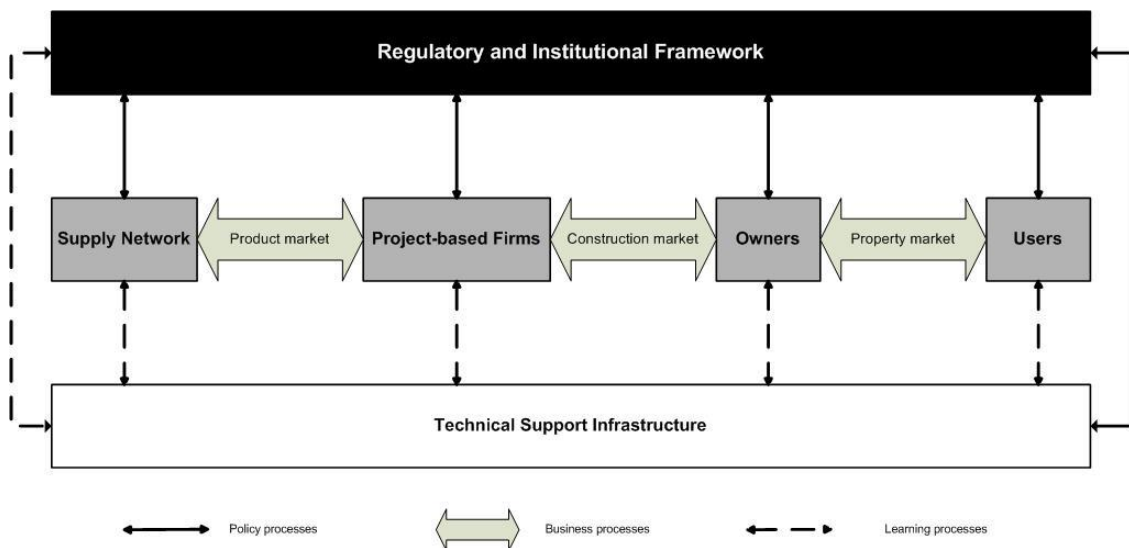


Figure 1: Systemic perspective on construction (Haugbølle et al., 2012: 452)

The majority of policy studies on the problem of knowledge in Danish construction have focused on how new research-based knowledge can be made available for use in the project-based companies of construction. Most of these policy studies criticise in particular the universities and other knowledge institutions for not disseminating new knowledge appropriately to the project-based firms of construction, in particular contractors and consultants. Thus, the preferred solution to the knowledge problem is to improve dissemination from the universities and the like through e.g. mandatory dissemination plans for R&D projects, joint information services e.g. as a sort of digital one-stop-shopping solutions etc.

However, a systemic perspective on the problem of knowledge as mentioned above indicates that it is far too narrow to focus on the dissemination from knowledge institutions. A systemic

perspective would rather suggest that the problem of knowledge can be found in four different locations:

- The interaction between the political-institutional apparatus on one side and business as well as users on the other side.
- The interaction between the individual companies and its customers throughout the entire supply chain spanning three separate markets of products, construction and property.
- The interaction between knowledge institutions and each of the business actors – supply network, project-based firms, owner and users of buildings.
- The capabilities and interaction within each of the individual units.

3.2 Firm versus project: Absorptive capacity

Especially the capabilities and interaction within each organisation has often been neglected in Danish policy studies, even though this is central to a firm's ability to adopt new knowledge. A central key concept in this context is 'absorptive capacity'. Cohen & Levinthal (1990: 128) defines this ability to absorb knowledge in the following way:

'...the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends is critical to its innovative capabilities. We label this capability a firm's absorptive capacity and suggest that it is largely a function of the firm's level of prior related knowledge.'

The development of a firm's absorptive capacity depends on both the individual's and the organisation's ability to adopt knowledge, which is both history-dependent and path-dependent. Cohen & Levinthal (1990: 132) further point out that the firm's ability to adopt new knowledge depends on the communicative structures inside and outside the firm, including the nature and distribution of expertise within the organisation:

'Absorptive capacity refers not only to the acquisition or assimilation of information by an organization but also to the organization's ability to exploit it. Therefore, an organization's absorptive capacity does not simply depend on the organization's direct interface with the external environment. It also depends on transfers of knowledge across and within subunits that may be quite removed from the original point of entry. Thus, to understand the sources of a firm's absorptive capacity, we focus on the structure of communication between the external environment and the organization, as well as among the subunits of the organization, and also on the character and distribution of expertise within the organization.'

In project-based industries like construction, the absorptive capacity is not solely linked to the firm as such, but as well to the often many projects being managed by the firm simultaneously and over time. Hence, the interplay between the firm as the basis and the individual projects as well as across projects is crucial for understanding and dealing with the problem of knowledge

in construction. In his earlier work with innovation in the project-based organisations of construction, Winch (1998) has suggested the following model for different types of knowledge flows between the project, the firm and the surroundings of both (see Figure 2).

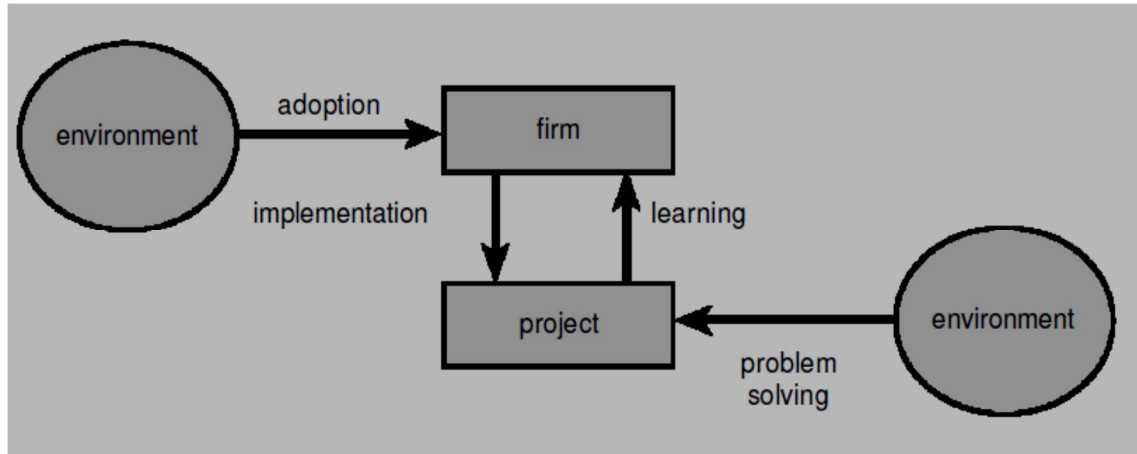


Figure 2: Knowledge flows between project and firm (Winch, 1998: 273)

The model is a reminder that the problem of knowledge must be addressed along at least three dimensions:

- External to the firm – either horizontally in networks with like-minded people for example within the same profession or vertically in networks across disciplines.
- In-between the individual projects and the firm.
- Within the project between the respective project participants, but external to the firms involved in a project.

What the model however fails to acknowledge is the need to address the knowledge flows taking place between different projects either simultaneously in time or consecutively over time.

3.3 No project is an island: Historicity and path dependency

Projects are not only vital for both new construction and refurbishment but the very organising principle of construction firms. The uniqueness of projects is often used as an explanation for why it is difficult to share knowledge and create change in construction. Despite the widely held assumption of projects being both unique and isolated events, projects are not isolated islands as Engwall (2003) points out. Instead projects are embedded in an organisational context and with a historicity marked by previous projects, parallel courses of events and ideas about the post-project future.

Following Engwall (2003), knowledge in projects is not isolated or necessarily unique, but is tied up on experience from previous projects as well as project-independent factors such as general business policies that go beyond the individual project. In this way, previous experience and general policies creates a path dependency that sets the scene for future projects (Figure 3).

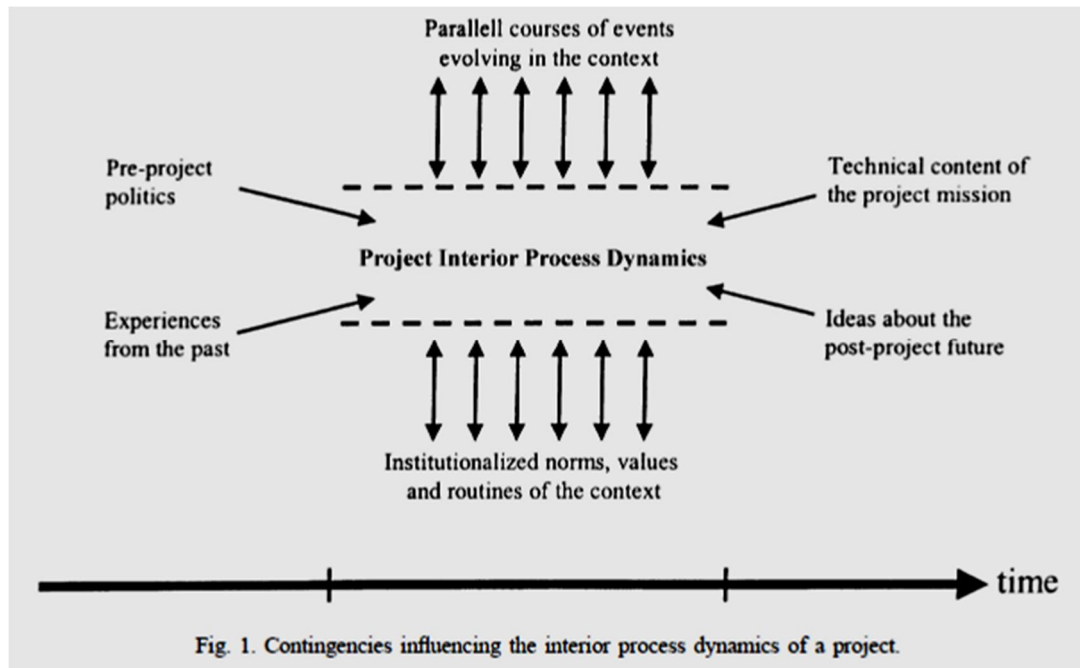


Figure 3: Factors affecting the project's dynamics (Engwall, 2003: 805)

In most Danish policy studies there is a strong rhetoric on the project-based nature of construction and the barriers to knowledge and change created by this very nature. However, a range of possible interventions related to the contingencies influencing the interior process dynamics of a project tend to be ignored. While these contingencies may be overlooked in policy studies, some of the major Danish consulting firms and contractors now attempt to address these in their internal training and course activities on management. But management and learning within and across projects is only side of the knowledge problem in construction. Another side of the problem is related to how trades and professions operate and are organised.

3.4 Learning: Communities of practice

Collaboration, knowledge-sharing and learning across the many trades and professions within construction is notoriously challenging as have been recognised by several (see e.g. Christensen, 2008 and Thuesen, 2007). But these shared communities of practice within trades and professions also hold strong a potential for being a part of the solution to (part of) the problem of knowledge in construction.

Communities of practice have in recent years received considerable attention in the context of organisational development and efforts to understand and improve knowledge and improve learning in organisations. Wenger (1998: 4-5) defines learning as an active participation in the practices of a community and forming of identity in relation to these communities:

‘A social theory of learning must therefore integrate the components necessary to characterize social participation as a process of learning and of knowing. These components (...) include the following:

- 1) Meaning: a way of talking about our (changing) ability – individually and collectively – to experience our life and the world as meaningful.*
- 2) Practice: a way of talking about the shared historical and social resources, frameworks, and perspectives that can sustain mutual engagement in action.*
- 3) Community: a way of talking about the social configurations in which our enterprises are defined as worth pursuing and our participation is recognizable as competence.*
- 4) Identity: a way of talking about how learning changes who we are and creates personal histories of becoming in the context of our communities.’*

With regard to innovation and change management, the problem of knowledge in Danish construction projects is not only a matter of learning new things, but also to ‘unlearn’. The ability to discard knowledge – where appropriate – is also an important aspect of communities of practice, although this is often overlooked.

Knowledge and learning across communities of practice like trades and professions within construction presents challenges because of the very characteristics that are also their strengths, i.e. the internal autonomy of the communities, their informal nature, and not least their differences in prevalence of knowledge types.

3.5 Tacit versus explicit knowledge: Repeated shifts

Knowledge management deals with collecting, developing, distributing and applying knowledge in organisations. One of the most important and seminal work was done by Nonaka and Takeuchi (1995), who studied knowledge and innovation in Japanese companies and developed the so-called SECI model. The SECI model analyses the interaction and transformations between tacit and explicit knowledge. The SECI model points out that both forms of knowledge are important and that the conversion between them is important (see Figure 4).

		TO	
		Tacit knowledge	Explicit knowledge
FROM	Tacit knowledge	Socialization	Externalization
	Explicit knowledge	Internalization	Combination

Figure 4: The SECI model – four types of conversion of knowledge (Adapted after Nonaka & Takeuchi, 1995: 62)

The construction process is typically characterised by the involvement of several firms and trades, which implies numerous and repeated shifts between tacit knowledge and explicit knowledge. The ability to handle these shifts in order to accumulate, disseminate and apply knowledge in practice is probably one of the construction industry's main challenges with regard to knowledge. As pointed out bluntly by Danish practitioners: First, the client must articulate his tacit and more or less explicit knowledge about his needs for a new building. The consultant then turns these into to explicit knowledge in the shape of formal documents such as drawings and specifications. This explicit knowledge is then being adopted and adapted to tacit knowledge, which is the primary knowledge base among the craftsmen in construction companies. Finally, the actual building will be managed by building caretakers based on their mix of explicit and tacit knowledge on caretaking of that particular building, and it will be measured against the more or less tacit knowledge of the end-users of how appropriate the services delivered by the building suits their needs.

4. Conclusions

This paper has provided a brief exploration of an extensive number of Danish policy studies and initiatives on knowledge and learning in construction over the past two decades.

The paper then moved on to outline an analytical framework to understand knowledge and learning within construction. This paper suggests an analytical framework that: 1) adopt a systemic perspective on construction, 2) highlight the absorptive capacity of firms as a crucial concept for adopting new knowledge, 3) is sensitive to the historicity and path-dependency of the individual construction project, 4) embrace communities of practice as the key framework for learning; and 5) manage the recurrent changes in knowledge types, notably from tacit to explicit knowledge and vice versa.

Based on this analytical framework, this paper has in broad terms analysed how the various Danish policy studies of the knowledge system have articulated the problem of knowledge in construction, identified how these articulations become controlling of the corresponding solutions, and pointed out some of the shortcomings as a result. With these insights in mind, it is the hope that future studies and public policies will adopt a more reflexive and reflective approach to the problem of knowledge in construction.

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Hindrances to Enterprise Risk Management in Construction Firms: An Organizational Learning Perspective

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Abstract

In recent years, holding a holistic view of risk management has become the trend in various industries. In this trend, enterprise risk management (ERM) has been viewed as the fundamental paradigm and has attracted the attention from the academics and practitioners worldwide. Implementing ERM in construction firms is inevitably associated with organizational learning. The objectives of this study are to (1) identify the critical hindrances to ERM in Chinese construction firms (CCFs) and (2) analyze them in tandem with theories of organizational learning. To achieve these objectives, a total of 36 hindrances to ERM and 12 hindrances to organizational learning were identified through a literature review, and a questionnaire survey was performed with 119 respondents from 119 CCFs in the global construction market. The results indicated that 20 hindrances were deemed critical, among which “insufficient resources (e.g. time, money, people, etc.)”, “lack of a formalized ERM process”, and “lack of internal knowledge, skills and expertise” were the top three hindrances. In addition, the critical hindrances to ERM were interpreted from the perspective of organizational learning, and the 12 hindrances to organizational learning were linked to the critical hindrances to ERM. This study presents the theoretical rationale behind the critical hindrances to ERM implementation and contributes to the literature through interpreting ERM implementation from an organizational learning perspective.

Keywords: Risk management, organizational learning, construction firm, hindrances.

1. Introduction

In recent years, enterprise risk management (ERM), as a holistic view of risk management, has attracted the attention from the academics and practitioners worldwide (McGeorge and Zou, 2013). The Committee of Sponsoring Organizations of the Treadway Commission (COSO, 2004, p.2) defines ERM as “a process, effected by an entity’s board of directors, management and other personnel, applied in strategy setting and across the enterprise, designed to identify potential events that may affect the entity, and manage risk to be within its risk appetite, to provide reasonable assurance regarding the achievement of entity objectives.” Because construction businesses are inevitably afflicted with various and complex risks, construction firms have been considered as prime candidates for ERM implementation (Zhao et al., 2013a). Implementing ERM in construction firms can be seen as a gradual organizational change, and Zhao et al. (2014a) interpreted ERM implementation in construction firms from the perspective of organizational change. In addition to organizational change, organizational learning is also necessary for ERM implementation. This is because learning is a medium for change (Alas and Sharifi, 2002), and improves the ability to adapt to change, at both individual and organizational levels (Garvin, 1993, Senge, 1990). Learning and change were not only parallel and simultaneous, but are also interactive processes, as learning has a mediating role in the change process (Lähteenmäki et al., 2001). In the tumultuous environment, learning also helps to reduce uncertainty and thus inevitably reduce resistance to change (Lähteenmäki et al., 2001). Hence, change and learning should not be isolated from each other and ERM implementation cannot be isolated from organizational learning.

In project-based construction firms, most management staff has been familiar with and adopted project risk management (PRM). Thus, it is necessary for the individuals who are accustomed to PRM to learn ERM fundamentals and how to further PRM contributions to ERM. Without this individual learning process, ERM cannot be implemented at all levels across the firm, because individual learning is the basis of organizational learning (Senge, 1990). In addition, the existing learning processes that support PRM can also contribute to ERM implementation, because PRM is an integral part of ERM. The focus on learning from risks is likely to institutionalize risk information and change PRM practices to a corporate-level approach (Dikmen et al., 2008). Furthermore, Smallman (1996) argued that organizational learning, together with data collection and collation as well as forecasting, comprised holistic risk management.

Implementing ERM in construction firms is not easy. Zhao et al. (2014b) reported that most of the Chinese construction firms (CCFs) based in Singapore had low-level ERM implementation. The low-level ERM implementation could be attributed to the influence of various hindrances (Zhao et al., 2015). The objectives of this study are to (1) identify the critical hindrances to ERM in CCFs in the global market; and (2) analyse these hindrances in tandem with theories of organizational learning.

2. Background

2.1 Hindrances to ERM implementation

Previous studies have reported that a number of factors hindered ERM implementation in various industries. Confronted with these hindrances, firms in various industries tend to find it difficult to fully implement ERM and the percentage of firms adopting or implementing ERM was not high. In the construction industry, Zhao et al. (2014b) found that none Singapore-based CCFs had high-level ERM implementation, whilst Liu et al. (2011) indicated that only 14.7% of the leading CCFs in the global market had fully implemented ERM. In this study, hindrances are barriers to initiating ERM and carrying out ERM along the maturity continuum, in all the phases of ERM implementation. In the earlier phase of the larger research project, Zhao et al. (2014a) identified a total of 36 hindrances from previous studies, as shown in Table 1.

Table 1: Hindrances to ERM implementation [Adapted from Zhao et al. (2014a)]

<i>Code</i>	<i>Hindrances to ERM implementation</i>	<i>Code</i>	<i>Hindrances to ERM implementation</i>
H01	Low data quality	H19	Perception that ERM interferes with business activities
H02	Lack of data	H20	Inadequate training on ERM
H03	Insufficient resources (e.g. time, money, people, etc.)	H21	Lack of an ERM business case
H04	Lack of a formalized ERM process	H22	Lack of perceived value or benefits of ERM
H05	Lack of risk management techniques and tools	H23	Lack of commitment of the board and senior management
H06	Lack of internal knowledge, skills and expertise	H24	Not perceived as a priority by senior management
H07	Lack of qualified personnel to implement ERM	H25	Lack of board or senior management leadership
H08	Lack of a risk management information system (RMIS)	H26	The movement of the ERM champion from senior management into other areas without a successor
H09	Unsupportive organizational structure	H27	Lack of consensus on benefits of ERM among board members and senior management
H10	Unsupportive organizational culture	H28	Other management priorities
H11	Lack of a common risk language	H29	Lack of a clear ERM implementation plan
H12	Lack of risk awareness within the organization	H30	Inability to coordinate with other departments
H13	Confidence in the existing risk management practices	H31	Lack of a set of metrics for measuring performance of ERM
H14	Existence or re-emergence of the silo mentality	H32	Unclear ownership and responsibility for ERM implementation

H15	<i>Lack of shared understanding and approach to risk management across departments</i>	H33	<i>Organizational turf</i>
H16	<i>Lack of understanding relating to effective ERM process</i>	H34	<i>Employees' reluctance to give up power</i>
H17	<i>Perception that ERM adds to bureaucracy</i>	H35	<i>People' reluctance to share risk information</i>
H18	<i>Perception that ERM increases costs and administration</i>	H36	<i>Recession and business downturn</i>

2.2 Organizational learning

Organizational learning can be defined as “a continuous testing of experience and its transformation into knowledge available to whole organization and relevant to their mission” (Senge, 1990, p.6). Organizational learning stems from the knowledge acquisition of the individuals within the organization, and progresses with the exchange and integration of this knowledge until collective knowledge is created (Hedberg, 1981, Jerez-Gómez et al., 2005). Although organizational learning has its roots in individual learning (Senge, 1990), it is distinct from adding together the individual learning of the organization’s different members (Alas and Sharifi, 2002, Hedberg, 1981).

Sfard (1998) proposed two metaphors of learning: the acquisition and participation metaphors, which are also known as the cognitive-behavioral approach and the sociocultural (or situated) approach, respectively (Ellström, 2010). From the perspective of the acquisition metaphor, the mind is a container of knowledge, and learning is a process of filling the container and implanting knowledge there. Knowledge is viewed as a property or capacity of an individual mind (Paavola et al., 2004). By contrast, the participation metaphor regards learning as a process of participation in cultural practices and shared learning activities. From this perspective, learning cannot be separated from working and other social practices where it is used (Brown and Duguid, 1991). In this view, learning is “situated” in these relations and networks of activities of participation (Paavola et al., 2004). Sfard (1998) argued that both approaches were needed. They are not simply rivals but complement each other. There is also a third approach to organizational learning: the knowledge-creation approach. It is based on the view that the production, transformation, and utilization of knowledge are fundamental for understanding organizational learning (Ellström, 2010).

Table 2: Hindrances to organizational learning

<i>Code</i>	<i>Hindrances to organizational learning</i>	<i>Code</i>	<i>Hindrances to organizational learning</i>
L01	<i>Lack of leadership commitment and support</i>	L07	<i>Reluctance to accept knowledge</i>
L02	<i>Lack of internal knowledge</i>	L08	<i>Lack of knowledge absorptive or retentive capacity</i>
L03	<i>Lack of organizational commitment</i>	L09	<i>Lack of channels for dialogue and sharing meaning</i>
L04	<i>Lack of psychological safety</i>	L10	<i>Arduous relationships</i>
L05	<i>Lack of motivation</i>	L11	<i>Downsizing or layoff strategies</i>

L06	<i>Reluctance to share knowledge</i>	L12	<i>Unsupportive organizational culture</i>
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Previous studies have identified several hindrances to organizational learning because individuals have been trained to think and act in conflicting ways (DiBella and Nevis, 1998). As indicated in Table 2, 12 hindrances to organizational learning are identified from previous studies (Argyris, 1995, Atak and Erturgut, 2010, Cohen and Levinthal, 1990, Ellström, 2010, Fisher and White, 2000, García-Morales et al., 2006, Hayes, 2007, Husted and Michailova, 2002, Lipshitz et al., 2002, Pfeffer, 1998, Popper and Lipshitz, 2000, Senge, 1990, Shrivastava, 1983, Szulanski, 1996).

3. Method and Data Presentation

As a systematic method of collecting data based on a sample, the questionnaire survey technique has been widely used to collect professional views in risk management research (Deng et al., 2014, Hwang et al., 2014, Mu et al., 2014, Zhao et al., 2014c). In this study, a questionnaire survey was performed to investigate the hindrances to ERM implementation. The comprehensive literature review supported the development of the questionnaire. In the survey, the respondents were asked to rate the influence of the 36 hindrances on ERM implementation using a five-point scale (1=very insignificant, 2=insignificant, 3=neutral, 4=significant, and 5=very significant).

Table 3: Profile of respondents

<i>Work experience</i>	<i>N</i>	<i>%</i>	<i>Designation</i>	<i>N</i>	<i>%</i>	<i>Location</i>	<i>N</i>	<i>%</i>
<i>5-10 years</i>	54	45%	<i>Senior management</i>	35	29%	<i>China</i>	35	29%
<i>11-15 years</i>	25	21%	<i>Department management</i>	26	22%	<i>Asia (w/o China)</i>	46	39%
<i>16-20 years</i>	17	14%	<i>Project management</i>	58	49%	<i>Africa</i>	28	24%
<i>21-25 years</i>	11	9%				<i>Europe</i>	4	3%
<i>Over 25 years</i>	12	10%				<i>Latin America</i>	6	5%

The population consisted of all the industry practitioners with extensive experience in risk management of CCFs in the global market. As there was no sampling frame in this survey, the sample was a non-probability sample. The non-probability sampling plan can be used to obtain a representative sample (Patton, 2001), and has been recognized as appropriate when the respondents were not randomly selected from the entire population, but were rather selected based on whether they were willing to participate in the study (Liu et al., 2016, Wilkins, 2011). A list of senior and middle management staff of CCFs were obtained and 500 questionnaires were sent out. A total of 119 completed questionnaires were received, representing a response rate of 24%, which was acceptable compared with the norm of 20-30% with most questionnaire surveys in the construction industry (Akintoye, 2000, Hwang et al., 2015). The profile of the respondents is shown in Table 3.

4. Results and Discussion

4.1 Ranking of hindrances to ERM implementation

In this study, the 36 hindrances were ranked based on their influence mean scores, which ranged from 2.82 to 4.29 (see Table 4). The normalized values of the mean scores were calculated to select the critical hindrances. This method was adopted by Xu et al. (2010), who identified the factors with normalized values equal to or greater than 0.50 as critical factors. Thus, the hindrances, which received the mean scores closer to the maximum mean scores, are deemed as critical hindrances. The analysis results indicated that 20 out of the 36 hindrances obtained normalized values above 0.50, implying that these 20 factors were critical hindrances to ERM implementation in CCFs.

“Insufficient resources (e.g. time, money, people, etc.)” (H03) was ranked top, suggesting that ERM implementation in CCFs was not assigned with sufficient time, money and manpower. The majority of time, money and people were invested into project construction, and insufficient resources were allocated for ERM programs, signalling that these firms did not attach adequate importance to ERM.

Table 2: Ranking of hindrances to ERM implementation

Code	Mean	Rank	Normalization	Code	Mean	Rank	Normalization	Code	Mean	Rank	Normalization
H01	3.73	11	0.62	H13	3.42	25	0.41	H25	3.73	11	0.62
H02	3.78	9	0.65	H14	3.24	28	0.29	H26	3.18	30	0.25
H03	4.29	1	1.00	H15	3.54	21	0.49	H27	3.33	27	0.35
H04	3.91	2	0.74	H16	3.5	23	0.47	H28	3.46	24	0.44
H05	3.82	8	0.68	H17	2.82	36	0.00	H29	3.83	7	0.69
H06	3.9	3	0.73	H18	3.61	20	0.54	H30	3.23	29	0.28
H07	3.87	4	0.71	H19	3.14	31	0.22	H31	3.66	16	0.57
H08	3.66	15	0.57	H20	3.86	5	0.71	H32	3.64	18	0.56
H09	3.64	18	0.56	H21	3.51	22	0.47	H33	3.01	32	0.13
H10	3.67	14	0.58	H22	3.85	6	0.70	H34	2.97	34	0.11
H11	3.34	26	0.36	H23	3.64	18	0.56	H35	2.9	35	0.05
H12	3.67	14	0.58	H24	3.71	12	0.60	H36	2.98	33	0.11
Normalized value = (Mean - Minimum Mean)/(Maximum Mean - Minimum Mean)											

“Lack of a formalized ERM process” (H04) received the second position. This result implied that if there was not a formalized ERM process in a firm, the ERM implementation in this firm would be significantly hindered because such a formalized process can serve as a guide for the staff involved in ERM implementation. The lack of such a formalized process can make staff misunderstand how to implementation ERM.

“Lack of internal knowledge, skills and expertise” (H06) was ranked third. This result suggested that CCFs lacked internal knowledge, skills and expertise relating to ERM, which significantly hindered ERM implementation in these firms. Although ERM was advocated in Chinese firms

after the State-owned Assets Supervision and Administration Commission of the State Council of China issued the Guidance to ERM for Central Enterprises in 2006, the CCFs still lacked internal knowledge, skills and expertise relevant to ERM and most of the overseas subsidiaries obtained these resources from their parent companies.

4.2 Interpretation from the organizational learning perspective

Some of the 12 hindrances to organizational learning can be used to interpret the critical hindrances to ERM implementation. Without the senior-level commitment and support, the learning culture would not be created; resources would not be invested into the learning and training programs; the staff would not perceive the learning as being emphasized; and finally, organizational learning mechanisms would not be set up and institutionalized. Thus, the critical hindrances relating to the top management (H23-H25), the organizational culture and structure (H09 and H10), the resource investments (H01-H08, and H31), as well as the training and understanding of ERM (H18, H20 and H22) can be linked to “lack of leadership commitment and support” (L01) in the hindrances to organizational learning.

According to the literature, organizational learning is associated with knowledge acquisition (Huber, 1991, Shrivastava, 1983), participation in the learning process (i.e. situated learning) (Brown and Duguid, 1991), and knowledge creation (Bereiter, 2002, Engeström, 1999, Nonaka, 1991). In the CCFs, ERM implementation involves knowledge acquisition from inside and outside the firm, the participation of the relevant staff in the training programs and risk communication, as well as the creation of knowledge from the ERM practices. Six factors (H01, H02, and H04-H07) significantly hindered ERM implementation because they contributed to the “lack of internal knowledge” (L02) relating to ERM. Specifically, as the data are the predecessor of information and knowledge, the lack of high-quality data can result in the lack of internal knowledge. Also, the lack of a formalized ERM process, relevant techniques and tools represents a low level of knowledge relating to ERM. In addition, the staff qualified to implement ERM are likely to have the relevant knowledge, skills and expertise, and the lack of such staff can therefore led to the lack of internal knowledge.

There should be a channel through which people share their ideas and knowledge. A risk management information system (RMIS) can serve as a platform where the relevant staff can communicate the risk information as well as the lessons learned in ERM implementation (Zhao et al., 2013b), while training programs allow external and internal trainers to share their experience and knowledge relating to ERM with others. Thus, “lack of a RMIS” (H08) and “inadequate training on ERM” (H20) hindered ERM implementation because they represented the lack of channels for sharing knowledge. As setting up such channels needs resource investments and senior-level support, the negative influence of the four hindrances (H03 and H23-H25) can also be interpreted using this hindrance to organizational learning.

Even though there are channels for dialogue and sharing knowledge, the effectiveness of knowledge acquisition depends on the individuals’ ability to absorb and retain the knowledge (Cohen and Levinthal, 1990, Szulanski, 1996). The personnel unqualified to implement ERM

may also lack the capacity for absorbing and retaining the knowledge relating to ERM, thus contributing to the lack of internal knowledge, skills and expertise. Therefore, the two hindrances (H06 and H07) can be linked to “lack of knowledge absorptive or retentive capacity” (L08) in the hindrances to organizational learning. In addition, downsizing or layoff strategies are often used when a firm faces a recession or business downturn. These strategies involve the departure or turnover of the staff, who may be experienced and knowledgeable, and would lead to the loss of the experience and knowledge (Fisher and White, 2000, Pfeffer, 1998). Thus, the two hindrances (H06 and H07) can also be linked to “downsizing or layoff strategies” (L11) in the hindrances to learning.

In some cases, the staff would fear that their self-interest would be threatened due to organizational learning, thus leading to the lack of psychological safety. “Perception that ERM increases costs and administration” (H18) is representative of “lack of psychological safety” (L04) because some staff may believe that the additional costs and administration threaten the firm performance, which is associated with the bonus or interest of them. Such a misunderstanding derives from the “lack of perceived value or benefits of ERM” (H22). Thus, the two critical hindrances (H18 and H22) can be linked to “lack of psychological safety” (L04).

Motivation measures are necessary for organizational learning (Szulanski, 1996). As the relevant employees need to spend time, energy and knowledge in ERM implementation, they should be convinced that these resources can pay off. Thus, the metrics to measure ERM performance should be developed and used. The tangible increase in firm performance can motivate the relevant staff to actively participate in the ERM implementation. In turn, the lack of such metrics and perceived benefits of ERM would discourage the staff from contributing to the learning process relating to ERM, thus hindering ERM implementation.

Organizational learning can be hindered by the unsupportive organizational culture, such as the blame culture (Hayes, 2007) and defensive routines (Argyris, 1995). Two critical hindrances (H10 and H12) can be linked to “unsupportive organizational culture” (L12) in the hindrances to organizational learning. As ERM implementation includes learning from the past mistakes, errors, failures and disasters, the unsupportive culture would render these negative issues as taboos and discourage the staff from investigating the root causes of them. Consequently, the employees would remain confident in the existing risk management practices and not believe that it is necessary to implement ERM, which is likely to lead to the underlying assumption that the risks can be dealt with by the current risk management practices. Thus, the staff would not attach adequate importance to the potential risks and lack risk awareness.

5. Conclusions

ERM implementation has been advocated in the construction industry and requires organizational learning in firms. This study attempts to identify the critical hindrances to ERM in CCFs and analyse these hindrances in tandem with theories of organizational learning. To achieve these objectives, a total of 36 hindrances to ERM and 12 hindrances to organizational learning were identified through a literature review, and a questionnaire survey was performed

with 119 respondents from 119 CCFs in the global construction market. The results indicated that 20 hindrances were deemed critical, among which “insufficient resources (e.g. time, money, people, etc.)”, “lack of a formalized ERM process”, and “lack of internal knowledge, skills and expertise” were the top three hindrances. In addition, the critical hindrances to ERM were interpreted from the perspective of organizational learning, and the 12 hindrances to organizational learning were linked to the critical hindrances to ERM.

Despite the achievement of the objectives, there are limitations to the conclusions. Firstly, the identification of the hindrances to ERM may not be exhaustive. Additionally, as the survey was performed with the CCFs, one should be cautious when the results are interpreted and generalized in other firms. Nonetheless, the implication of this study is not limited to the CCFs because the theoretical rationale behind the critical hindrances can be used to interpret the hindrances in other construction firms. In addition, this study contributes to the literature through interpreting ERM implementation from an organizational learning perspective.

Future studies would investigate the interaction mechanisms among the hindrances to ERM implementation, and identify the influence paths comprised by some of these factors. The theoretical rationale behind these mechanisms and paths would be found in organizational learning theories, and a set of best practices, which help the management to handle the influence of these factors and pursue the benefits of ERM, would be proposed based on the interaction mechanisms and influence paths.

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Implementing Social Responsibility in Construction Project: An Empirical Investigation on Stakeholders' Interest and Power

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Abstract

Given the enormous social and environmental impacts of construction lifecycle, organizations in the construction supply chain realise the need to implement social responsibility (SR) in their construction projects. Different project stakeholders have different understandings towards SR and they display different capabilities of setting forth initiatives, of calling for supports, and of achieving outcomes. This research aims to investigate the stakeholders' interests and power on SR implementation in construction projects and thus discover the invisible gaps between the stakeholders' concerns and influences. A total of 35 SR Issues (SRIs) categorized into seven themes were identified from construction lifecycles perspective. A questionnaire survey was subsequently conducted among the construction practitioners in Hong Kong to investigate the stakeholders' interest and power on these 35 SRIs. Paired t-test and descriptive statistical analysis were adopted to reveal the gaps between stakeholders' interest and power. This study could provide enlightenments to project stakeholders for them to identify the SRIs that they have power on; however, with inadequate commitment to implement. Suggestions can also be made for construction organizations, including main contractor, developer, government, and consultants, to distribute their finite resources optimally to implement SR in construction projects.

Keywords: Social Responsibility, Project stakeholder, Construction project management, Project social performance, Sustainability

1. Introduction

Construction organizations are facing unprecedented pressures and challenges in performing their social responsibility (SR) because of the social and environmental impacts caused by their construction activities (Othman, 2009). According to the report of UNEP-SBCI (2014), the entire lifecycle of buildings consume one-third of the worlds' energy, accounting for 30%–40% of the worlds' greenhouse gas emissions, 40% of the world's resources, and 12% of global water use. Construction in general also has a poor reputation in terms of ethical issues (Ho 2010, Ho 2011, Oladinrin and Ho 2014), being widely regarded as a sector rife with corruption and bribery (Moodley, Smith et al. 2008). In order to improve the notorious reputation of the industry, there is a need for attentions on the implementation of SR practices in construction projects.

SR Issues (SRIs) in construction projects focus on diverse aspects, such as health and safe working conditions, sustainability, environment, community development, and philanthropy. Given the uneven allocation of social resources and public attention, SRIs are attended to in different degrees. Organizations tend to engage in the high-profile SR programs to reinforce their reputational competitiveness on the market (Broomhill 2007). Owing to the Matthew effect, these issues would temporarily become the flavour of the mouth, whereas some important issues may be ignored or may receive inadequate attention. Investigating on the emphasized and the neglected SRIs are highly important in making appropriate SR strategies in the future.

With regard to the various SRIs, different project stakeholders focus on different priorities (Jonker and Nijhof 2006). Stakeholders from public and private sectors should take accountability for the overall project social performance (Shen, Hao et al. 2010). They engage in different ways to initiate, support, enforce, and supervise the implementation of SRIs. Given their different standings and available resources, project stakeholders tend to have their own understanding towards SR and display different abilities to accomplish their initiatives. However, what stakeholders are interested in may not always be what they are most capable of. In addition, SRIs would only be successful if powerful stakeholders utilize their power and exert their influences strategically (Prado-Lorenzo, Gallego-Alvarez et al. 2009). Stakeholders thus need to realize where their power lies so that they can distribute their resources optimally to maximize their overall social performance.

Although SR has been extensively studied, limited attentions have been devoted on the implementation of SR in the context of construction projects (Zeng, Ma et al. 2015). In addition, the stakeholders' interest and power on SRIs has never been compared. In this paper, we tried to answer the following questions. What are the most pressing SRIs in construction industry at present? What SRIs should be prioritized in the future SR policy? Does any gap between stakeholders' interest and power exist? How could stakeholders strategically engage in different SRIs? This study intends to find the answers to these questions through an empirical research conducted among Hong Kong construction practitioners to investigate the current situations of project stakeholders' interest and power.

2. Literature Review

2.1 SR in construction projects

SR was introduced as self-regulatory initiatives for businesses for the benefit of the wider society (Sheehy, 2014), and SR has recently received extensive attention from the academic and industrial communities (Schultz et al., 2013). Whether SR is profit-oriented or society-oriented or whether SR is voluntary or compulsory in nature are not the most crucial problem to be solved; SR could be a continuum between two extremes and consistently shifting along with the changing social requirements (Bhimani and Soonawalla 2005, Pirsch, Gupta et al. 2007). Taking SR as a contemporary moral standard for the proper conduct of business, responding to social problems should also be embedded as one of the purposes in the pluralistic organizational objectives (Enderle 2006).

Construction activities are associated with vast social and environmental problems, including construction wastes, noise pollution, eco-disturbance, severe working conditions, resources exploitation, and corruption and bribe (Moodley, Smith et al. 2008, Barthorpe 2010). Construction projects provide opportunities and potentials to different stakeholders. Many stakeholders (e.g. the companies along the construction supply chain, construction practitioners, end users, and societies, etc.) benefit from construction development while the construction activities exploited substantial natural resources and bring harms to environment and communities. There is a voice that stakeholders alongside enjoy their benefits but also owe similar amount of responsibility. Although SR has become popular among scholars and industrial leaders, few studies have investigated SR in the context of construction industry and is particularly rare in construction project environment (Zeng, Ma et al. 2015). Several studies through archival analysis and interviews that were conducted in some developed countries have shown that some large construction companies have realized the significance of SR and have agreed with the necessity of embracing moral commitments to the society (Petrovic Lazarevic 2008). However, the implementation of SR practices and programs are ineffective and inefficient because of the diverse and fragmented nature of the construction industry (Jones, Comfort et al. 2006). Looking from the perspective of the stakeholders, this research assesses the different concerns and powers stakeholders have on SRIs; thus, this study would facilitate SR implementation in construction projects.

2.2 Stakeholders' interest and power

Construction projects usually involve numerous stakeholders and even hundreds of organizations and individuals that can affect or be affected by these projects, and the stakeholders have different interest and demands throughout the whole project lifecycle (Packendorff 1995, Aaltonen and Kujala 2010). An investigation on the stakeholder' interest on infrastructure projects shows that conflicts and contradictions are inevitable among different stakeholders (Li, et al. 2012). This conclusion also applies on stakeholders' preferences on SR. Lindgreen, et al. (2009) investigated the American organizations and found that these organization place varying emphasis on SR. Likewise, Zeng, et al. (2015) proposed a project SR

framework for major infrastructures, demonstrating that project stakeholders should display different spectra of SR in different phases of their projects.

Obviously, not every stakeholder exhibits the same capabilities to attend to SRIs in construction projects. The stakeholders' power has been discussed for decades as an important dimension of stakeholder salience in the three-attribute model of Mitchell, et al. (1997). Some stakeholders with claims or interest may not possess the corresponding power to influence (Mitchell, et al. 1997). By contrast, some powerful stakeholders who exhibit superior ability to initiate some SRIs may not be enthusiastic in delivering these capabilities. Regardless of their intentions and preferences, powerful social actors are supposed to bear the corresponding responsibilities according to the fundamental principle; otherwise, they shall lose their power in return (Davis 1967, Enderle 2006). Therefore, the stakeholders being aware of their power and responsibility is crucial so that they can use these capabilities to influence the implementation of SR agenda in construction projects.

Analysis of the stakeholders' interest and power is an important task in stakeholder management (Polonsky 1996, Polonsky and Scott 2005). However, the analysis was made from the perspective of the focal company, and the result serves as the basis in devising the corresponding stakeholder strategies (Friedman and Mason 2004, Eesley and Lenox 2006). The mechanism by which the stakeholders' interest and power are distributed on different SRIs and whether there are any gaps between stakeholders' interest and power on SRIs exist remain to be elucidated.

3. Methods

To ensure the content validity of the survey, we identified the SRIs through archival analysis and expert screening. First, a pool of 80 SRIs specifically related to construction lifecycle practices were extracted through archival analysis. The sources included academic literature (journal articles published from 1970 to 2015 and were searched in Google scholar using the keywords CSR, sustainability, business ethics, construction, building sector), corporate reports (annual CSR/ sustainability report for the last five years of top construction companies, including Bechtel, The Turner Corp, AECOM, Kiewit Corp, Gammon, and Leighton), CSR standards, guidelines, and initiatives of international organizations (publications from GRI, ISO, Oxfam, UNEP, and WBCSD). Second, we invited 20 experts of project management experts to eliminate the SRIs that they consider unimportant or reduplicative, in order to come up with a shorter list of SRIs to be used in designing a questionnaire. This process was conducted using the Delphi method; after three rounds of anonymous questionnaire, a list containing 35 SRIs was finalized with the under 20% contradiction. The list covered the whole project lifecycle, including the three construction phases, namely, pre-construction, construction, and post-construction stages. In each stage, the SRIs were classified under seven CSR subjects in accordance with the ISO 26000 (SR Guidance). These subjects were 1) organizational government (OG); 2) human rights (HR); 3) labor protection (LP); 4) environment (En); 5) fair operation (FO); 6) customer issues (CI); and 7) community involvement and development (Co). During the screening, the major related stakeholders were also required to be nominated by the

experts. A total of seven major contractors were identified, namely, main contractor (MC), developer (DV), end user (EU), government (GV), consultants (CS), NGOs, and district councils. Using these 35 SRIs and 7 related stakeholders, the questionnaire for this study was built in the form of a matrix, with the 35 SRIs as the row titles and the 7 stakeholders as the column titles. In the matrix blanks, the respondents would be asked to evaluate their interest and perceptions of the 7 stakeholders' influence on each SRI using a 5-point scale. The word "influence" was used instead of "power" because of their similarity in daily usage and the negative connotation of the word "power" (Brass and Burkhardt 1993). The questionnaire aims to determine the respondent organizations' subjective interest and to objectively evaluate the 7 main stakeholders' power on the 35 SRIs.

For the pilot study, three versions of the questionnaire (English, Traditional Chinese, and Simplified Chinese) were delivered to small groups of people who use the corresponding language. A formal survey was subsequently conducted on 120 practitioners invited from different stakeholders from the construction industry in HK. Considering the complexity of the questionnaire, the survey was conducted in a paper-based method. Assistance was provided in case the respondents have any queries or confusions. Finally, 89 valid questionnaires were collected (valid response rate 74%). The respondents are categorized mainly into four groups of stakeholder: MC companies ($n = 35$), DV companies ($n = 11$), GV departments ($n = 6$), CS companies ($n = 20$), and the rest are categorized as others, which include EU, investors, NGOs, sub-contractors ($n = 17$).

The data on all 35 SRIs were first analyzed as a whole. Considering the disproportion of the sample in this survey, the data was required to be reweighted to reduce the over- or under-representation of the stakeholder groups before calculating the average for the holistic analysis. The average stakeholders' interest and power on the 35 SRIs were compared based on the reweighted data. Second, the entire sample was divided into four subgroups according to stakeholder grouping (MC, DV, GV, and CS). In each subgroup, paired t-test was adopted to test the differences between the stakeholders' interest and power. Paired t-test is frequently used to test the significant difference between two observations in a group of subjects (Hsu and Lachenbruch 2007). Furthermore, to illustrate the details of the interest-power gaps for each stakeholder group, the interest-power profile in seven subjects and the interest-power fluctuations throughout the project lifecycle stages were shown for detailed comparative analysis.

4. Results and Discussion

4.1 Overall gaps between interest and power in all stakeholders

In Figure 1, the stakeholders' average interest is generally higher than the average power, indicating the stakeholders' positive commitments to SR, although the lack of adequate power to launch their initiatives is one of their obstructions. The stakeholders' interest on 35 SRIs reveals that much attention has obviously been devoted on LP issues and some of En issues and CI, whereas limited attention was devoted on OG and Co issues. This result corroborate with

that of an investigation on UK construction companies, where health/safety and environmental issues are currently the hotspot SRIs, whereas less concern are devoted on community and governance (Jones, Comfort et al. 2006). The disparities between interest and power vary significantly among the seven subjects of SR. The SRIs on LP, FO, and CI have the significant gaps between higher interest and lower power. The result is reasonable because HK government

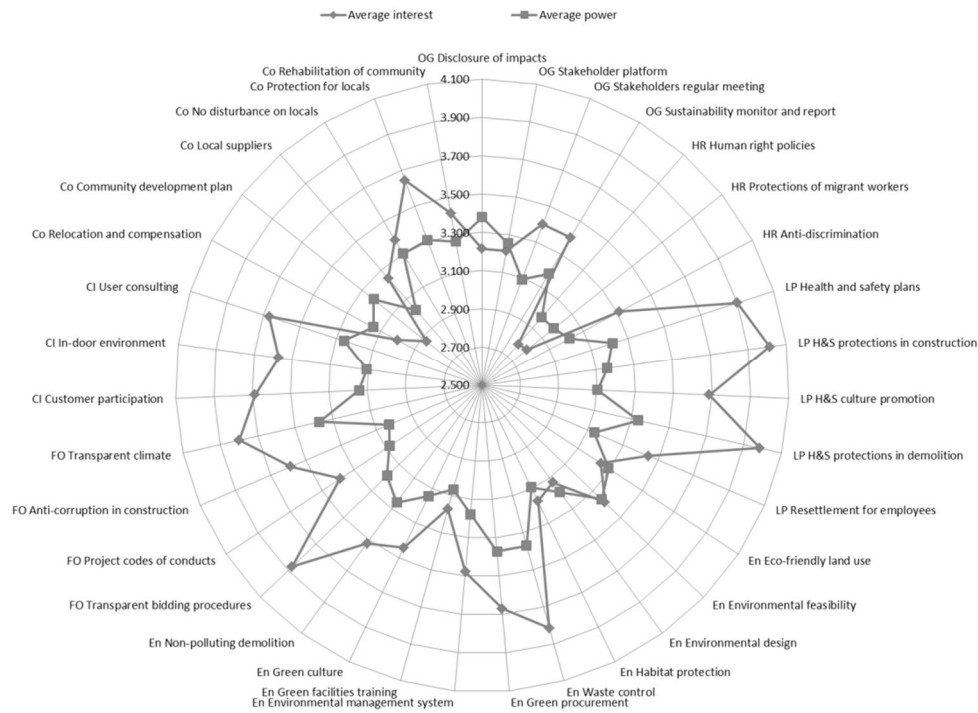


Figure 1: Overall gaps between stakeholders' interest and power

put construction health and safety as the top focus of industrial legislation. Moreover, HK is one of the leading transparent markets in the world (ranked 17th out of 175 countries in corruption perception index in 2014). This finding show that the legislation of local government highly influence the businesses' emphasis on SR. The SRIs that stakeholders' interest is higher than their power (LP, FO, CI, and part of En) are beyond the ability of any single stakeholders and require the communications and collaborations among multiple project parties from public and private sectors (Bendell, Collins et al. 2010, Savage, Bunn et al. 2010). By contrast, stakeholders have more power compared with their interest on HR, and part of OG and Co. More concerns and resources should be invested on these issues because these are within their current capabilities; however, these issues are neglected by stakeholders due to some reasons, such as disclosure of project impacts on the environment or society (OG), HR and protections of migrant workers (HR), and relocations and preparing community development plans (Co).

4.2 Main contractors (MCs)' interest and power on SRIs

The MCs are one of the core project team members, and they take charge of the most essential processes in the project lifecycle. Most SRIs in construction projects will not be successful without the effective engagement of the MCs. The result of the paired t-test on the MC

subgroup (Table 1) shows that the mean of MCs' interest is not significantly different from the mean of their power ($t = -1.409$, $p = 0.159$). This finding indicates that the MCs' preferences on SRIs and self-perceptions of power are approximately consistent. MCs' power is slightly higher (mean = -0.05934) but not statistically significant. Figure 2 shows that the MCs' power is superior over their concern levels mainly in the dimensions of CI and FO issues. In the project lifecycle, the MCs' interest-power difference is largest in the construction phase than in the undifferentiated beginning and end phases. Moreover, MCs show superior power on LP issues and in the project construction phase. Thus, the occupational health and safety protections issues, especially the on-site protection and safety measures, should be mainly dominated by the MCs. In addition, the SR initiatives of the MCs are more effectively implemented during the construction phase, that is, when they are more powerful to coordinate resources and obtain support from other stakeholders.

Table 1: Paired t-test result of MCs' sub-group

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
MCinterest - MCpower	-.05934	1.27029	.04211	-.14198	.02330	-1.409	909	.159

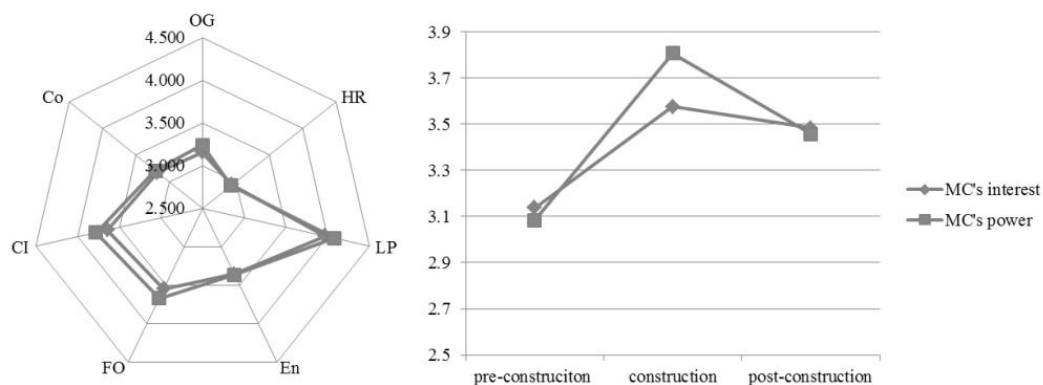


Figure 2: MCs' interest-power in the seven subjects and in the three project lifecycle stages

4.3 Developers (DVs)' interest and power on SRIs

The DVs generally play a powerful role in construction projects because they can directly raise their demands in bidding documents or contracts, as well as the social requirements of the construction outcomes. The paired t-test shows that the DVs' interest and power are significantly different ($t = -2.709$, $p = 0.007$) (Table 2), indicating that the mean of DVs' power is significantly higher by 0.14063 than the mean of the DVs' interest. This difference shows that the DVs still exhibit the potential of fulfilling their responsibilities on some issues where they may not be recognized as important. Further comparison of the seven subjects were made and the result (Fig. 3) reveals that the DVs possess more power but devoted less interest in the SRIs

on Co. Moreover, Co issues have attracted vast attentions in the SR agenda, especially in mining industry (Jenkins and Yakovleva 2006). The major DV in mining industry have exerted much effort to obtain social license to operate in local communities. However, data has revealed that community issues apparently difficultly attract DVs' attention in the construction industry. On this point, construction DVs should recognize their capabilities in community issues, devote themselves in developing local facilities, care for local residents, and contribute to local employments. In terms of the project lifecycle, DVs' power is highest in the pre-construction stage, exceeding the interest in the same period. By contrast, DVs' power drops to the lowest point in the construction stage and power is considerably lower than the interest. Considering that the DVs' interest continuously rises but the power dramatically decreases after the construction began, DVs should make comprehensive SR plans in project inception and design stage and presents all the plans before construction starts.

Table 2: Paired t-test result of DVs' sub-group

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
DVinterest - DVpower	-.14063	1.01735	.05192	-.24270	-.03855	-2.709	383	.007

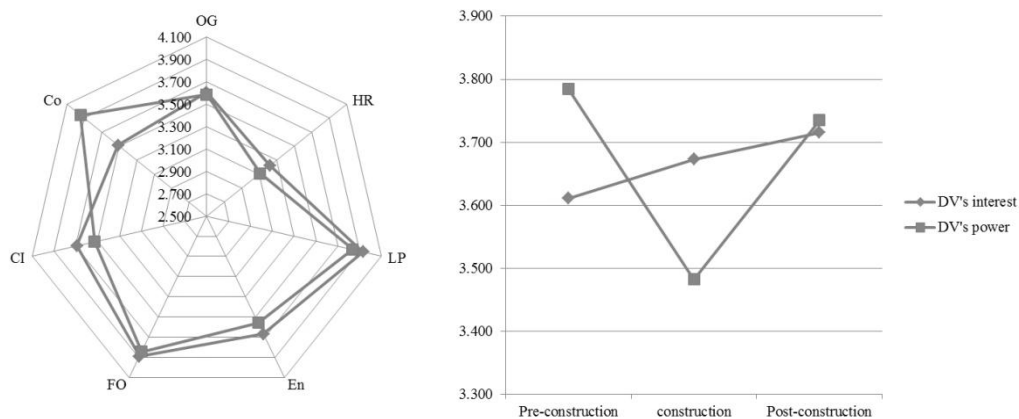


Figure 3: DVs' interest-power in the seven subjects and in the three project lifecycle stages

4.4 Governments (GVs)' interest and power on SRIs

The GV departments set the baseline for the SR of projects; therefore, their power is undoubtedly high. However, whether GV's interest to set forth to higher level of SR legislation, or encourage SR implementation, is in the same level with their power is questionable. Table 3 demonstrates that there exists a significant difference between the GV's interest and power ($t = -5.224$, $p = 0.000$). The mean of GV's power is higher by 0.33333 than the GV's interest, indicating that in HK, GV's attentions on SR in construction projects are not considerably sufficient. This phenomenon is possibly caused by the uneven distribution of funds among the different departments, as well as the current strategies of the construction authorities. This lack of attention on SR legislation possibly results in the lagging development of construction market

in HK. Among the seven subjects (Fig. 4), the GVs' power-interest gap is most distinctive in the HR dimension, suggesting that the attention the HK GVs' is paying on HR issues are inadequate in view of its social development level. In addition, the government should further endeavor to devise HR policies that are beneficial to the minorities and that eliminate discrimination in construction projects. Similar to DVs, the GVs exhibit the highest power in pre-construction stage, and this power remains considerably high in the whole lifecycle. However, the GVs' interest on SRIs is relatively low and reaches its lowest level in the construction stage.

Table 3 Paired t-test result of GVs' sub-group

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
GVinterest - GVpower	-.33333	.92459	.06380	-.45911	-.20755	-5.224	209	.000

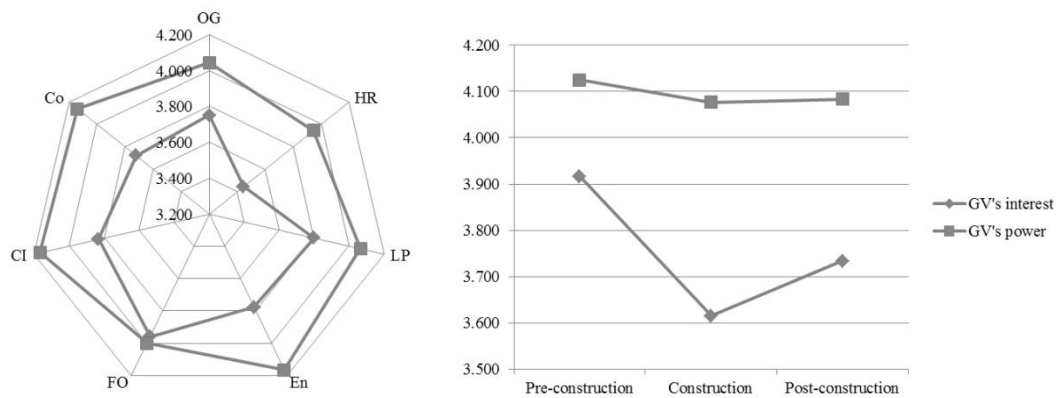


Figure 4: GVs' interest- power in the seven subjects and in the three project lifecycle stages

4.5 Consultants (CSs)' interest and power on SRIs

Significant gap is also detected (Table 4) between the CSs' interest and power ($t = 5.044$, $p = 0.000$). However, the opposite pattern of difference is observed; the interest is greater by an average of 0.25215 than the power, implying that the CSs are more proactive and aggressive on SRIs in the construction industry. CSs possess the most advanced knowledge or techniques in improving project social performance and their attitude toward SRIs are relatively positive. However, given that CSs are normally under the command of their clients, implementing their SR plans without the DVs' supports is difficult, although CSs could provide socially responsible alternatives for DVs to decide, such as greener or more resource efficient design, stakeholder communication scheme, and community development plans. This interest over power is observed in all of the seven subjects, especially in the CI and FO dimensions (Fig.5). To effectively achieve the SR goals, CSs must actively align with more powerful stakeholders, such as DVs and MCs, to initiate and implement the SRIs. Figure 5 also shows that the gaps between CSs' interest and power increases along with the progress of the project. This finding implies

that it becomes more difficult for CSs to implement their SRIs if they did not bring them up before the construction began.

Table 4 Paired t-test result of CSs' sub-group

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
CSinterest - CSpower	.25215	1.32064	.04999	.15401	.35029	5.044	697	.000

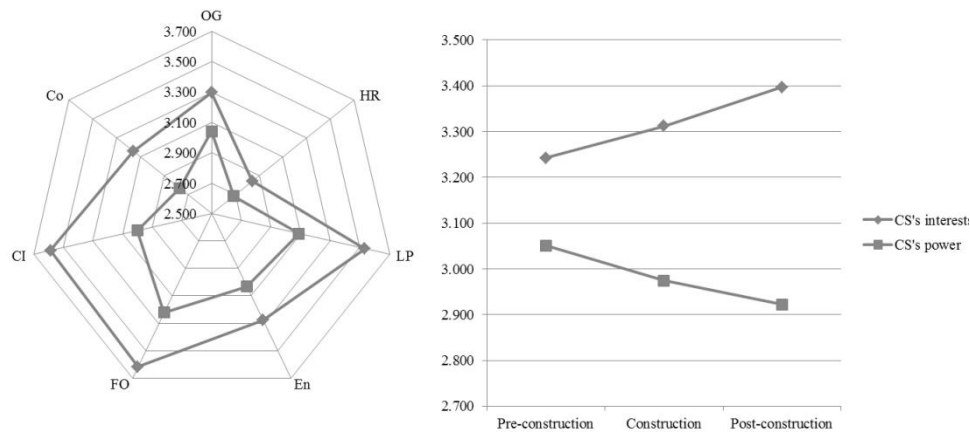


Figure 5: CSs' interest- power in the seven subjects and in the three project lifecycle stages

5. Conclusions

The comparison between stakeholders' interest and power revealed that some SRIs (labor protection, fair operation, customer issues, and environmental issues) are in greatest need of stakeholders' collaborations and joint efforts for their successful implementation. Some issues, including re-allocation and compensation of local residents, development plan for community, and disclosure of the social and environmental impacts of projects, call for more attention from project stakeholders. Main contractors, as key members of project teams, know the SRIs that they have power on. They have power to implement labor protection issues, including employees' health and safety in different project stages. In addition, main contractors should take advantage of their prevalent status in the construction stage to implement their SR initiatives at the right time. Compared with the exclusive power that developers have in presenting SR demands in project scope, developers showed inadequate interests on implementing SRIs. And this lack of interest phenomenon implies that the construction developers have the ability to set forth community development plans and community protection issues but do not have enough motivations to implement them. Moreover, although developers are influential, their status is only superior before construction begins. Government departments should lead the implementation of SRIs in construction projects; however, they have insufficient interest on most SRIs, particularly during construction stage. By contrast, consultants are more disposed on performing SR, even though they lack in power. It suggests

that consultants should begin reinforcing their controls on SRIs by aligning with the powerful stakeholders (e.g. governments or developers).

Understanding the stakeholders' interest and power can reveal the implications of the distribution of responsibilities of SRIs in construction projects. Interest implies the stakeholders' intentions and goals on SR, whereas power is the responsibility that they are expected to assume. The result of this study will not only serve as guidance to project managers in engaging powerful stakeholders on SRIs implementation, but also as decision supports for construction organizations to strategically allocate their finite resources on the SRIs that they have superior power on. This investigation has also shed light on the SRIs that are currently neglected by powerful stakeholders; these SRIs call for future concerns and investments. However, the sample size should be increased and balanced among the stakeholder groups to make the result more representative. Considering that this questionnaire survey is devised in the context of HK construction industry only, the results can be hardly utilized in other regions because the results may vary under different social background.

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The Virtue of Sustainability

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Abstract

The ambition of this conceptual paper is to better understand the fundamentals upon which sustainability can be achieved within the context of the construction sector today. The most common methodological approaches to achieving sustainability seem to be based on the presumption that an ever increased refinement of assessment tools of different sorts, – such as LCA, LCC, C/B-analysis, etc. – will eventually provide sufficient for assuring the sustainability of project based ventures. In this paper we argue that the implementation and refinement of such tools cannot be said to secure sustainability of projects given their inherent limitations.

The base premise of the research is that control systems typically function well for promoting organizational or individual behaviour to attain project objectives. They are equally essential in most forecasting and anticipation of events that can lead to undesirable consequences in a project. No control system, however, how detailed and effectively implemented it might be, can foresee every eventuality or unanticipated circumstances. Literature shows that assuring sustainability is highly dependent on proper risk control, predictability, framework conditions, and long term assessments. These are all factors that not easily fall in line with the above mentioned systems. Thus, if sustainability is to be achieved through projects, control systems etc. will not suffice to assure sustainability.

The big question is then what is to replace such control systems. The idea of this paper is to explore the insights from classical virtue ethics – in the tradition from Aristotle – to articulate an alternative path to achieving sustainability than through ever more rigorous control systems. The central notion here is the one of character, most notably the character of the project manager. Projects are realised by project teams under the leadership of a project manager. Enabling the project manager to cope with the eventualities threatening the sustainability of the project thus becomes essential. There is a crucial need for enabling future sustainable project managers to handle this kind of tasks.

Keywords: ethics, sustainability, virtue, education

1. Introduction

This paper outlines an understanding of what the contemporary understanding of sustainability can gain from insights from so-called virtue ethics in the tradition from Aristotle (2009). This is carried out as part of a more general enquiry within the field of the ethics of the Norwegian AEC (Architecture, Engineering and Construction) industry. The ambition is seeing the concept of sustainability as lying in so to say the keel water of that of ethics, the first being a translation of terms to make practical morality operational within the engineering disciplines.

The importance of increasing the awareness among engineering practitioners concerning themes covered both by sustainability and ethics seems crucial to attaining what Mirsky and Schaufelberger (2014) maintain as the most important topic to the future of the AEC industry, notably “honourable, professional practice” (Mirsky and Schaufelberger, 2014). More recently, different industries and trades have witnessed an increasing interest in the field of applied ethics in general and in professional ethics in particular (Christoffersen, 2011). Different professions establish rules and regulations, such as medical doctors, teachers, social workers etc., and the number of publications is ever increasing. The authors of this paper have so far not seen this trend reflected strongly in publications concerning the AEC industry in general, or in actual industry agreements in Norway. Notable exceptions from this general statement include the writings of Bown et al. (2007), Bröchner (2009), Corvellec and Macheridis (2010), Fellows et al. (2004), Hill et al. (2013), Ray et al. (1999)).

Considering that the AEC industry in general and in Norway in particular typically receives attention as an industry of doubtful virtue, 1) where neither the police, the tax authorities nor the professional organisations fully master the challenges posed by professional practice (Andersen et al., 2014); 2) where the inherent complexity in itself opens the opportunity for suspicious dealings (Gunduz and Önder, 2012); 3) where fraudulent business practices undermine the reputation of the industry (Slettebø et al., 2003); and 4) that lacks a clear vision based on a fortified ethical foundation (Wolstenholme et al., 2009), we find this strange. As Hill et al. (2013) comments, there is probably no simple solution, no “quick fix”, to the challenges of ethical nature that the industry faces. Tackling such challenges necessitates, it seems, both insight and endeavour. The notion of sustainability seems to be one key to addressing such problems within the AEC-industry at large.

The concept of sustainability, however, is multifaceted, and is used in different manners within different contexts. As Gomis et al. (2011, 174) point out, ‘sustainable business’, ‘sustainable technology’, ‘sustainable agriculture’, ‘sustainable economics’, etc. are all buzzwords of the literature today. According to Adams (2006), ‘[a]nalysts agree that one reason for the widespread acceptance of the idea of sustainable development is precisely [its] looseness. It can be used to cover very divergent ideas [...]. The concept is holistic, attractive, elastic but imprecise’ (2006, 3). This differentiated use has in fact, according to Marshall and Toffel, ‘nearly rendered the term sustainability meaningless’ (2005, 673). Those venturing into the literature will in fact find a breath-taking number of different understandings and definitions. In his non-conclusive going-through, Hasna (2010) lists 67 definitions.

Despite the apparent imprecision concerning the comprehension of the notion, a certain general agreement does nonetheless seem to exist. As Adams points out, the ‘core of mainstream sustainability thinking has become the idea of three dimensions, environmental, social and economic sustainability’ (2006, 2). Sustainability can be analysed with different aspects in mind, but the three dimensions can be used to categorise the identified sustainability factors or elements (Flores et al. 2008). For a discussion of the comprehension of the three pillars, their balancing act, and the different analytic levels according to which it seems necessary to implement them successfully, we refer to Haavaldsen et al. (2014).

It is easy to despair when faced with such seemingly impossible matters of precise knowledge and definition. If turning the question around, however, it takes another colour. If – rather than looking at the definitions, different understandings etc. of the phenomenon – we examine the reason for the term surfacing, the picture alters.

1.1 Sustainability and ethics

When examining the use of the sustainability, there seems to be a strong linkage between the concepts of sustainability and of ethics. A main ambition of this work is to outline what implications this linkage can entail, notably concerning the difference between rules and virtue-based approaches.

Ethics is commonly perceived to be the science that investigates what one ought to do. Moral, on the other hand, is typically considered as the practical mechanisms through which such behaviour is judged. In particular based on the common etymological roots of the two concepts, we in the following consider them as fairly synonymous, basing the exposé on the first of the two.

At a very general level, one main cleavage within the field of ethics can be found between so-called rule-based and virtue-based approaches (we do not here say that all ethical theories fall within a scope that is relevant for this distinction, solely that these occupy a primordial place in the field of ethics). What we here call rule-based covers in fact a variety of theories that are hugely diverse, the most influential today are probably deontology (in the tradition from Kant) and different forms of utilitarianism (such as presented by Mill, 2002). This distinction has been masterfully been described by Anscombe (1997).

What brings together these major intellectual currents is that they proclaim that action ought to be justified and considered ethical or not according to a rule of some sort. For Kant, this rule was formulated in the so-called categorical imperative. For the utilitarian, the idea of the greatest good for the greatest number of people tends to be the rule according to which one is to act in the world.

Virtue-based ethics, on the other hand, takes a different stance to the question of judging what is ethically estimable. Rather than focussing on abstract principles from which rules of conduct can be determined, virtue ethics in the tradition from Aristotle focuses on what it calls the

character of the actor. The question haunting fourth century BC Athens – how can one assure that the inhabitants of the republic act in an ethically sound manner – in fact resonates deeply within today's societies in general – and within the professions that form the AEC-industry in particular. This character is typically sought developed using examples, to expose what is ethically good and blameworthy behaviour. To put this in contemporary engineering language, we can say that deductive top-down rules based approaches of the rule-based ethical systems are replaced by an inductive bottom-up approach in virtue-based approaches.

1.2 Rule-based vs. virtue-based understanding of sustainability

If then, we propose that the concept of sustainability ought to be understood as following closely that of ethics, it should follow that the cleavage between rule-based and virtue-based approaches should be as crucial within the context of sustainability as within that of ethics.

To undertake conceptually the implications this insight, however, seem to be rarely treated in the literature, and, to take the consequences of this into actual practice seems even further from the main research agenda, as we perceive it. Some notable exceptions exist; see for instance Helgadóttir (2008) for an example of an analysis inspired by Aristotelianism.

In order to address this general challenge, we address the following research questions:

- 1.) What are the main challenges to sustainable practice within the Norwegian construction industry today?
- 2.) What measures can be identified as reasonable to address these challenges?

Questions of this type are inherently difficult to examine from an empirical perspective. They are of a principal nature, meaning that their essence tend to slip from empirical investigations. Therefore, we in the following address these questions in a conceptual manner, illustrated with some general reflection upon general frameworks. The main point is to outline what – from both theoretical and practical perspectives (as understood by the authors of this paper) – can be identified as the main challenges to sustainable practices within the AEC-industry.

2. Methodological approach

The methodological approach constituting the research behind this paper is threefold in nature. First, a literature study was carried out in accordance with the procedures described by Blumberg (2011). A documentation study was conducted in order to provide an overview over the approaches chosen among 25 major actors within the Norwegian AEC-industry, notably an examination of their ethical frameworks. The reason for selecting the large companies was an anticipation of that they want to be in the forefront and show the way for smaller companies. The ten contractors was selected from top of the 2015 top 100-list (based on annual turnover) of the magazine *Byggeindustrien* (<http://www.bygg.no/100-storste>). The authors picked the five public owners based on their general knowledge of the Norwegian construction industry. The private owners are more randomly selected, but the selection criteria included visibility in the

public debate of social affairs, membership in Grønn byggallianse [Green Building Alliance] and/or have recently developed projects that received BREEAM-NOR certificates for the design phase and/or completion. The engineers were the five most popular on the 2015 career barometer, a result from a survey among approximately 8000 students initiated by a private media house (<http://www.karrierestart.no>). All the examined companies describe their code of ethics on their web pages, but a few did not publish them there. Finally, we examined the so-called millennium goal of the UN in order to see what this general framework could imply for the understanding of the broad picture.

3. Findings – How actors actually address the challenges?

As Haavaldsen et al. (2014) outline, sustainability can be understood at several analytic levels, and according to several perspectives. In the following, we examine two approaches we perceive to be situated at a strategic level, notably the ethical frameworks of 25 major companies from the industry (national level) and the millennium goals of the UN (international level). These approaches differ in that the overall approach of the ethical frameworks to the subject matter is a relatively hard ruled-based approach; whilst the millennium goals stress a rather fluid approach open to interpretation. As we shall see, challenges of different natures follow each of these two main approaches.

3.1 Codes of conduct interpreted as intended to sanitise the AEC-industry nationally

Most major companies within the Norwegian AEC-industry have ethical guidelines or codes of conduct, the distinction between which is somewhat blurred. What is of interest in this context, is that they all ambition to codify the behavioural stance of members of the company. Ethical codes are adopted by organizations to assist members in understanding the difference between 'right' and 'wrong' and in applying that understanding to their decisions.

On their webpages, the public owners appear as engaged in ethical issues because of their own descriptions of their Code of ethics. According to their own descriptions, their Code of ethics consist of several layers, with for example guidelines for contact with property owners, ethical guidelines for suppliers etc. Despite their engagement, only one public owner has made the Code of ethics available through the webpage. One approach to increase transparency – as public owners should – would be to make the code of ethics easily accessible for all stakeholders. Two of the contractors have not published their Code of ethics at their webpages.

Private owners seem – at least on their webpages – to be concerned with ethics and ethical guidelines. Two private owners that form part of a larger mother organisation with international activities have extensive guidelines that reach for standards above the minimum legal requirements. Two private owners are mainly operating in the Norwegian property market, and their Codes of conduct describe the distinction between legal and illegal, but not the distinction between ethical and unethical. One of the private owners has not established an own Code of conduct, but is planning to do so within short time.

Among the engineers, four have published their Code of ethics on their webpages. The guidelines seem to have general formulations. The fifth one, which has not published their guidelines, describe on their webpage a procedure where their employees have to sign that they have read and understood the meaning of the Code of ethics. A scrutiny of these codes reveals a surprising level of divergence, as table 1 shows.

Table 1: Ethical codes of 10 contractors, 5 public owners, 5 private owners and 5 engineers within the Norwegian AEC-industry

Organisation	Distinction between legal/illegal	Distinction between ethical/unethical	Accessible on web	Number of text pages
Contractor 1	Yes	Yes	Yes	22
Contractor 2	Yes	Yes	Yes	10
Contractor 3	n/a	n/a	No	n/a
Contractor 4	n/a	n/a	No	n/a
Contractor 5	Yes	No	Yes	1,5
Contractor 6	Yes	No	Yes	2
Contractor 7	Yes	No	Yes	9
Contractor 8	Yes	No	Yes	1
Contractor 9	Yes	No	Yes	3
Contractor 10	Yes	Yes	Yes	8
Public owner 1	Yes	Yes	Yes	14
Public owner 2	n/a	n/a	No	n/a
Public owner 3	n/a	n/a	No	n/a
Public owner 4	n/a	n/a	No	n/a
Public owner 5	n/a	n/a	No	n/a
Private owner 1	Yes	Yes	Yes	10
Private owner 2	n/a	n/a	No	n/a
Private owner 3	Yes	No	Yes	2
Private owner 4	Yes	Yes	Yes	3
Private owner 5	Yes	No	Yes	10
Engineer 1	Yes	Yes	Yes	14
Engineer 2	Yes	Yes	Yes	20
Engineer 3	Yes	Yes	Yes	1,5
Engineer 4	n/a	n/a	No	n/a
Engineer 5	Yes	Yes	Yes	9

Most remarkably, their extent varies between one and 22 pages. Secondly, their availability on the net is variable; some are merely not accessible for the general public (without providing any clear explanation for this withdrawal), a fact that renders this analysis problematic. Thirdly, and most importantly, all available codes distinguish clearly between legal and illegal behaviour, condemning the last clearly, whilst the difference between what is ethical and unethical, however, is more blurry.

It is in fact this latter point that is of prime interest to our analysis: All of the examined codes of ethics describe the distinction between what is legal and what is illegal. Among the contractors, only Contractor 1, Contractor 2 and Contractor 10 describe the distinction between what is ethical and what is unethical. Five of the contractors have quite similar codes of ethics, which – roughly – tell their employees to follow the minimum legal requirements. If their employees want to, they can reach for stricter requirements, but that will be their choice.

In our view, this fact points to the weakness in rule-based approaches as observed earlier. There seems in general to be no limit to what you can do, as long as you stay within the limits of the law within these codes of ethics. It thus seems that actors not being aware of the difference between ethical and lawful behaviour has developed a majority of these codes of ethics. On a more general level, this points in fact to the shortcomings of such rule-based frameworks: actors operating within these frameworks can in fact go very far in acting in what can be called an unethical manner, without this action conflicting with the code.

3.2 The 2030 Agenda for Sustainable Development

On the 25th September 2015, world leaders gathered in New York to adopt the 2030 Agenda for Sustainable Development. The Agenda that was agreed upon comprises of 17 new Sustainable Development Goals listed in table 2. The objective was to produce a set of universally applicable strategic goals that balances the three dimensions of sustainability.

The main characteristic of these formulations is how general they are in nature. These are, in fact, policy statements, and it is clearly difficult to implement them directly in projects. Much can be said on the subject of their roundness, giving ample place for interpretation.

Table 2: The Sustainable Development Goals as proposed by the Agenda for Sustainable Development (UN General Assembly, 2015).

<i>Goal 1: End poverty in all its forms everywhere</i>
<i>Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture</i>
<i>Goal 3: Ensure healthy lives and promote well-being for all at all ages</i>
<i>Goal 4: Ensure inclusive and quality education for all and promote lifelong learning</i>
<i>Goal 5: Achieve gender equality and empower all women and girls</i>
<i>Goal 6: Ensure access to water and sanitation for all</i>
<i>Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all</i>
<i>Goal 8: Promote inclusive and sustainable economic growth, employment and decent work for all</i>
<i>Goal 9: Build resilient infrastructure, promote sustainable industrialization and foster innovation</i>
<i>Goal 10: Reduce inequality within and among countries</i>
<i>Goal 11: Make cities inclusive, safe, resilient and sustainable</i>
<i>Goal 12: Ensure sustainable consumption and production patterns</i>
<i>Goal 13: Take urgent action to combat climate change and its impacts</i>
<i>Goal 14: Conserve and sustainably use the oceans, seas and marine resources</i>
<i>Goal 15: Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss</i>
<i>Goal 16: Promote just, peaceful and inclusive societies</i>
<i>Goal 17: Revitalize the global partnership for sustainable development</i>

It seems hard to argue against these general formulations. What is of prime importance is their all-encumbering nature. This trait is often criticised in this type of policy documents. The analytic force of such general statements, however, is that they typically leave the actors free to apply the statements to their own context – within the boundaries of their semantic extension. The key element here, however, is the translation from policy statements to sustainable practice, in other words, how to translate the goals that indicate the intended virtue of our generation into practical, achievable project within the AEC-industry.

3.3 Translating the goals into practice

If we first look for the three dimensions of sustainability embedded in the 17 goals in this list, we may find direct or indirect traces of all three. The dimensions are taking on different nature depending on the goal in view. If we look at the first goal, for instance, it is obvious that the goal has a number of social and environmental challenges in addition to the economic dimension.

When planning such projects – that is, interpreting the way from the policy level to actual project realisation – we have found it useful to distinguish between three goal levels where all dimensions of sustainability may be determined from the given (broad) context. This provides a better understanding of the practical issues contributing to the complexity of sustainability.

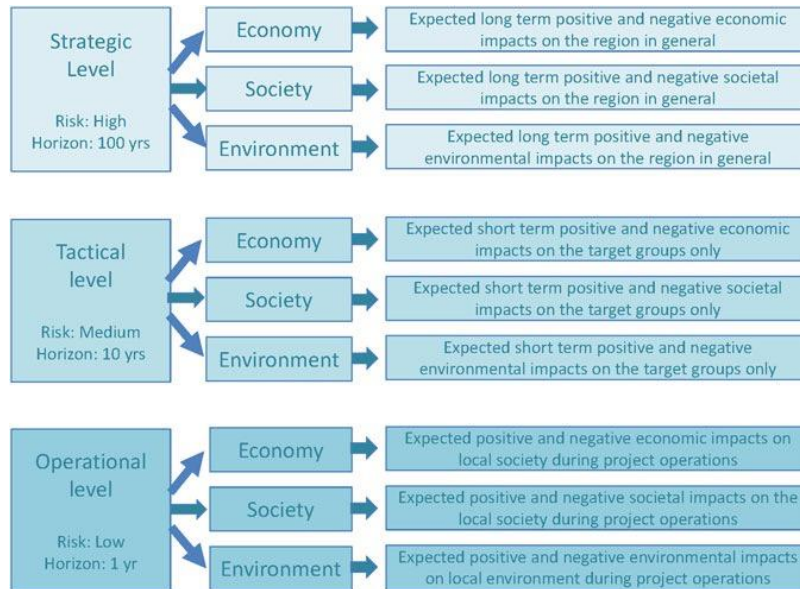


Figure 1. Suggested criteria for assessment of sustainability of projects (Lædre et al., 2015)

The figure outlines the three pillars of sustainability as sorted according to the three analytic levels of strategic, tactical and operational. It also underlines the risk elements pertaining to each of the analytic levels. Lastly, it stresses the differences in temporal horizon typically characterising the different analytic levels. Lædre et al. (2015) go far more into detail.

In other words, it seems useful to evaluate all goal levels of identified project concepts before finally deciding about them. The main reason for this is that the assessment of the three different dimensions of sustainability by addressing economic, social and environmental impacts will certainly vary with the goal level in focus.

4. Discussion and conclusions

The underlying argument in this paper has been to reconsider the recourse to rules as the unique prism through which trying to control activities of an industrial nature with multiple actors. The AEC-industry present a striking case of an industry where such rule-bound optimism stands seems futile – at least in the eyes of the authors of this paper, as the examples cited above clearly indicate. We set out to address what are the main challenges to sustainable practice within the Norwegian construction industry today and what are the corresponding reasonable measures to these challenges. On basis on this, we make the following claims: 1) There seems to be a near universal identified need for a sustainable practice within the industry. This seems to

be reflected in the codes of ethics examined. In this paper, we have tried to illustrate how the virtue-based approach can help developing this. 2) The international approach, however, seem to take the virtue-based ethics too far in that their limits are too loose in that the need for translation into engineering practice becomes too complicated. A national strategy for concretising this overreaching might be a way to proceed.

It seems to the authors of this paper that there is a profound need for knowledge-based apprehensions of how to act. Virtue ethics in the tradition from typically recommends the use of examples to enlighten the actors of the correct choice in the specific situation. In order to render this a bit more concrete, we propose the following practical recommendations:

- Expand the understanding of the rules of the profession – and the limits of the rules.
- Expand the understanding temporal aspects of the endeavours you undertake
- Understand the analytical levels of sustainability assessments
- Enable students to learn from examples – people and projects
- All organisations need involve new employees in the ethical foundations of the organisation's practice – not just in ethical codes.

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Green Business Models and Organisational Changes: Lessons from the UK Construction Sector

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Abstract

Green business models (GBMs) can support green growth because they are based on green value creation and capture with emphasis on clients role. However, GBMs require substantial investment and strong change capabilities. This paper maps organisational changes associated with GBMs transformation. For this purpose, 19 semi-structured interviews are conducted with a heterogeneous sample of academics and managers from the UK construction sector. The interviews then are analysed by a means of thematic analysis with aim to capture any common changes and to form similar patterns of changes which occurred within the sample. Surprisingly, there are a lot of similarities that can be grouped broadly into three major themes: green profile development; structure; and operations. In addition, the change starts from the strategic level (policy) to the operational level but it may be triggered by the people at the operational level. Furthermore, GBMs not only change product/service and process but also catalyse broader systems change of the green value chain. Therefore, construction organisations have to accept that transition to GBMs will bring significant changes to the way they work if these models are to flourish.

Keywords: Change, construction, green business models, UK, and systematic change.

1. Introduction

As sustainability becomes an even more prominent matter of concern for the construction sector, the understanding and enactment of so-called green business models (GBMs) will become more pertinent (Boons & Lüdeke-Freund, 2013; Jing & Jiang, 2013) . Sustainability will lead to fundamental changes in the business world (Esty & Winston, 2009) with the construction businesses being no exception. Naturally, the resulting new business environment brings about enormous opportunities and challenges that can shake the competitive landscape of industries to the core (Boons et al., 2013; Sommer, 2012). *“Thus, hesitant managers should be asking themselves: How do sustainability issues influence the future success of our current business model? And: How can we adapt them to best mitigate the risks and take advantage of*

opportunities arising from sustainability issues?” (Sommer, 2012 pp.5). GBMs can be a means towards competitive sustainability because they are based on green value proposition creation to customers and capture of profit and reputation. Henriksen et al. (2012) provided a definition for GBMs as follows: “*GBM innovation is when a business changes part(s) of its business model and thereby both captures economic value and reduces the ecological footprint in a life-cycle perspective*”. Therefore, the GBM concept can explain sustainability in terms of creating value and how value is defined (Abuzeinab & Arif, 2013). In addition, the GBM can help organisations to transform their abstract environmental strategies into viable business concepts (Sommer, 2012). Furthermore, concentration on the GBM can help better evaluation of current construction organisations BMs and assess their future suitability regarding sustainability aspects and competitiveness (Mokhlesian & Holmen, 2012; Sommer, 2012). However, it is vital for studies on this field to define GBMs explicitly to reduce the ambiguity around the concept (Abuzeinab et al., 2014).

According to Aho (2013), GBMs have the potential to transform construction organisations. However, this remains relatively unknown and the research is under-developed in this area. The aim of this paper is to investigate organisational changes associated with GBMs transformation in the construction sector. To achieve this aim, it is vital to choose an appropriate research method because little is known about GBMs and organisational change. The remainder of this paper is structured as follows: Section 2 presents the theoretical perspective of this study where sustainability within the construction sector is reviewed briefly followed by a review on sustainability and organisational change in general literature. The review has demonstrated lack of research dealing with organisational change and GBMs in the construction context. The justification of research method is presented in Section 3 where qualitative methods are deemed relevant for this exploratory study. By applying manual thematic analysis, three major organisational changes (themes) are found and discussed in Section 4. Conclusions are presented in Section 5 including limitations and future direction for the topic.

2. Literature review

In the UK, construction is a major sector of the national economy. Rhodes (2014) stated that the construction sector accounts for 6% of the economic output and provides employment for 6.5% of the population. According to Akadiri & Fadiya (2013), several initiatives supporting sustainability of the construction sector have been developed such as regulations, voluntary policies, economic measures and fiscal incentives. Examples of these initiatives include: changes to the Building Regulations; Aggregates Levy; Landfill Tax; and Renewable Grant Schemes. Assessment tools and demonstration projects have been showcased to demonstrate the effort of the government in addressing sustainability issues. Despite these efforts, sustainability in the construction sector is still lagging behind other sectors (Brennan & Cotgrave, 2014). A possible explanation is that the current research has focused on products and services but has ignored the organisations and their changes in responding to sustainability. This study aims to contribute to this gap by identifying major organisational changes associated with GBMs. Organisational change aims to move from the current state to a more desirable one ranging from evolutionary

changes to revolutionary ones driven by internal and external factors (Lozano, 2013). Common organisational changes reported in the literature include: strategy, culture, politics, and operations with some overlapping changes (Lozano, 2013).

There are several studies linking sustainability and organisational changes within the general sustainability literature. For example, Lozano (2013) investigated barriers to organisational change related to corporate sustainability by using three case studies. He recommended that organisations need to plan the change to integrate technological and human changes to succeed. In addition, he summarised typical organisational changes associated with corporate sustainability: changes in mental models; the development of future vision for sustainability; management; structure; operations; and proposals of actions to achieve these. Hottenrott et al. (2016) examined the relationship between green technology adoption and organisational change in manufacturing firms. Their research provided new insights into increased productivity resulting from the complementarity effects of new green technologies and adaption of organisational structure. Furthermore, Lozano et al. (2015) advocated the importance of integration of organisational change for sustainability within higher education teaching curriculum. These examples demonstrate the emergence of organisational change for sustainability as a new discipline. However, similar studies and approaches within the construction sector are rare (Albino & Berardi, 2012).

Existing studies investigated sustainability requirements within the construction sector. For example, Akadiri & Fadiya (2013) studied the role of top management commitment, government regulations, and construction stakeholder pressures in determining environmental sustainability practices to aid better decision-making for construction sector. Few studies have investigated the role of leadership and top management of construction organisations in driving sustainability (Brennan & Cotgrave, 2014; Opoku et al., 2015). The current study provides a new approach dealing with the organisational changes relevant to GBMs for the construction sector. Although there are studies available linking GBMs and the construction sector, none of these have examined the impact of GBMs on the organisational change. Examples include Aho (2013) who studied sustainable buildings from the BM perspective and Mokhlesian & Holmen (2012) who examined green construction using the BM as an analytical tool.

According to Sommer (2012), GBMs often require substantial investment of capital and other resources and are intertwined with the existing business environment in complex ways. GBMs therefore tend to conflict with conventional business practices and structures. For this reason, many business leaders, including those in construction, overlook the potential benefits of GBMs and fail to question their existing business logic and investment decisions with regard to sustainability issues. Identifying the organisational changes associated with GBMs will increase the uptake of GBMs because construction organisations will be in a better position to prepare for these changes. Albino & Berardi (2012) stated that studies focusing on organisational change relevant to green buildings are required because they will lead to a systematic transition of the sector towards sustainability. The current study is exploratory in nature owing to lack of similar studies within the construction sector. The next section presents the method used for data collection and analysis.

3. Research method

The aim of this paper is to empirically investigate organisational changes associated with GBMs transformation in the construction sector. Since the topic under investigation is relatively new, a qualitative method is deemed appropriate. The inherent flexibility of qualitative studies and their potential for revealing complexity were particularly relevant to this research, since the topic of investigation was complex in nature (Amaratunga et al., 2002). In addition, qualitative data has often been promoted as the best approach for discovery and exploring a new area (Amaratunga et al., 2002). These features are well aligned with current research aim. Detailed semi-structured interviews were conducted with 19 academics and managers from the UK construction sector. The target sample was purposive sampling to achieve representativeness of main actors of the construction sector value chain. A purposive sampling technique uses participants who are both accessible and willing to participate in the study (Renukappa et al., 2012). The profile of interviewees was chosen according to the following selection criteria:

- Senior/managers in the construction industry
- Relevant experience in sustainability strategies and practices
- A decision maker regarding sustainability issues, for example, being able to initiate and implement future plans
- Ideally, a sustainability manager, expert or officer.

Table 1 presents the details of the interviewees for further information.

Table 1: Interviewee's details – Total of 19 participants

<i>No</i>	<i>ID</i>	<i>Type of business</i>	<i>Job title</i>	<i>Years of experience</i>	<i>Size of company</i>
<i>1</i>	<i>A1</i>	<i>University</i>	<i>Professor</i>	<i>15</i>	<i>2500</i>
<i>2</i>	<i>A2</i>	<i>University</i>	<i>Professor</i>	<i>15</i>	<i>2500</i>
<i>4</i>	<i>AR1</i>	<i>Architects</i>	<i>Architect & director</i>	<i>20</i>	<i>6</i>
<i>5</i>	<i>AR2</i>	<i>Architects</i>	<i>Associate architect</i>	<i>20</i>	<i>6</i>
<i>6</i>	<i>AR3</i>	<i>Architects</i>	<i>Associate architect</i>	<i>14</i>	<i>110</i>
<i>7</i>	<i>AR4</i>	<i>Architects</i>	<i>Associate director architect</i>	<i>9</i>	<i>12</i>
<i>3</i>	<i>CS1</i>	<i>Consultancy</i>	<i>Freelance consultant</i>	<i>36</i>	<i>1</i>
<i>8</i>	<i>CS2</i>	<i>Property and construction consultancy</i>	<i>Environmental manager</i>	<i>5</i>	<i>350</i>
<i>9</i>	<i>C1</i>	<i>Contractors</i>	<i>Director</i>	<i>50</i>	<i>50</i>
<i>10</i>	<i>C2</i>	<i>Contractors</i>	<i>Sustainability manager</i>	<i>17</i>	<i>800</i>

11	C3	Contractors	Senior sustainability manager	14	5000
12	C4	Contractors	Senior sustainability manager	12	6000
13	O1	Others – Property development	Construction director	36	16
14	O2	Others - Procurements	Sustainability manager	8	50
15	CL1	Clients/ Local Authority	Capital programme director	40	10.000
16	CL2	Clients/ University	Associate director operations & facilities	36	260
17	CL3	Clients/ University	Building surveyor	20	245
18	CL4	Clients/Local Authority	Operational facilities manager	15	10.000
19	CL5	Clients/ University	Environmental & sustainability officer	10	250

As shown in Table 1 above, all of the interviewees had considerable experience in the construction sector. In particular, they had relevant experience on green issues with some of them having ‘environmental’ or ‘sustainability’ within their job titles. The sample has covered major actors of the construction value chain including architects, consultants, contractors, clients, procurement, and property developer.

The analysis is focused on extracting meaning from the interviews which were analysed by means of thematic analysis. The thematic analysis refers to an analytical approach involving examination of discussions to establish meanings and intentions (Patton, 2005). It also refers to qualitative content analysis which has been used in construction research (Harty et al., 2007). The results are presented next and arranged into three subsections representing the major themes emerged from the data analysis.

4. Results and discussions

The Interviewees were asked to report all the changes in their organisations when they implemented green practices or initiatives. The aim was to capture any common changes and to form similar patterns of changes which occurred within the sample. Surprisingly, there were a lot of similarities that can be grouped broadly into three major categories. These categories are: green profile development; structure; and operations as shown in Figure 1.

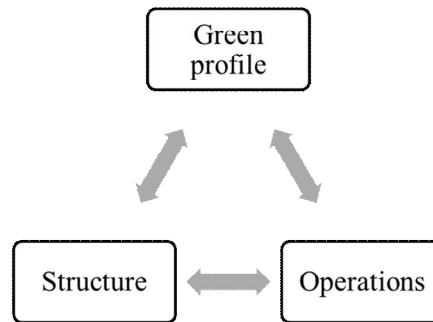


Figure 1: Major organisational changes of GBMs

Figure 1 above presents three major categories of organisational changes as emerged from the data analysis. Each of these major categories of changes is discussed in the subsections below.

4.1 Green profile development

It was evident that a green journey is usually initiated as a reaction to growing risks which can be regulations and uncertainties and it is characterised by discoveries. From the interviewees' answers, green decisions are based on two major reasons. Firstly, a compliance reason coupled with an ethical reason responding to the overwhelming scientific data about climate change and environmental degradation. Secondly, a market reason to seize the green opportunities and demonstrate capabilities in offering green solutions. Alternately, organisations may pursue the green issues for a combination of the above two reasons.

However, market opportunities including clients demand have dominated the interviewees answers as a major reason for offering green solutions. According to AR1 "*there are expectations for business in the marketplace today to have a level of environmental credibility.*" This demonstrates the market drivers and the current and future expectations from businesses and organisations leaders. Therefore, it is better to start doing some changes and actions now before it is too late. It was also evident that some organisations within the sample started to deal with green agenda as a source of value creation instead of a legal imperative. These organisations have focused on building green profile starting by relevant training and in-depth knowledge. For example, the architects AR1, AR2, and AR4 have done various training on lower environmental impact buildings design such as offsite construction and code for sustainable home principles. This has some support in the literature. For example, Shiers et al. (2006) developed an environmental profiling system for construction products to aid designers in choosing relevant products. The authors suggested that availability of information and knowledge will encourage the practitioners to build their green capacity and track record. Furthermore, Albino et al. (2009) conducted a study of sustainability driven companies to understand their behaviours. The results showed a high relationship between the development of green products and the existence of environmental strategies. Therefore, it can be suggested that construction organisations need to start with a formulation of green strategies before they can move on to

develop their green profile. A well formulated strategy will facilitate a systematic development of green profile to build a green brand and hence attract more revenues from similar projects and services.

Most of the participants suggested that a green profile should include quick wins or quick returns such as lighting upgrades and efficiency measures as well as longer-term, higher risk/higher reward strategies. Although they have agreed that GBMs in essence are long-term investment, they added that a collective approach is needed including policy and financial institution support. It can be suggested that long-term planning for GBMs requires major changes in current practices. The necessary investment to change can be financed by short-term profits or quick wins that will help build the green profile at the same time (Aho, 2013). In addition, the short-term profits can help alleviate the frequently cited barrier of environmental sustainability: cost (Brennan & Cotgrave, 2014). Developing a track record of green capabilities is vital for construction organisations to attract clients and to develop their awareness and appreciation of GBMs. According to Brennan & Cotgrave (2014), clients education and awareness are essential for sustainable construction. However, it is the responsibility of the construction sector to educate clients. We argue that before educating clients, the green profile has to be developed by the organisations to gain credibility. Akadiri et al. (2012) emphasised the role of top management in developing green buildings to build brand equity, innovate, and grow revenues. Consequently, building a green profile will require leadership and champions from top management hierarchy.

4.2 Structure

The results showed that most organisations are not embedding green-oriented resources into pre-existing organisational structure. They are instead adopting new structure and developing new performance indicators.

For example, most of the organisations within the sample established a specialist unit or environmental/ sustainability officer's position to drive the agenda. Some organisations have a large dedicated unit and others have a dedicated individual. This merely depends on the size of the organisation. Not only can there be the specialist unit or individuals, but also some voluntary roles within the staff such as an environmental champion and then it is made part of each individual's job description. The voluntary roles can be seen as empowerment for staff that can promote the green solution and allow them to participate in finding innovative solutions. This view is echoed in other empirical findings in companies in which sustainability practices are contributing to profits and so called "Harvesters." The findings reported lessons learnt such as: Harvesters usually change the organisational structure or adopt new structures and establish the position of sustainability officer (Kiron et al., 2012).

The dedicated environmental/ sustainability units or individuals have a major role to play on green business intelligence. In this role, they focus to identify clients with green agenda to work with and to offer them tailored services. C3 from the contractor group gave an example where they worked with an existing client to offer energy efficiency services. C3 stated that "*as part of*

a facility bid for a local authority we offered them energy investment where we pay the up-front costs and they pay us back from the savings.” This was possible because of the green intelligence staff that had good client knowledge and understood their aspirations and strategic targets.

Additional role of environmental/ sustainability unit or individual is to be able develop and communicate the business case of green practices internally for different departments and externally for clients and supply chain. For example, C3 from the contractor group stated that *“as long as it [referring to new green initiative] works financially you can find away and you can evolve it to client saving them money and saving you money they it is going to have a very good chance of going forward.”* Nevertheless, an important issue has been raised by the interviewees that it is not always possible to make the business case in financial terms therefore construction organisations may look at alternative areas such as enhancing the reputation, making a clear statement of commitment to green issues, and social benefits.

The participants described another change in the structure where the operational units or individuals responsible for environmental sustainability have to report at the strategic level. In many cases there will be a strategic board manager responsible for the operational levels. For example, C2 from the contractor group indicated that *“at the moment the sustainability managers reporting to the health and safety director but some more senior appointments will be made so the sustainability managers will be reporting to head of sustainability”*. This strategic backing demonstrates the leadership commitment towards green agenda and empowers the position of environmental/ sustainability units or individuals to have a stronger influence on the organisation. However, CL5 from the client group stated that her current position as environmental and sustainability officer should be diminished over the time as a result of true embedment of environmental objectives within the organisation where this position should be part of everyone job responsibility.

4.3 Operations

The participants explained that the operations have changed significantly across many areas such as collaboration, technology embedment, procurement, and working patterns.

Organisations not only change themselves in response to environmental considerations, but they also become more collaborative inside and outside the organisation boundaries. It was evident within the sample there was a great collaboration and team work across the different organisation units. For example, C3 stated that he works closely with the financial department in developing and identifying green opportunities. Some of these organisations work more closely with their clients and suppliers to develop their green practices compared to their past experience of standard practices. Some of the participants explained their collaboration with certain professional networks that have specialised expertise in environmental issues and their work with the supply chain to ensure that green values are embedded within all activities. A typical comment was, *“If you think that in your company you have everything you need, you are totally*

self-sufficient you need nothing from the outside world then you are mistaken. You have a false view because you start to believe you have the right answers.” Consultant (CS1). Therefore, construction organisations should work more closely with their supply chain to ensure that they adhere to the same principles. Larger organisations may provide support for their supply chain and partners for better results. This is vital because of the unique nature of the construction sector where there is a chain of actors involved to deliver products and services (Ballard & Kim, 2007; Kohler, 2008). Albino & Berardi (2012) noted that structure of the construction process is a major barrier to green practices because it is based on temporary arrangements between multiple organisations to deliver a project. Bossink (2007) highlighted the importance of studying the changes of organisational relationships in green practices. Therefore, the findings of this study are a means to overcome this barrier by encouraging collaboration between organisations. Another possible solution is to focus on integrated green projects delivery because it facilitates long-term relationships and shared value delivery.

The operation becomes more reliant on technology because it facilitates work efficiency. For example, the architects within the sample stated their movement to paperless documents. In addition, AR1 and AR2 explained the advantage they have by establishing a strong ICT documentation and automation services. They have a strong knowledge repository to facilitate communication and learning across the organisation. Furthermore, technology has a vital role to play in the changing process such as sensor technology which can help achieving more efficient consumption of energy and water and influencing behaviour to promote low carbon culture and efficient practices. Energy display is also seen as important technology advancement in raising awareness and encouraging lower consumption levels.

Moreover, CL1 and CL4 from local authorities stated that their organisations have changed the way of procurement where they started to procure only from suppliers who match specific criteria to ensure those suppliers are committed to the green agenda. This has some support from the literature where Albino & Berardi (2012) investigated relationships between construction organisations in sustainable practices. The results suggested that organisations tend to work with others that have green portfolio to show their commitment to sustainability.

Finally, some of the organisations within the sample introduced more flexible working patterns to reduce the travel miles and invested on online facilities to work across geographical regions. For example, CS2 stated that they communicate with their head office through online conferencing and thus reducing the need to travel and lowering their carbon footprint.

The results showed that GBMs can lead to major organisational changes therefore construction organisations should be prepared to accommodate these changes. In addition, it is vital to deal with these changes systemically and to embrace the close relationship between them. This study highlighted the role of supply chain in delivering GBMs and its impact on operational change. Consequently, construction organisations will need to work closely with their supply chain to achieve wider progress towards GBMs.

5. Conclusions

This paper has focused on investigating organisational changes pertinent to GBMs transformation in the UK construction sector. As the subject under investigation is a relatively new, qualitative method is chosen to better understand the subject. 19 semi-structured interviews are conducted with a varied sample representing academia and the sector practitioners. Thematic analysis is then applied to extract the results.

The results showed that organisational changes were grouped into three major themes. Firstly, green profile development where construction organisations start to build and market their green credentials. As the public awareness grows, organisations will find this is a pressing issue to survive in the market. Secondly, organisation structure by establishing a specialist unit or a member of staff to lead green practices and strategies. This position is vital drive the agenda and to make a clear statement of commitment towards GBMs. Finally, a major organisational change rests on the operations practices such as increased levels of collaboration internally and externally, technology embedment to drive efficiency, procurement, and working patterns. Therefore, construction organisations have to accept that moving to GBMs will bring significant changes to the way organisations work. This study contributed to better understanding these changes hence construction organisations can be prepared to address these and channel their resources and capabilities toward the identified areas of change.

Although this study has provided new insights on the relationship between GBMs and organisational changes for the construction sector, it has some limitations. First, GBMs remains fundamentally under-researched topic particularly in the construction context. This has implication on finding comparable construction studies that would have influenced the results of the current research. Second, the research is focused primarily in the UK construction sector and is relied on empirical data from UK only. Therefore, it is difficult to generalise the findings beyond the investigated context. A wider qualitative inquiry as to how GBMs change construction organisations is recommended for future research. Furthermore, the possibility to compare findings of the present paper with organisational changes in other European countries remains desirable.

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Performance Based Building by U.S. Architects: An Investigation into Attitudes and Adoption

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Abstract

Performance Based Building (PBB) was initially developed alongside sustainability to resolve separate but related issues. Work in the field began with attempts to harmonize design and construction methods and products across national and cultural barriers. Reduction in energy and water consumption, additional added value to the owner and novel, responsive design forms become later goals of PBB efforts. Regulatory, technical, cultural and process-oriented barriers to adoption have been identified within specific disciplines.

There are a number of PBB tools that integrate the full lifecycle of building design and occupation. These tools offer the potential to address many of the causes of the gap between the predicted and actual performance of buildings seeking high levels of sustainability. The mixed-methods research design began with a questionnaire for participant identification and proceeded to in-depth explanatory interviews that explored the barriers and drivers to adoption encountered in daily practice.

Awareness appears to develop slowly, sometimes organically through the firm's interests, but more often via pilot projects and committed pathfinder clients. Opportunity and demand subsequently build. Some firms capitalize on this as a market differentiator while others are pulled along by mandates or more mainstream clients who have recognized the business value. These experiences build basic functional knowledge which, in turn, is developed with the involvement of specialist consultants and software tools into more sophisticated technical knowledge. Levels of sustainability and performance previously seen to be impractical are slowly transformed into standard practice. This process renews itself as committed clients and organizations seek again to demonstrate their values beyond conventional business.

This information can guide the efforts of those seeking to advance the adoption of PBB among U.S. architects. Additional research into the effects of firm culture and the role of committed clients in developing new processes appears warranted.

Keywords: architecture, design, performance, sustainability, values

1. Introduction

The traditional architectural design process begins when the owner hands a complete program of spaces to the architect and ends when the building is ready for the owner to move in. Pre-design and post-occupancy evaluation have emerged more recently as formal services (American Institute of Architects Staff 2013). As the fields of sustainable and high performance design have become mature, a multitude of technical tools and rating systems have emerged to address individual aspects of design. A smaller set of tools and techniques have also been developed seeking to guide the design team in how decisions are made and which goals are pursued.

This research began with the conjecture, based on the author's personal experience, that awareness and adoption of Performance Based Building (PBB) among U.S. architects is low. This research then focused on identifying the barriers and drivers within the specific context of architectural practice and the first-hand experiences of those practitioners. By exploring those experiences, both actual and perceived barriers were identified for further research.

A review of the literature revealed a number of actual and potential barriers, but few explanatory models. Awareness is a barrier that can be measured directly via surveys and questionnaires. However, it is not likely for one to be able to give an insightful answer to the circumstances of his or her own ignorance. The popular Leadership in Energy and Environmental Design (LEED) program served as a proxy for the less well-known concept of PBB. Empirical studies into different delivery systems have centered on project performance during construction (Konchar and Sanvido 1999) but are more recently beginning to investigate how those methods influence operational outcomes (Esmaceli et al 2013). Those relationships are complex and beyond the scope of this research. A two-step mixed-methods approach was able to illustrate the transition of sustainability and building performance from an expression of a small group of clients' values to the design mainstream. The value of these insights lies in their ability to aid the work of those pursuing broader adoption of PBB among U.S. architects.

2. Literature Review

2.1 Conceptual Background

The essentials of contemporary PBB were defined in the 1982 report to the International Council for Building (CIB), "Working with the Performance Concept in Building." The report begins, "The performance approach is, first and foremost, the practice of thinking and working in terms of ends rather than means. It is concerned with what a building or building product is required to do and not with prescribing how it is to be constructed." (Gibson 1982, p. 4) The other key concepts that Gibson (1982) outlines are testing the proposed solution against those

requirements and evaluating the final constructed work against the original benchmarks. The CIB continued to develop a research program for PBB through the 1980s and 90s.

This laid the groundwork for a multinational research effort that gave rise to the Performance Based Building Thematic Network that ran from 2001 to 2005 (International Council for Building 2013). That work culminated in a series of final reports intended to establish a consensus for PBB throughout Europe and the United States. Performance standards then become the means by which to judge the productivity of the discourse between supply and demand. Technical applications have developed in step with the advance of technology and computing. The US Department of Energy now lists 411 software applications for measuring and comparing differing aspects of building performance (Building Technologies Office: Building Energy Software Tools Directory 2013).

2.2 Benefits and Barriers

These tools and practices offer an array of potential benefits; increases in Key Performance Indicators (KPIs) with Gross Value Added (Barrett et al 2007), dynamic links between performance parameters and building geometry (Oxman 2008), and even carbon absorbing cities (Geyer & Bucholz 2012). Fowler (2011) and Hammond (2005) point to mandates Federal organizations have enforced as an important determinant of the successful adoption of PBB.

Despite these benefits, many barriers to adoption remain. The lack of acceptance among regulatory bodies was one of the first to be identified (Gross 1996). The increasing technical complexity of the design process limits who can perform more sophisticated performance simulations (Shi and Yang 2013) and the number of simulations that can be performed (Flagler, Haymaker 2007). Outside of large property portfolios managed by a single entity - namely governments and a few large private companies - smaller organizations have not been able to demonstrate the business value that PBB offers successfully (Barrett et al. 2007). Sexton and Barrett (2005) and Panuwatwanich et al. (2009) found that PBB must explicitly address business logic and value in order to find broader acceptance. Seeking to explore the limits of performance across many domains creates fragmentation of the design process. For example, daylighting, facade design and energy performance have become independent consultancies at the same time that the need for the integration of those systems into the whole of the building has become increasingly apparent (Satterfield et al. 2009). Perceived liability, adversarial relationships and the lack of a skilled workforce also constitute cultural barriers (Wright 1996). An organization with a culture that values performance will learn how to express that value to others by integrating the myriad available technical tools. In the case of hierarchically structured federal agencies, that cultural change has been mandated from the top. Without such a mandate, there seems to be no consensus within the reviewed literature regarding the tools or methods that would most effectively address this issue.

2.3 Integration

In contrast to fragmentation of the design process, integration was identified as the primary means by which barriers to PBB can be addressed (Bakens et al. 2005, p. 155):

Fixed classification or inflexible separation of the demand and supply sides also do not help. Instead, a programme structure and activities that promote maximum interaction of up- and downstream stakeholders, and of participants in the different phases of building life, should be encouraged to promote integration and remove barriers.

Lützkendorf et al. (2005, p. 13) created a typology of performance instruments and tools that maps their application across these phases of a building's life. Few of the tools they identified are intended to span all phases of design. All but the ASTM Standards and Design Quality Indicators (DQI) are intended for residential design or are limited in scope by region-specific database information. Similarly, the Soft Landings framework grew from a desire to incorporate user feedback from the end of the design cycle, rather than front-loading technical information before design begins (Way 2004; Bordass, Leaman 2005). Because these systems have the capability to be broadly inclusive of the design process, they are referred to as integrated tools for the purposes of this research.

Highly optimized building performance concepts tend toward complex, multi-dimensional trade-offs that are embedded deeply within the final built solution. This makes identifying the benefits derived from any specific design decision guided by PBB principles particularly challenging. Tools that integrate PBB throughout the design life-cycle offer significant potential benefits. However, their adoption may hinge on the internal dynamics and culture of the organizations seeking to make use of them.

3. Methodology

3.1 Research Design

Given the complexity of the performance-based landscape, is it reasonable to expect the practicing professional to be knowledgeable about the use of these tools? The reviewed literature suggests there has been little formal investigation into the state of knowledge among architects practicing within the U.S. While many barriers and drivers were identified during the literature review, correlations between these variables were not suggested. Without those correlations to explore in a quantitative manner, an alternative method was selected. A two-stage process was developed to first narrow the field and then explore it in greater detail. The first stage was a brief questionnaire only seeking to identify individuals with experience in the systems in question. The second stage was developed as an open-ended and exploratory interview to reveal the specific context of each firm in which the interviewee operates (Weiss 2004). In this mixed-methods approach, the questionnaire is not intended to be a statistically reliable tool. It is used to enhance the qualitative exploration of the interviews. This method

aligns with the participant selection variation of the explanatory model for mixed-methods research (Creswell, Plano Clark, 2007).

3.2 Questionnaire

A brief questionnaire was developed to identify individuals with experience in the systems in question. To maximize results, the questionnaire was sent to individuals whose expertise was known to the author or whose qualifications were readily available through published resources, including the United States Green Building Council directory and past members of the AIA national Committee on the Environment. The questionnaire was restricted to three questions: awareness of the subject PBB systems, experience with those systems, and willingness to participate in an in-depth interview. LEED templates and forms were included to ensure a baseline of familiarity with sustainability and building performance. Due to the small sample size relative to the potential total population, statistical analysis of the questionnaire results was limited to internal comparisons.

3.3 Interviews

Interview participants were self-selected through the questionnaire process. After establishing basic facts, the majority of the interview was structured in a biographical arc, beginning with personal history of the subject, working towards present experience, and finally projecting into the future. The method of focusing on a single, specific time is referred to as the Critical Incident Technique, which Chell (2004) asserts is an effective method to elicit more detailed and accurate recollections of past experience. This was also intended to establish a flow that would produce a more active and engaged conversation. This appeared to have been successful as the responses grew longer and more detailed as the interviews progressed.

The analysis of the interviews followed the model outlined by Seidman (2013). Recordings were transcribed and those transcripts were coded for keywords based on the barriers and drivers identified in the literature review. Other keywords emerged as repetitive themes across multiple interviews. The frequency of these keywords was charted and the strongest concepts were grouped together along with any counter-examples.

4. Results and Analysis

4.1 Questionnaire Results

Seventy-two professionals were contacted via e-mail with 20 responding over a period of 48 days. Six of those 20 were aware of one of the subject systems and only two had first-hand experience. All had first-hand experience with the LEED templates.

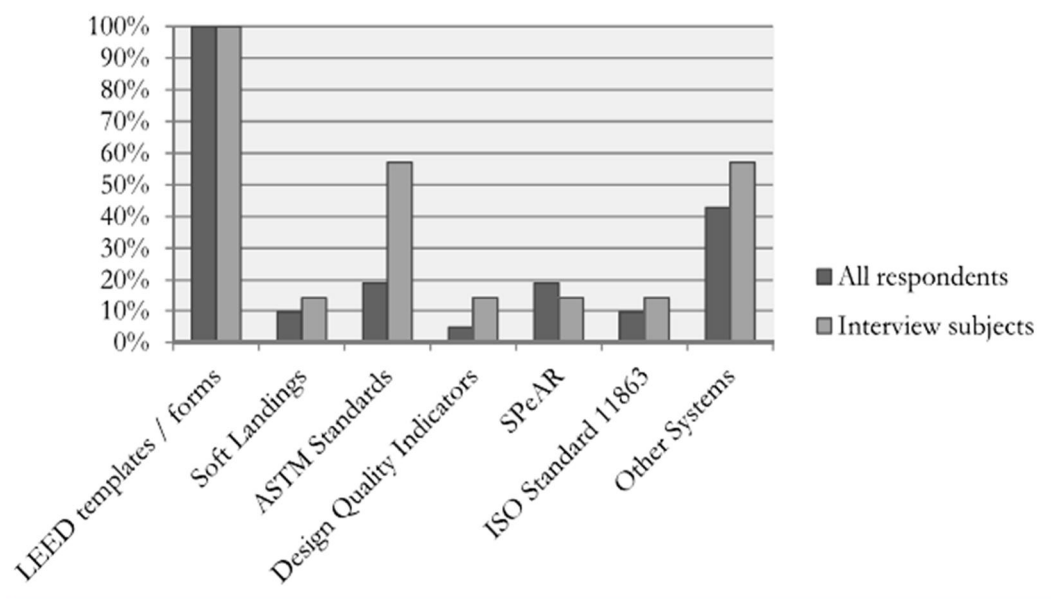


Figure 1: Have you evaluated any of the following systems for use in your practice?

Green Globes and the Living Building Challenge where the two most commonly mentioned of the other systems. Two trends are readily discernable from this data; LEED is ubiquitous among respondents and, while not completely unknown, awareness of the other subject systems is not as pervasive. The interview subject's experience appears to be consistent with the larger group of respondents with the exception of the ASTM Standards.

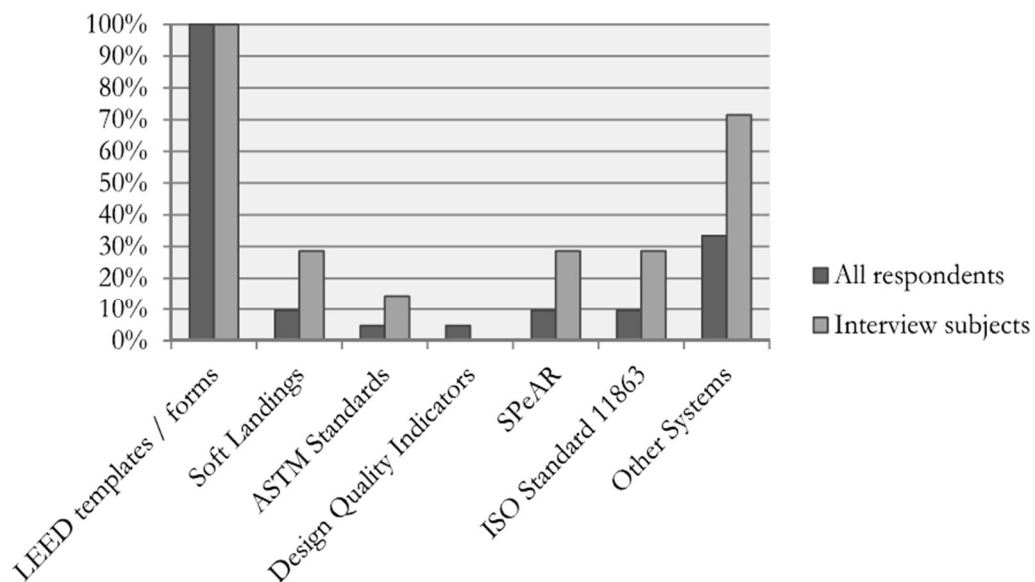


Figure 2: Have you been involved in a project that used one of these systems?

The same two trends were demonstrated by the results for first-hand experience with the low levels of adoption of systems other than LEED being even more pronounced. In this case, it appears that the interview subjects may have slightly more experience with alternate systems than the overall group.

4.2 Interview Results and Analysis

Twelve of the questionnaire respondents elected to provide contact information for the purposes of scheduling interviews. Ultimately, interviews were arranged with seven of those individuals. When asked to reflect upon their earliest experience with PBB, a strong trend emerged. Six of the seven had been involved in the LEED pilot program to varying degrees. For five of those six, a non-profit organization, governmental body or another pathfinder client was mentioned in reference to this initial experience. When asked about barriers to PBB that had been encountered during the course of these initial experiences, financial cost was identified by five of the seven subjects. However, several related concepts were specified: increased design fees, rating system certification fees, actual construction costs, and uncertainty in the bidding process leading to inflated costs. The perception of increased cost was described as having outlasted the reality among some clients. Education of both the design and construction teams was also cited as an early barrier. Responses to the question of what values drove the design team to push through and overcome the barriers that were encountered centered on three ideas: market differentiation, firm values, and client values.

Asking interviewees to identify the benefits the design team had realized from the inclusion of LEED or PBB strategies proved more difficult to frame in a manner that elicited useful feedback. For the four that did address the question directly, one response serves as a succinct summary: *“There are really three prongs of what we received from that [experience]. One was how to do the LEED documentation, but also our reputation as a firm doing sustainable design and our ability to design a building that was at a higher benchmark than what we had done before.”*

At this point in the interviews, the focus shifted from present-day experience to speculation regarding the future. Mandates were identified as particularly powerful tools in this regard, especially when tied to funding mechanisms. The specific example of federal and local government adoption of LEED certification was cited by three subjects. A similar state level program, also tied to bond funding for construction costs, was also cited. The business case for performance was also cited: *“...there would have to be a policy or mandate or there would have to be, basically, undeniable quantitative return on investment...”*

The role of building standards or rating systems that reach beyond the conventional also emerged. In particular, the difficulty of achieving the Living Building Challenge was cited as a driver for those organizations seeking to express a qualitative commitment to sustainability that goes beyond what can be evaluated in traditional quantitative terms. It was suggested that this may be intentional on the part of both the clients and the rating organization. One subject questioned the premise of the question and responded:

The path to make anything go on an upswing is instead of making it voluntary, make it compulsory, which then, sort of diminishes the altruistic nature of going after it, which is why Living Building Challenge and various other projects aren't actually interested in having more projects but rather a number of demonstration projects.

This suggests that the creative tension between aggressive rating systems that go beyond the industry's current abilities to measure value and the widespread, tested and proven systems forms a mechanism by which the qualitative values of some organizations are made quantitative and revealed to the broader market.

5. Discussion

5.1 Pathfinders and Mandates

The initial experiences of the interview subjects were defined by pathfinder clients and mandates. The pathfinder client plays a critical role in the adoption of new performance standards by pushing through barriers based on their values rather than waiting for a demonstrable return on investment to justify their efforts. This contradicts Barrett et al.'s (2007, p. 16) assertion that "...project teams can only really achieve incremental change without this lead [mandates]." Regulatory obstacles were scarcely mentioned in the interviews, which suggests the concerns voiced by Gross (1996) may have lessened in the intervening years. The role of the pathfinder client appears to shift the need to quantify building performance in business terms identified by Sexton and Barrett (2005) as well as Bakens et al. (2005) from the initial adoption phase to later stages of the process. Adoption of PBB may be better served by including or marketing to those clients rather than focusing on design professionals. This finding parallels the "innovation champions" Brandon (2006) describes as driving technological and design-process adaptations. Pathfinder clients are distinct from innovation champions insofar as Brandon ascribed their efficacy to the force of individual personality and not organizational values. In both cases, however, industry does respond to client demand. This research did not contradict prior findings that mandates are powerful tools for driving the adoption of new systems to the broader market, but it does suggest they follow pathfinder clients in the overall process.

5.2 Process

The emergence of software tools and specialty consultants to serve the architectural profession pre-dates the PBB concept. Four subjects agreed in principle with the concerns and difficulties voiced by Shi and Yang (2013), Reinhart and Fitz (2006), and Crawley et al. (2008). However, the magnitude of these issues and their impact on the final output were both downplayed. It appears that firms have grown comfortable evaluating those tools and consultants and have developed ongoing processes, whether formalized or not, that allow them to adapt to the proliferation of both specialties in the normal course of operations. This incremental approach echoes Yetton et al.'s (1994) findings regarding the initial adoption of CAD technology in the late 1980s and early 1990s.

The same institutional inertia could be a barrier to the adoption of process-oriented tools that do not match the organization's current design methods. This supports Hammond et al.'s (2005) claim that *"...successful implementation of a performance-based approach for Facilities and Constructed Assets is best if embedded in an overall performance-based approach for the whole organization."* However, the lack of awareness of those specific tools appears to have manifested itself in an absence of specific information on this topic within the interviews.

5.3 Feedback

The need to incorporate feedback is growing in recognition of the continued uncertainty of outcomes, otherwise known as the performance gap. Two contributing factors were identified by interview subjects. First, modeling tools are developed and used for documentation and standards compliance, not necessarily for their predictive capabilities. Second, occupant behavior, both at the organizational and individual levels, can be very disruptive to optimizing building performance. Some clients and firms are now actively seeking feedback which may indicate that the adoption of this practice is beginning to grow along a similar arc as LEED. The AIA 2030 Commitment, a single-attribute system comparing predicted and actual energy use intensity, has recently emerged as another example currently adopted by 99 U.S. architecture firms (American Institute of Architects Staff 2013).

5.4 Other Issues

A handful of other issues emerged through the course of the research. It appears that LEED's ubiquity drowns out many other systems. Green Globes may be a viable alternative to LEED but is still far less prevalent. PBB in the U.S. may be dependent on recognition by and incorporation into one of those two systems. Liability is seen as a barrier by some and a driver by others. Performance guarantees and the health impacts of chemicals within building materials were specifically identified. These are significant to the issue of PBB, as they represent potential changes to the professional standard of care for designers that relate directly to specific dimensions of building performance. The findings appear to confirm Wright's (1996) assertions regarding performance, while the topic of chemical health impacts may be a more recent emergence not addressed as thoroughly in the existing literature. International work, where design oversight of contractor activities is prevented by contract or practice, is an area of promise for the PBB concept. Design documents that do not rely on prescriptive methods could help ensure that the final built product meets the intent of the design and needs of the user across significant cultural and technical divides.

6. Conclusions

This research sought to identify barriers and drivers to the adoption of PBB amongst U.S. architects so that those tools may be more commonly brought to bear upon the gap between predicted and actual building performance. The specific context of architectural practice and the first-hand experiences of those practitioners were explored to yield insight into the practical

judgement that guides their work. The picture that emerges is of a progressive process that builds over time.

From the data gathered from the interviews, it appears that awareness has developed slowly, sometimes organically through the firm's interests, but more often via pilot projects and committed pathfinder clients. Opportunity and demand subsequently appear to build. Some firms capitalise on this as a market differentiator while others are pulled along by mandates or more mainstream clients who have recognized the potential value in business terms. These experiences build basic functional knowledge which, in turn, is developed with the involvement of specialist consultants and software tools into more sophisticated technical knowledge. Levels of sustainability and performance previously seen to be impractical are slowly transformed into standard practice. This process renews itself as committed clients and organizations seek again to demonstrate their values beyond conventional business. While the sample size of this research cannot be considered broadly generalizable, the coherence of the story told by the interviewees suggests these conclusions represent one thread of experience within the industry.

The implication is that PBB cannot be pursued as an end of its own. PBB is, by definition, focused entirely on what can be measured, demonstrated, and improved. This leaves no space to include the more far reaching and ambitious concepts that capture the imagination of pathfinder client organizations, but have not yet demonstrated a reasonable return on investment. Without that intrinsic driver, those seeking to extend the use of PBB must find another path. Adoption can be most readily furthered by embedding PBB principles as deeply as possible into the rating systems and standards, such as the Living Building Challenge, that do offer this existential demonstration of commitment.

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Designing LCCbyg: A Tool for Economic Sustainability

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Abstract

The principles of lifecycle costing or whole-life costing has been around for decades, but the implementation of the principles has been modest or even weak despite the obvious advantages of integrating maintenance, operation and management aspects into the design of new buildings and facilities. Several explanations to this apparent paradox have been offered including the absence of robust tools, cost key figures and commonly agreed calculation assumptions along with weak economic incentives, the inherent project focus of designers and contractors etc. In early 2015, the Danish government launched a new package of tools for sustainable construction. The complete package includes a general guideline to sustainability, two specific guidelines on lifecycle costing (LCC) and lifecycle analysis (LCA), a general introduction to the lifecycle of construction and two new tools for doing lifecycle costing (LCCbyg) and lifecycle analysis (LCAbyg). Based on the methodology of structured analysis and agile software development methodology, this paper will review existing tools, discuss (some of) the design choices made and summarise lessons learned from the development of the tool LCCbyg for lifecycle costing. First, this paper will provide a typology of existing tools into three categories with distinct characteristics and associated benefits and drawbacks: 1) Spreadsheets, 2) stand-alone applications, and 3) web services. Second, while the software interface only displays limited unique features and functionalities compared to other available tools, the inherent data model applied in the tool provides a number of unique design choices. These design choices make the tool highly robust to future development; incorporate a fully open standard in XML format for easy exchange with other applications; provide the users with a high degree of adaptability to their specific requirements; and reduce the need for an elaborate classification scheme for cost and building components that would otherwise severely restrict the adaptability of the tool.

Keywords: Sustainable construction, lifecycle costing, agile development, open standard, data model

1. Introduction

The challenge of sustainability has been around for decades. The Brundtland report (1987) introduced sustainability as the balanced development of three pillars: environment, social and economics. Despite progress, there still is a long way to go for governments, businesses, academia and civil society. In 2014, the Danish government (Regeringen, 2014) issued a new building policy with five strategic actions including one action on sustainable construction. This strategic action included a series of initiatives to promote sustainable construction, among others a guidance package. This package was launched in early 2015 and includes a general guideline on sustainable construction (Energistyrelsen and Birgisdóttir, 2015), two guidelines on environmental assessments (LCA) (Birgisdóttir and Nygaard Rasmussen, 2015) and lifecycle costing (LCC) (Haugbølle, 2015), a foundational report on the building's life cycle (Nygaard Rasmussen and Birgisdóttir, 2015) and two tools for environmental assessments (labelled LCAbyg) respectively economic assessments (labelled LCCbyg).

The principles of lifecycle costing or whole-life costing has been around for decades, but the implementation of the principles has been modest or even weak despite the obvious advantages of integrating maintenance, operation and management aspects into the design of new buildings or refurbishments. Several explanations to this apparent paradox have been offered including the absence of robust tools, cost key figures and commonly agreed calculation assumptions along with weak economic incentives (see e.g. Haugbølle, 2015).

Applying the principles of lifecycle costing has for several years been mandatory for both social housing and governmental buildings. While the social housing sector has developed sector-specific tools, the government building agency has effectively neglected its obligations to apply and to disseminate knowledge on lifecycle costing. This negligence was criticized in strong terms by the Danish National Audit Office (Rigsrevisionen, 2014) and the Danish Public Accounts Committee (in Danish, Statsrevisorerne) putting pressure on the building agency to take action on lifecycle costing. Meanwhile due to unfortunate circumstances the building agency had to employ a new CEO, who came from a municipal building agency with a high profile on sustainability and lifecycle costing. Further, three new trends have in recent years actualised a wider use of lifecycle costing in construction (Haugbølle, 2015):

1. New governmental regulation issued in 2013 on quality assurance, public-private partnerships and lifecycle costing in public construction, which requires all public clients (not only governmental) to apply lifecycle costing in projects above certain thresholds.
2. The establishment in 2012 of the German certification scheme DGNB adopted by the Green Building Council Denmark for sustainable buildings and urban areas where economic quality has a very prominent position.
3. The new European procurement directive from 2014 that makes it easier to use total cost of ownership (TCO or lifecycle costing) as an award criterion in competitive tendering rather than just lowest cost.

With these new dynamics in mind, the time seemed ripe to consider how lifecycle costing may be addressed and operationalised. The objectives of this paper are 1) to provide a typology of LCC tools and discuss benefits and drawbacks of different types of tools, and 2) to reflect on the design process of LCCbyg and share lessons learned during the software development process.

2. Methodology

The tool LCCbyg was developed for the Danish Transport and Construction Agency (Trafik- og Byggestyrelsen, 2016) by the Danish Building Research Institute in collaboration with a small software firm. The combined competence of the project team members covered lifecycle costing, data modelling, software architecture and user interface design.

This study is based on a combination of the structured analysis approach and the agile approach for software development. The development has been divided into two main stages: the development of version 1.0 in 2014 and the development of version 2.0 in 2015. Due to conference deadlines for paper submission, this paper primarily addresses the development of the first version. This process can be subdivided into three main phases: Analysis of present situation; formulation of requirements; and development and testing of the tool.

The analysis was carried out using so-called ‘structured analysis’ (Delskov and Lange, 1999). As spreadsheets are effectively the industry standard of performing LCC calculations, it was relevant to analyse the design, inherent data model and calculation procedures of spreadsheets more closely. The methodology was adapted to only include the Data Flow Diagrams, Data Dictionary and Process Descriptions. The second phase covers requirement specification, which the customer writes on the basis of the analysis and own requirements and wishes. In this case, the specification of requirements was developed in parallel with the second half of the analysis as well as the early design stage. The third phase covers the actual design of the application. In addition to structured analysis, this work was in part based on the 12 principles of agile software development (Fowler and Highsmith, 2001). To mention a few of the principles being followed in this project, the project team was a self-organising team with a flat organisational structure based on a recognition of complementary competences among team members; the iterative development process was based on frequent sprints; intensive face-to-face conversation took place through weekly project meetings; changing requirements was welcomed (even late in the process) and adapted regular to changing circumstances through close interaction with a highly knowledgeable reference group and potential users; and the team focused intently at delivering working software as the principal measure of progress.

The approaches of structured analysis and agile development were supported by empirical evidence from a range of sources. The analysis phase provided an overview of existing national and international tools. Based on this overview, the LCC tool for DGNB certification developed by the Danish Building Research Institute was selected for closer scrutiny as this is a very recent example of this development path, the project team had easy access to the coding, and the tool closely follows the approach in similar tools. The purpose of the analysis phase was to explain and document the DGNB system’s use of variables and rules of calculation in order to support

the subsequent design phase. The analysis phase also included participation in industry courses on LCC and interviews with and observations of practitioners using LCC tools. During the requirement setting phase extensive dialogue with the funding agency and the reference group was carried out based on e.g. the presentation of mock-ups and draft versions of the tool's reporting schemes. The development and testing phase further extracted empirical evidence through e.g. the use of a structured test protocol by the test persons.

3. Analysis of existing tools

3.1 Existing approaches

A number of different approaches and tools to manage whole-life costing or lifecycle costing already exist both nationally and internationally. Two standards are relevant here: the international ISO15686 series on service life planning (ISO, 2008) and the European EN15643 series on sustainability of construction works (CEN, 2012). Several instructive books and guidelines have also been published over the years. These include among others the very first publication by the Danish national building research institute on economic optimisation of insulation (Becher, 1949), strategic investment and financing (Hedegaard and Hedegaard, 2008), a practical guide to selecting materials from a whole life costing perspective (Caplehorn, 2012), a comprehensive overview of different LCC models and engineering design issues within various business areas of application (Dhillon, 2010) as well as a textbook for engineering students on economic analysis, estimation and management in product development of complex systems (Farr, 2011).

The most widespread type of tools is based on the spreadsheet platform available in most standard software packages for office use (typically Microsoft's Excel spreadsheet). These include among others a low-energy optimisation tool for Danish social housing, the Norwegian government's building agency's tool LCProfit, the LCC tool used in the Danish DGNB certification scheme as well as a range of internal company-specific spreadsheets. Another but less frequent type of tools includes stand-alone applications. These include among others the tool BLCC offered by the US Department of Energy. A third type of applications is web services where calculations are made online using some kind of web browser linking to a server hosted by the service provider or a web hotel. These include among others the mandatory tool for doing LCC calculations in Danish social housing with regard to new buildings and major refurbishments as well as a web service version of the Norwegian LCProfit. A fourth type is apps for tablets and smartphones, but these are currently non-existent.

3.2 Characteristics of different technical solutions

While a spreadsheet solution offers a number of benefits including relatively low development costs, spreadsheets are notoriously fraught with errors. As pointed out by Panko (2008) *"...the issue is how many errors there are, not whether an error exists. And out of 113 investigated spreadsheets 88 % are found with errors."* A web service solution makes it possible to have one common interface, but requires additional resources for optimisation to different browsers as

well as extensive management resources. Apps for smartphones and tablets are spreading fast and offer great value for the user “on the move”, but are often cumbersome for daily office use. A desk top application is the main platform for the user groups, but desk top application may need to be available for three different operating systems (Windows, OS X and Linux). Linux is used to a very limited degree (around 1 % of the market), while OS X is used to a larger degree (some 8 % of the market). The Windows operating system in its different versions is by far the most widespread operating system, accounting for around 90 % of the market (StatCounter, 2015). Since the operating system OS X has various options for running Windows applications, solutions based on the Windows operating system would potentially cover the vast majority of all desk tops. Table 1 provides an overview of the benefits and drawbacks of each of the four technical platforms for developing LCC calculation tools.

Table 1: Characteristics of technical solutions

<i>Characteristics Type</i>	<i>Benefits</i>	<i>Drawbacks</i>
<i>Spreadsheet</i>	<i>Great flexibility Wide spread use Integrated in office suites</i>	<i>Many possible errors (often hidden)</i>
<i>Web service</i>	<i>Same interface on all platforms</i>	<i>Optimisation to different browsers Require fast internet connection File handling requires extensive management of servers, security etc.</i>
<i>Mobile/tablet</i>	<i>Wide spread and increasing use</i>	<i>Cumbersome for extensive office use Customised solution required for each mobile platform</i>
<i>Desk top application</i>	<i>Mature and open source libraries for XML, PDF and graphs Main platform for user groups Integrated in work processes, including backup and storage</i>	<i>Three operating systems (Windows, OS and Linux)</i>

3.3 Structured analysis of a spreadsheet tool

An important difference between a software application and a spreadsheet is not the technical difference, but rather that the user is developing calculation solutions. Where the programmer has learned to follow a strict methodology that involves an ongoing focus on troubleshooting, the spreadsheet developer rarely follows any method other than increasingly adding cells. Where a spreadsheet developer sees a variable as a position in a given layer or cell in the spreadsheet, the programmer will see the variable without position. In practice this means that the variables are all unique in their naming, and are available in a variable list. For the programmer the outcome of two interacting variables becomes a new variable, described and

reportedly named in the variable list. For the spreadsheet developer an interaction between two positions leads to a third position. In both cases, the calculation will be correct, but in a further development of the application, the programmer would only have to control the variable list. The spreadsheet manager must ensure all rearward positions, which gives a large number of corrections, particularly when multiple columns or rows need to be inserted. References in data, x-refs, are often troublesome because they tend to break.

In order to decipher the logic of the system the starting point was to note the responsibility of data entry and the resulting variables in the DGNB LCC-tool. The tool's calculation views and balances were then reviewed in order to document the use of input variables and to find and explain the resulting calculations (system variables) included in later calculations.

The variables were described in a 'Data Dictionary', and calculation routines were described in 'Processes'. The variables used in the processes were double-checked with the data dictionary, and the processes themselves independently described. Finally, the variables were taken directly from the spreadsheet and listed alphabetically and in conjunction with process variables and data dictionary. Figure 1 shows the result of this analysis as a high level view.

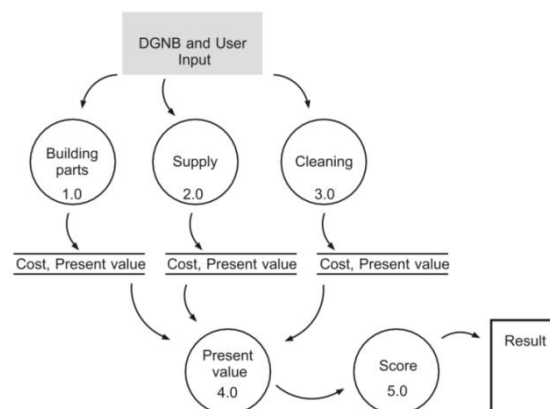


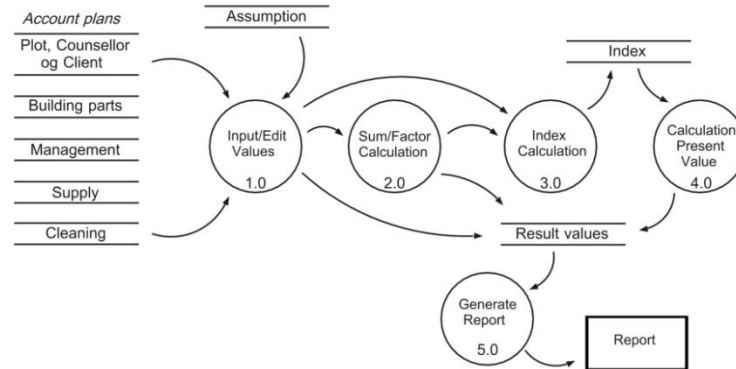
Figure 1: The system's procedural context (High level)

4. Setting requirements

Figure 2 shows the principle of the system where account plans will be completed and customized by the user (Process 1.0), after which the values are used in the subsequent calculations. 'Account plans' contain a number of items the user can select as needed. Interest rates are not implicit in account plans, but located in the register 'Assumptions'. The values entered by the user are stored both in the register 'Result values' and transferred to the calculation processes. The system calculates totals and factors (Process 2.0), which is later used in the calculation of the index values (Process 3.0). Some values are not included in the calculation of factors and sums, and used directly in the index calculation. The purchase will not be calculated as index or present values, and therefore saved directly in the register 'Result values'. The index values are saved for each year of the chosen calculation period. On this basis the present values are calculated (Process 4.0). All input, used standard values, and the calculated present value are placed in the register 'Result values', which forms the basis for

generating a ‘Report’ (Process 5.0). Process 1.0 and 5.0 are ‘semi-manual’ while Process 2.0, 3.0 and 4.0 are automated.

Figure 2: Outline of the system



Each of the predefined building parts has been associated with values for ‘Lifetime’, ‘Maintenance rates’ and ‘Replacement rates’. The values are taken from a report on lifetimes by SBi (Aagaard et al., 2013) and supplemented with maintenance rates and replacement rates from the price calculation database V&S Prisdata and the Green Building Council Denmark (2014). Lifetime is indicated as number of years the building component is functional and does not need replacement. When the estimated lifetime of a building component expires, the building component is replaced. Maintenance of the building components is specified as a percentage of the purchase price (the construction of the physical building components). Maintenance is calculated for each year of the calculation period, so the value represents an annual maintenance cost. Replacement is also a percentage of the purchase price of the building components, but appears only in the calculations of the year in which the lifetime expires.

The account plan for ‘Building parts’ calculates acquisition cost of the building, maintenance of the building components and replacement at end of life (Figure 3).

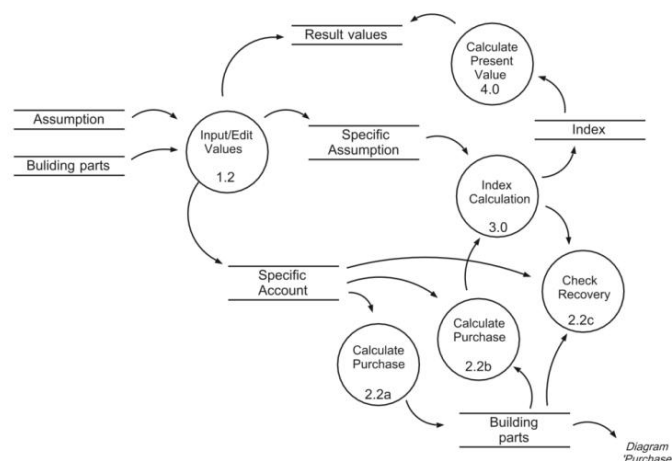


Figure 3: Calculation of building parts

For each year during the calculation period an indexed value and a present value is calculated. The input and editing made by the user in Process 1.2 is used in the calculations and saved simultaneously in the 'Result values'. The register called 'Acquisition of building parts' is also used in 'Acquisitions'. The account 'Building parts' contains parts classified under SfB group 1-6 (Byggecentrum, 2012).

5. Converting requirements to a solution

5.1 XML as data format

Data – and specifically data related to building structures with a long life – must be stored in a manner that allows data to be retrieved over time independent of specific tools, software, operating systems and hardware. The unique properties of the XML format makes it ideal for storing hierarchical data directly in a data tree, thus avoiding the need for the often troublesome references. It also allows adding and deleting posts where needed and belong in the logical structure. Consequently, the system store and exchange data in XML, as it makes it possible to store data in clearly defined structures without sacrificing flexibility. Storing data in a human readable format also allows data files to work outside the tool and it allows project file authors to create new project types by hand and merge outside data by using existing XML tools.

In naming the XML elements, tags and attributes are exclusively in English to avoid future problems with external XML tools. All tags and attributes are written in lowercase. Although it is possible to achieve a slightly higher human readability by using letter casings such as Camel-Case, the benefits are outweighed by the many trivial errors that can arise later when trying to figure out the correct casing for an element or attribute. The choice also allows the software code to define software objects as Camel-cased and XML elements as all lowercase, making it easier to identify what is referred to when working on the code base.

Many automatic XML-to-code generators will default to serialising data into elements rather than attributes. In order to preserve human readability, and make the XML correspond to the logic behind, it was chosen to handcraft the XML/Data Object conversion. This allows for values to be stored as attributes inside the relevant tags and reserve element creation for bearers of the hierarchical information. Making this distinction is helpful for deciding how the XML structure should look like when adding and refactoring the data format.

5.2 Development platform

In order to contain, edit and standardise the use of the aforementioned XML file, the project team chose to write a software program. In order to do that, an execution platform and one or more programming languages must be selected. A number of considerations were taken into account including use on the web, multi-platform compatibility, mobile and desktop use, industry standards, prevalence of programming languages, and availability of free, open source third-party extensions. As a consequence the application was created in C# as a Windows Presentation Foundation (WPF) application.

5.3 Graphical User Interface (GUI)

The general approach has been to design the application as a series of steps represented by tabs in the project pages. These are bound to the underlying software objects that are updated directly and with a minimum of filtering. An update of a value in the GUI triggers a complete recalculation of all results in the model. This allows showing in real time the effect of a specific change in value on the calculation. The cost data breakdown structure holds the account plan elements. These are shown in two tabs: one for editing structure and setting key values, and one for entering the main body of user values. The overall calculative results are shown in a tab labelled 'Conclusion'. The application can deliver output in three different forms: 1) a PDF document for circulation to decision-makers, 2) an XML file for others to continue working with, and 3) a spreadsheet.

5.4 Software structure

The software started its life as a relatively “thin” wrapper around the XML file, the idea being that calculations and formulas were held in accompanying XSLT style-sheets, and XSLT transformations made the calculations. The idea was that formulas and calculations could be shared as XSLT files allowing for future expansion and flexibility. The software lived through quite a few iterations in this form. In the end it proved too slow to execute and too cumbersome to maintain. Thus, it was decided to rewrite the core of the program using a more “classic” approach. The XML file is now serialised and de-serialised from/to software objects, each XML element getting a corresponding code class with the necessary fields and members. The rewrite resulted in a core that can now update its results in real time.

The model that was finally settled on was in part a result of the initial analysis of the existing spreadsheet solutions, and in part a result of realizations that took place while implementing the model and features. A great deal of work went into modularising parts of the calculation and the different functionalities. By standardising the calculation at the lowest possible level, calculations at higher up levels avoid having to deal with ‘if/then’ scenarios, where the source of the data has to be accounted for. The exclusion of references makes it easy to edit the structures without having to synchronize with an external reference. External references are not entirely excluded as the format has a ‘code’ attribute meant to identify the account plan row in another context such as SfB or similar.

The reporting feature is based around the idea of a clear separation of data and presentation as it is known in HTML and CSS. It has been important to limit the intertwining of presentation data, and data needed for the presentation, so where presentation data is necessary in the project file, it has been moved to separate elements. Table 2 shows the elements that both the XML file and the internal software model shares.

Table 2: Description of the system elements

<i>Elements</i>	<i>Description</i>
<i>accountplans</i>	<i>Account plans are structured in main-groups, sub-groups and rows.</i>
<i>basevalues</i>	<i>Each row comes with the possibility to store key values obtained from real life use, used as a common starting point of the calculation.</i>
<i>costdatabreakdown</i>	<i>This element holds the account plans.</i>
<i>inputvalues</i>	<i>The input-values store the specific user data. There is one set of input-values per row per version.</i>
<i>periods</i>	<i>The general prerequisites are stored inside periods, the main one being “period-of-analysis”. Future periods can exist next to the main “period-of-analysis”.</i>
<i>project</i>	<i>A collection of the elements below.</i>
<i>projectcollection</i>	<i>A collection of projects. Typically describing the same building(s) in different development stages.</i>
<i>projectcollectioninformation</i>	<i>Metadata and comments, some of which are output to the report.</i>
<i>projectinformation</i>	<i>Metadata and comments, some of which are used in the report function.</i>
<i>results</i>	<i>Results are stored inside their relevant parent element.</i>
<i>resultgroups</i>	<i>A list of and labels for the common way calculations are posted.</i>
<i>viewdefinitions</i>	<i>A list of selectable views including their names and accompanying texts. The views are the parts that make up the PDF report.</i>
<i>versions</i>	<i>Calculation and value sets. The names and description of alternatives are listed here.</i>
<i>versionresults</i>	<i>The common calculation results are stored here. Because the results at this level are standardised into specific result groups, it is possible to compare results from projects structured differently structured.</i>

The calculation flow starts at the account plan <row> level and follows a bubble-up method:

1. Resolve the origin of values, and pick the correct set for the row + version calculation. Different account plans will have different value sets. As an example an “acquisition” account plan, will only have a “unit-price” value, while a “maintain-renew-and-restore” plan will have the values “amount”, “unit-price”, “lifetime”, “maintenance” and “restore” values to calculate from. It is at this level that prerequisites and inflation rates are applied.
2. Calculate the acquisition cost (if relevant), and the indexed values, throughout the calculation period. Repeat this for each selected version.
3. While there are differences on the row level, results can now be treated uniformly from here on up. Sub-group results are simply sums of the underlying rows, main-group results sum up the sub-groups, and on the account plan level, main-groups are summed up as the top level of results of the plans.
4. The account plan results are then summed up and posted in the categories as described in the result groups.

Although the application has at the outset adopted the SfB classification scheme, the application

is fully open to other classification schemes. Rather than waiting for a national committee to form consensus on a new national classification scheme for building parts, a choice was made to store data in an editable structure that can be customized at run time by the user. Consequently, the data files has been flagged in order to mark elements as ‘locked’, and the GUI edit features are turned off accordingly.

6. Conclusion

The principles of lifecycle costing or whole-life costing has been around for decades, but the implementation of the principles has been modest or even weak despite the obvious advantages of integrating maintenance, operation and management aspect into the design of new buildings and facilities. Based on the methodology of structured analysis and agile software development methodology, this paper reviewed existing tools and discussed (some of) the design choices and summarised lessons learned from the development of LCCbyg – a new tool for lifecycle costing launched in its first version by the Danish government in early 2015.

First, this paper provided a typology of existing tools into three categories with distinct characteristics and associated benefits and drawbacks: 1) Spreadsheets, 2) stand-alone applications, and 3) web services. A fourth type – apps for mobile platforms – is not yet relevant as a calculation tool.

Second, while the software interface only displays limited unique features and functionalities compared to other available tools, the data model inherent in the tool provides a number of unique design choices. These design choices make the tool highly robust to future development; incorporate a fully open standard in XML format for easy exchange with other applications; provide the users with a high degree of adaptability to their specific requirements; and reduce the need for an elaborate classification scheme for cost and building components that would otherwise severely restrict the adaptability of the tool.

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Business Model Innovations for Low or Zero Carbon Building: An Analysis of Empirical Research from 1996 to 2015

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Abstract

The low or zero carbon building (LZCB) approach has been promoted in many countries, however, the claimed environmental, social and economic benefits from utilizing this approach are often impaired or unrealized. Traditional organizational business models face challenges in the delivery of LZCBs, and require re-thinking in order to create and sustain competitiveness and economic value. However, there is a deficiency of previous research into the commercial viability of LZCB from the perspective of business model. The aim of this paper is thus to develop a conceptual model of business model innovation for LZCB, and to identify archetypes of business model innovations for LZCB and their general development trend over the study period. The research was carried out through a meta-analysis of the literature of business model and LZCB. Evidence was collected and examined from 98 empirical studies of business strategies and processes for LZCB and industrial or corporate reports on LZCB published during the period 1996 - 2015. Through analysing the collected qualitative data using Nvivo 10 and HistCite™, the paper develops a conceptual framework of business model innovation for LZCB, which compasses three core components: value proposition, value delivery and creation, and value capture. Business model innovations are explored from these three core components respectively to describe common patterns and mechanisms of business model innovations for LZCB. The evolution of business model is tracked based on the qualitative analysis of LZCB projects of industry players over a twenty-year period (1996-2015). The results show that organizations generally adopt three interrelated innovative approaches to promoting LZCB, namely, reconfiguration of value proposition for customers, reconstruction of delivery mode and stakeholder network, and innovation of revenue generation logic. The archetypes of business model innovation and business model evolution path support the successful delivery of LZCBs. The findings contribute to a systematic understanding of the relationships between business model and LZCB.

Keywords: Business Model, Low Carbon Building, Zero Carbon Building, Innovation, Data Mining

1. Introduction

The term ‘business model’ has gained substantial attention in literature and industry since the emergence of e-business and the so-called new economy boomed. Recent management and business literature has widely used this term as an effective management tool for companies’ value creation and company performance (Osterwalder, Pigneur et al. 2005, Bocken, Short et al. 2014). Broadly speaking, two types of uses of this concept are identified. On the one hand, the concept articulates a series of activities between different ‘building blocks’ to produce a proposition that can generate value for customers. Business model is closely related to a company’s competitive advantage and expresses the business logic of a specific company through designing business products, services and activities (Rasmussen 2007, APEC 2009). On the other hand, the business model construct has been utilized in the facilitation of technologies or innovations (e.g. Chesbrough and Rosenbloom 2002, Zott, Amit et al. 2010). An appropriate business model can increase the market attractiveness of a technology and transform certain attributes of innovation into sources of the economic value creation (Bohnsack, Pinkse et al. 2014). In this view, “progressive refinements” to business model (Demil and Lecocq 2010) i.e. business model innovations are required to adapt to the external environment and/or to create a competitive advantage.

The construction industry, nevertheless, is a sector where the concept of business model seems to be far underdeveloped. Discussions of business model in the construction industry are mostly embedded in the literature of competitive advantage, strategic management, and innovation. The building industry holds the promise to reduce carbon emissions and improve energy efficiency due to the enormous energy consumption the industry accounts for. According to IEA (2014), building blocks consume 32% of the total energy use worldwide. The carbon emissions of buildings are predicted to reach 42.4 billion tonnes in 2035 due to the continuous increase of buildings and the growing expectation of building services by occupants (USEIA 2014). A wide range of technological innovations, such as energy efficient technologies, renewable technologies, and microgeneration technologies, can be potentially used as a part of the solution for achieving low or zero carbon targets. Despite the conceptualisation of technical rationality, low or zero carbon buildings (LZCBs) still face challenges in penetrating mainstream building markets. The problems faced by business practitioners include that LZCBs challenge prevailing construction practices (Johnson and Suskewicz 2009), the lack of customer preferences and market attractiveness (ZCH 2010), and the requirement for new knowledge, experience and managerial expertise associated with LZCB (Pless, Scheib et al. 2014). It has been argued that, firms need different business models to address these problems and come up with new sources to generate economic value in addition to their contribution to environmental sustainability (Chesbrough 2007). However, the emerging ‘LZCB sector’ is still in search of viable business models. Various business models are being simultaneously experimented, trial-and-error learned within and across early adopters (Sosna, Treviño-Rodríguez et al. 2010, Teece 2010).

Compared to the widely reported benefits and up-take barriers of LZCBs, there is quite limited understanding of the building companies’ business models for the uptake of LZCBs. Firms’

processes of business model innovation and evolution is still vague. This paper thus aims to address these knowledge gaps by exploring the general development trend of literature in the fields of business model and innovation, the conceptual framework of business model innovation and its main constituents, main archetypes of business model innovation for LZCBs, and the evolution roadmap of business model evolution for LZCBs. The paper develops a structured approach to extracting and creating value from LZCBs by innovative business models. The research on which this paper reports was carried out through a meta-analysis of scholarly publications and LZCB project reports of key industry actors in the field of business model.

2. Methodology

This section describes the methodological approach which systematically locates and analyses the research related to business model in the field of LZCBs, from both academic journal publications and reports and magazines of industry and key project players. As shown in Figure 1, the research on business model not only explored and identified research thematic objects with classical approach, but also processed and structured the thematic objects and bibliographic data with text mining techniques. The two approaches are interrelated and mutually enforced with continuous feedback loops.

At Stage One, four criteria were applied in the literature survey to determine the research scope and time framework. To retrieve the bibliographic data, first, the term ‘business model’ is included in the title of the paper. In view of massive articles on the subject of business strategy and business management, the search eliminates papers that only make an incidental references to business model. Second, to ensure the quality of the data, scholarly peer reviewed articles were retrieved from the Web of knowledge database, while proceedings, book reviews, commentaries, reports, and working papers were excluded. Third, since the research focus is LZCBs, the research areas were limited to “business economics”, “engineering”, “operations research management science”, “energy fuels”, “environmental sciences ecology” and “construction building technology”. The journals that have no concern on the construction sector were eliminated from the search results. Fourth, since the nature of the research is primarily empirical, the paper searched for and extracted business cases for LZCB projects, covering trade magazines and corporate/project reports, which provides detailed descriptions of LZCB projects and associated business models, and offers insights into perceptions and business strategies towards LZCBs. The search period starts from year 1996 when the number of LZCBs increased at a clear growth rate (see Pan and Ning 2014).

To conduct meta-analysis of the data retrieved at Stage 1, a two-phase approach was applied in the following 3 stages. At the first phase (Stage 1 and 2), the bibliographic data from Web of Knowledge was analysed with HistCiteTM software to give an overview of the research field over the study period. The abstracts and author keywords were further analysed to extract the most frequent terms and phases. The results indicate the main themes and components of business model innovation, which provide a comprehensive basis for the development of the conceptual model of business model innovation.

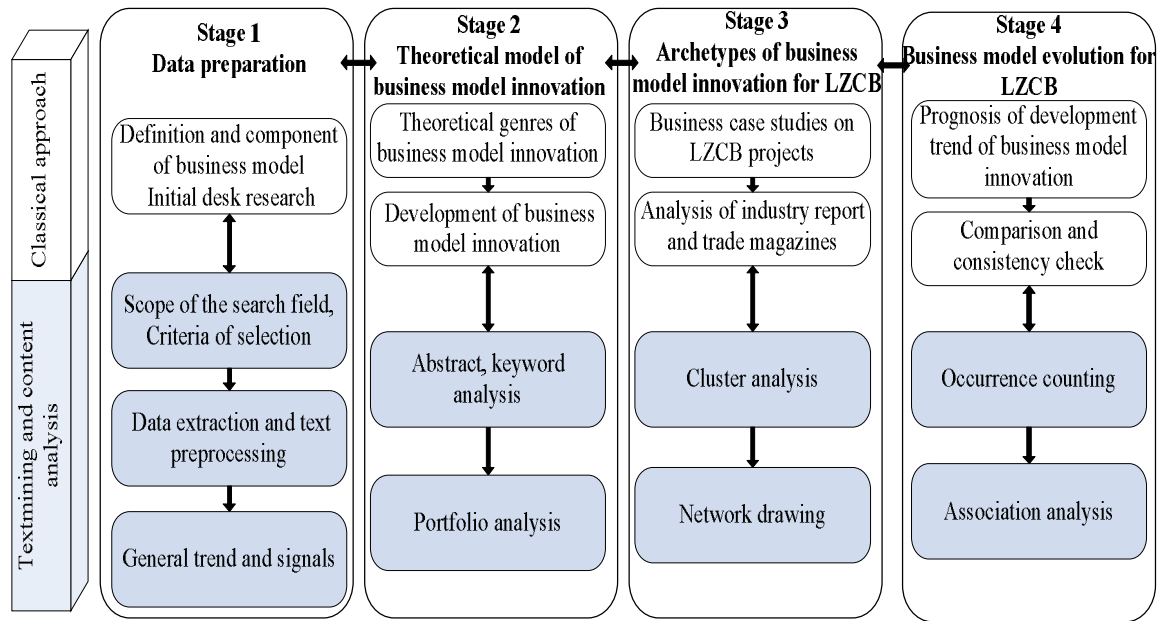


Figure 1. A meta-analysis-based process model adopted in the paper

At the second phase (Stage 3 and 4), qualitative data analysis software Nvivo 10 was used to organize and analyze data of empirical studies from academic articles and trade periodical/reports. First, the information that connects to the main components of business model innovation was labelled and structured according to the conceptual model. The objective of this step is to derive the archetypes of business model innovation in the context of LZCBs. Second, the occurrence number of business model innovations at the core themes of business model innovation will be counted and statistical analysed to give an overview of the development trend of the identified archetypes of business model innovations. Business models of large firms and small and medium enterprises (SMEs) that have delivered LZCBs were traced over the timeline in order to generate the roadmap of business model evolution regarding LZCB development. The contingent events were also identified, the effects of which were examined by exploring the explanatory power of the events on the LZCB market evolution in chronological order.

3. Findings

The main findings of the study are presented in this section, which are centered on the general trend of business model, the conceptual model of business model innovation based on the dominant themes emerged from bibliometric analysis, and the archetypes of business model innovation for LZCB and their evolution.

3.1 Profile of research on business model and LZCB

Before exploring the theoretical framework and archetypes of business model innovation for LZCBs, the paper detects the origins and particularly the surge of the business model documents. The paper searched the titles of scholar articles in the Web of Knowledge database for the word string "business model". The number of the search results is shown in Figure 2.

According to the search criteria and screening process, the search results include 483 articles published in 299 journals in the field of business model in total from 1996 to 2015. The query suggests that the term “business model” rose to prominence until the middle of 1990s in the construction sector, though it appeared in an academic article in 1957 (Bellman, Clark et al. 1957). A general growth trend can be observed in the publications on the topic of business model.

In the field of LZCB, the paper identified 639 papers that featured “low OR zero carbon OR carbon neutral* OR sustainab*” and “building OR home OR hous* OR project” in their titles. There is a significant trend of growth of the number of academic articles during year 1986 and 2005. Most of the articles that reported the environmental aspect only focused on the element of carbon emissions or energy consumption. The contribution of LZCBs on the environmental aspect was consistently the main theme of the majority of the articles.

In the field of intersections between business model and LZCB, however, a limited number of articles can be obtained from the database. After the screening process, a total of 98 articles were retrieved from the database, which were validated to be concerned with the business models of LZCB. The results of this step illuminate the knowledge gap on business model for LZCB, and generate the first inputs for generating a conceptual framework of business model innovation.

3.2 A conceptual framework of business model innovation

The components and process of business model innovation have been emphasized and widely studied in the recent decade. In the business and management discipline, the literature in this stream examines the innovations of business model from two perspectives: activity-based approach and value chain-based approach. The activity-based approach characterizes the innovations of business model as a system of interdependent activities reacting to environmental changes. Afuah (2004) described a business model as the set of activities a firm performs, the way the company performs them and complemented assets supported these activities. Zott and Amit (2010) defined the term ‘business model’ as an activity system supported by the focal firm and its partners. Artto, Wikström et al. (2008) analyzed business models of project-based firms, and identified the impacts of services on business model innovation from the project delivery process.

The other stream of research conceptualises business model innovation as a flow of value chain. Osterwalder and Pigneur (2010) described a business model as “the rationale of how an organization creates, delivers, and captures value”. Lenssen, Bocken et al. (2013) developed a value mapping tool for sustainable business model, and examined the business model innovation by mapping the value captured, missed, destroyed and opportunities of sustainability. Demil and Lecocq (2010) developed a RCOV framework of business model (resources & components, value proposition, organization) and viewed business model evolution as fine-tuning process involving changes both within and between its main components.

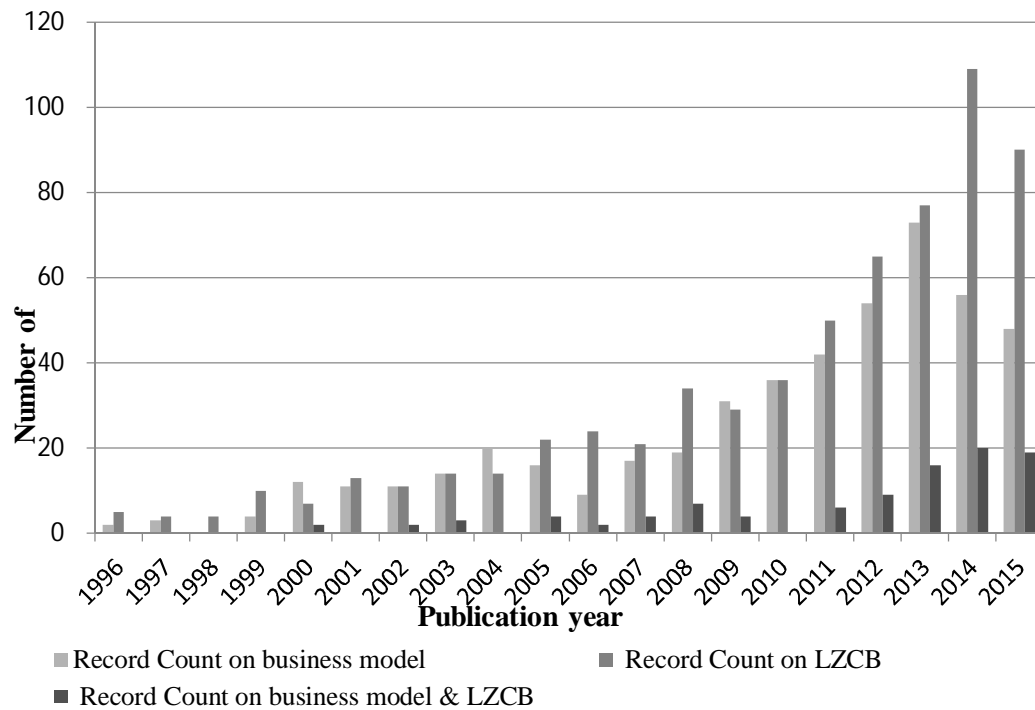


Figure 2. Recent development of research in the field of business model and LZCB over the timeline

While the two dominants logics of business model innovation have been established in the management discipline, the novel part of this section is to verify the theoretical assumption in the field of LZCBs through text mining of abstract phases and keywords in the bibliographic data derived at Step 1, and to identify recent themes/components of business model innovation for LZCBs. Figure 3 shows a word cloud map and a frequency table of the top 50 terms.

Figure 3 and Table 1 show the key areas of business research on LZCBs. Topic related words (sustainable, building, business, model, innovation, project, green, etc.) and stopwords (using, based, provide, study, paper) were removed since they are general and display no content.



Figure 3. Word clouds of top frequent terms from 1996 to 2015

Table 1. Frequency table of top 32 terms in abstracts and keywords

<i>Terms</i>	<i>Frequency</i>	<i>Terms</i>	<i>Frequency</i>	<i>Terms</i>	<i>Frequency</i>
<i>develops</i>	194	<i>production</i>	61	<i>operation</i>	49
<i>design</i>	115	<i>service</i>	59	<i>household</i>	49
<i>environmentally</i>	93	<i>cost</i>	56	<i>urban</i>	49
<i>managing</i>	71	<i>systems</i>	55	<i>construction</i>	48
<i>industry</i>	66	<i>economic</i>	55	<i>city</i>	47
<i>value</i>	64	<i>social</i>	54	<i>markets</i>	45
<i>technology</i>	62	<i>efficiency</i>	53	<i>environments</i>	44
<i>policy</i>	62	<i>governments</i>	53	<i>organizations</i>	44
<i>pricing</i>	62	<i>process</i>	52	<i>engineering</i>	39
<i>performance</i>	57	<i>plans</i>	49		

The terms “household”, “market”, “value”, “performance”, “service”, and “environmental” closely relate to products/ services that are provided to the customer/occupants sector, i.e. ‘value proposition’. Terms such as “plans”, “develop”, “design”, “manage”, “construction”, “organization”, “engineering”, and “process” describe the delivery process of LZCB projects, and organizations and stakeholders that are involved in the value delivery process. This category of terms can be attributed to “value delivery and creation”. ‘Value capture’ is another element that was emphasized in Table 1. “Pricing”, “cost”, “economic”, “urban”, “government”, and “market” portray the structure of cost and revenue, which include building scales, pricing and financing strategies, government incentives, and any additional incomes. Combining the analytical results above, the paper structured the conceptual model of business model innovation for LZCB as three interrelated components: value proposition, value delivery and creation, and value capture, as shown in Figure 4.

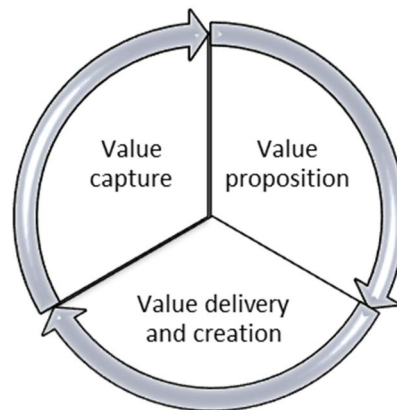


Figure 4. Conceptual model of business model innovation for LZCB

3.3 Business model innovations for LZCB: archetypes and evolution

Firms' experiences and related complemented resources and networks in empirical studies were examined in this section. Based on the developed conceptual model mentioned above, archetypes of business model innovations have been identified from the three main components respectively. The archetypes in the category of 'value proposition' (LZCBs and related services provided to target customers) can be distinguished from variations in building types/purposes, scales and contents of product/service. For the 'value delivery and creation', this paper tracked changes in the modes of LZCB development and delivery, and associated stakeholder networks. The activities in the value creation process depend upon the range of value proposition, may cover the land acquisition, design, preconstruction, construction, operation, demolition and recycling phases. With regard to the 'value capture', this paper explores how LZCBs were brought to the market, how firms compensate cost from the revenues schemes, and whether there were financing reimbursements and government incentives supporting LZCBs. The archetypes in the three categories are summarized in Figure 5.

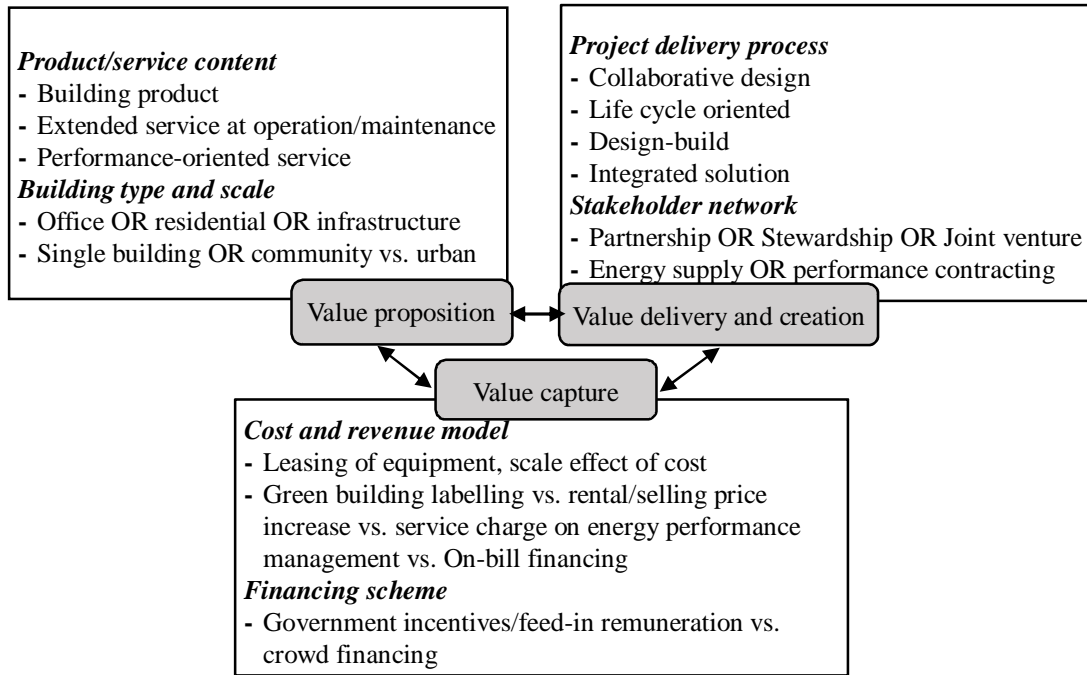


Figure 5. Main archetypes of business model innovation for LZCB

Value proposed to building owners and occupants locates at the centre of a business model structure. Evidence from studies proved a range of -0.4%-12.5% higher building cost for LZCB compared to conventional code-compliant buildings (WGBC, 2013). To prove the LZCB assets value to customer and improve customer acceptance is therefore the foremost issue for developers. Depends on the building type and purpose, higher sale prices/lease rates, lower life cycle cost, and improved indoor air quality and resulted improved productivity have been demonstrated in various resources. In addition, supported by product service system theory, companies have extended their value proposition from building itself to a combination of building products and services in operation and maintenance stage. In this way, developers have shifted customers' focus from building ownership to use-based functionality. Measured by the

building scale addressed, the majority (63%; 75) of the identified articles targeted their research object to a single building, and some (17 and 21 respectively) examined community scale LZCB and urban scale LZCB. The identified research by building type was mainly contributed by the articles examining residential buildings (38%; 45) and the commercial buildings (35%; 41), with marginal contribution from those studying multipurpose buildings (7%; 9). Among the studies addressing the product or service provided to end-users, aside from the vast majority of research addressing LZCB itself, one half (50%; 59) examined the extended service provided to customers in a building's life cycle process. This result reveals the significance of customer-oriented service after commission, which is consistent with the emphasis of the group of articles regarding users' concerns on building performance (47%; 56).

To successfully deliver LZCBs in the value creation process, companies should make full use of available resources and capabilities within project delivery processes and stakeholder networks. Key strategies in the delivery process identified from the dataset include: collaborative design, integrated solution, proactive contracting, value recycle from 'waste', and design-build mode etc. Since most building stakeholders' knowledge on LZCB is minimal at current stage. To design functionally low or zero carbon, the collaborative inputs of all specialists are proved to be successful in multiple projects. Opinions are sought from clients, designers, architects, community and end-users to optimize design solution for best performance. In addition, proactive contracting such as design-build mode has been adopted in LZCBs project to maximize contractors' inputs and improve the project time performance. Correspondingly, firm actively expand its stakeholder network through partnership, stewardship and Joint Venture. To proactively engage with stakeholders and keep a stable long-term relationship, companies have managed to improve the cost efficiency, and maximised its positive societal and environmental impacts.

By project delivery process, the largest group of the business model articles for LZCB focused on the examination of design stage (52%; 61), followed by the group mentioning the construction stage (38%; 45), and operation and maintenance stage (24%; 61), while very few examined business models of LZCB from the supply chain and project planning stage. The collaborative design and integrated solution are emphasized in the articles examining design stage and delivery mode, the number of which reach about two fifth (52) of articles. Moreover, the life cycle oriented solution is another salient point in the literature, almost one third of the articles were concerned with the lifecycle impact of LZCB and life cycle oriented design.

Innovative financing and revenue schemes help create LZCB case if these innovations help to overcome the relatively higher upfront cost. Aside from loans and government incentives for low or zero carbon, new schemes have been employed, such as equipment leasing, crowd financing, pay-per-use, ESCO model, and green building benchmarking. Over one third (44; 37%) of the articles addressed the governments' role in the delivery of LZCB, which includes government incentives, feed-in tariff schemes, and remuneration. While a relatively small number of articles have reported the use of utility manager (17) (such as ESCO) in the operation stage and the green building labelling (11) as innovative revenue models.

From qualitative analysis of LZCB practices of key industry players over the timeline, firms generally take their existing business model for conventional building projects as a starting point to incremental adjust and refine, in order to bring LZCBs in their business domains. Due to variations of firms' scales, history backgrounds and complemented assets, firms have different abilities to tap into LZCB business and react to change initiatives at external environment. Incumbents and entrepreneurial firms adopt different. Relying on the economies of scale and well-developed partnership network, large established firms have ability to experiment LZCB projects with multiple business models simultaneously, fine-tune and select the standard business model for LZCB in future. The future target of these firms is to achieve production scales with LZCB and optimize cost efficiency.

Compared to large incumbents, small and medium-sized enterprises (SMEs) in the building sector are less constrained by their dominant business model. The novelty is their main value proposition for customers. However, due to the relatively vulnerable customer base and assets, they are more susceptible to external incentives and contingent events. Generally, SMEs are most likely to test a single business model at one time. In the value delivery process, SMEs are more agile to cooperate with outside partners, and make use of their expertise and knowledge. For the value generation logic, SMEs have to explore innovative ways to fund the projects. Aside from loans and capital investment, green building certification, on-bill financing, and government incentives such as feed-in remuneration schemes and have been applied in the financing and revenue strategies.

4. Conclusions

This paper has examined the literature of LZCB and business model and industrial practices of LZCB during the period 1996-2015 through a structured meta-analysis. One conclusion of this paper is that a significant knowledge gap has been identified between the fields of business model and of LZCB with regard to their general development. This knowledge gap is evidenced by the remarkable difference in the quantity of relevant publications. Although there has been a general growing research interest in both the fields of business model and LZCB separately, research that integrates the two is limited. Another conclusion of the paper is that from the analysis of the key terms used in abstracts and keywords, three thematic focuses have emerged, i.e. value proposition, value delivery process, and value capture. These themes together form a conceptual framework of business model innovation for LZCB. A further conclusion of the paper is that through the analysis of the detailed contents and empirical data, archetypes of business model innovation have been explored from the three emerged core components. Two different paths that large firms and SMEs have adopted to evolve their business models for LZCB have then been identified over the timeline.

The findings of this paper illuminate effective mechanisms that firms can adopt to promote LZCB and help detect the future trend of LZCB development. Future research should explore the interdisciplinary field of business model innovation for LZCB, which has been identified as a knowledge gap. It should help to track the trajectory of business model innovations and examine their relevant impact on the delivery of LZCBs.

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BIM Product Libraries for Life Cycle Support

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Abstract

Building information modelling (BIM) is believed to improve the information management flow through the whole life cycle of the building. In current practice, benefits of BIM are generally used at the design and construction phases. Despite the progress of BIM technologies and practices, product data management (PDM) is neither well known nor common in the industry. There is a need for product libraries that are software neutral including standardised data content and structure, in order to provide consistent and unbroken flows of information through the whole life-cycle of buildings. Examples from other industries (e.g. mechanical engineering) could encourage the development of product libraries. The product libraries that exist today for construction projects are primarily software specific and directed to various user groups and cause interoperability issues when used over time and between actors. Enhanced and standardised libraries would potentially increase sustainability in the construction. This paper presents the current state of BIM product libraries for the construction industry (in BIM mature countries) in the context of information format (proprietary or open), content (generic or manufacturer specific), structure (level of granularity for geometry and information), provider (software vendor, commercial, or in-house), and usage (project phase, contract type). Finally a proposed framework with through life support is presented based on existing open international standards, life cycle phases and the high level building classification framework standard ISO 12006-2.

Keywords: BIM, Product Library, Level of Detail, Level of Information, Life cycle support

1. Introduction

There is a growing interest in developing product libraries internationally. The actors are national bodies, manufacturers and specialist companies who see a potential in the market, but do not address the issue of production and distribution of product information for the emerging open BIM software systems. The main developments of library objects, called BIM objects in this paper, are addressing proprietary formats supporting only one or few software systems. This increases the cost of populating product libraries as multiple formats must be supported and also increases the difficulties maintaining them over different platforms and over time (Duddy et al., 2013). Different contract types use generic and manufacturer specific BIM objects differently

over the life cycle of the construction projects – and possibly also during operation and maintenance, see Figure 1, which illustrates when generic and manufacturer objects are generally used in different delivery methods during the project life cycle (Vahenurm, 2014).

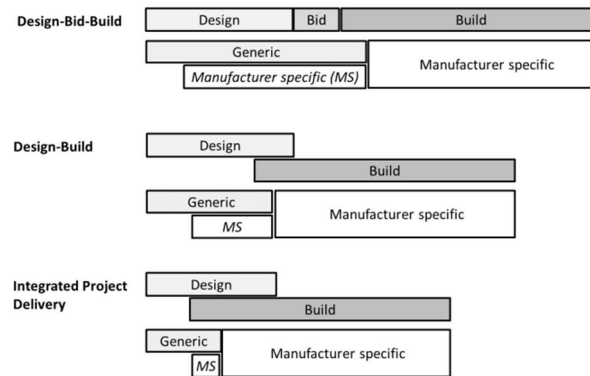


Figure 1: Project delivery types and use of Generic and Manufacturer specific BIM objects (Vahenurm, 2014)

There are several different types of product libraries with BIM objects available and suitable for different phases of the construction projects, depending on the level of specialisation of geometry and information linked to the objects in the library. Some typical examples are:

- CAD/BIM libraries coming with the design software – generic BIM objects
- Product type libraries compiled by different associations – standard components in industry segments, e.g. ducts
- Manufacturer's libraries manufacturer specific products
- Project libraries project specific, selected for the project
- Company libraries in-house preferred, selected from old projects

These libraries have very different structures, content and formats and they have also limited support for different levels of detail and information. There is lack of open BIM product information in well-structured and rich information content libraries supporting the whole life cycle of products and buildings.

1.1 Background

Several studies have been carried out regarding product libraries with the focus on accessibility to product information from manufacturers and beneficial ways of interacting with product information (Amor et al., 2004). One of the criteria for comparison of content in the different libraries is the level of definition (LOD) as defined by the American Institute of Architects. For building products, this can be summarised as LOD 200 indicating the approximate size and position of a product or construction type through increasing levels of detail to LOD 400, which is a fully detailed definition of the product/construction type to be installed. LOD 500 is reserved for a verified on-site installation. (Duddy, et al., 2013). The problem is that there are very different interpretations and definitions for these concepts, as well as how and when to use them

during the construction process. Amor et al. (2004) state that the following issues are remaining barriers to the uptake and development of online product libraries: *Products' data representation, Extraction of data from manufacturers, Business models for online catalogues, Contextual impact of project requirements, Mapping between representations, Support for preferences, Life-cycle support*. Until these barriers are overcome we can expect our access to powerful online identification and incorporation of manufactured product information to be severely constrained (Amor et al., 2004).

1.2 Purpose and Method

This study is focusing on presenting the current state of BIM product libraries supporting the construction industry and the barriers for a wider uptake. The context is information format (proprietary or open), content (generic or manufacturer specific), structure (level of granularity for geometry and information), provider (software vendor, commercial, or in-house), and usage (project phase, contract type).

The research question is: How can a framework for through life support of BIM objects, based on existing open international standards, life cycle phases and a high level building classification framework standard, be a solution to overcome barriers to the uptake and development of online product libraries?

Method: The study was carried out as a review of literature in journals and conferences on BIM product libraries. Also implementations of BIM product libraries in Europe and Australia were reviewed and analysed, as being in the forefront. Planning, implementation and operation of product libraries were in focus. The study started in June 2014. The findings were used as requirements for an object model framework for through life support of BIM objects. They were compared with the life-cycle support for open BIM at the BIM Collaboration platform and experiments carried out at KTH, Royal Institute of Technology (Tarandi, 2015).

2. Definition of used concepts

Product library – “a storage where information about products can be found and accessed.” (Stangeland, 2013). As no formal definition exists, this can be a starting point. The content of a Product Library should be products corresponding to BIM objects in the BIM models used in the construction processes. The products have geometry, which can be parametric, and they can have properties with units and values. The classification of objects and properties is vital, and is preferably defined by a dictionary, like buildingSMART data dictionary (bSI, 2015). Today no common guidelines or open standards for BIM object libraries are implemented and used (Palos et al., 2014).

BIM objects - The product objects in a BIM, Building Information Model, are also called BIM objects and they have a geometric representation of physical products and can be high-level assemblies at various levels of detail, including specific products (Eastman, et al., 2011). The granularity of the BIM objects should be matched with the International framework for Con-

struction classification ISO 12006-2:2014 (2014) to fit industry practice for bill of quantities and construction planning.

3. Development of product libraries

Paper catalogues including descriptions, parameters and illustrations were substituted with electronic online product libraries (Amor, Jain & Augenbroe, 2004) when information technology solutions improved. Today, several providers have started to offer online BIM orientated product libraries which include BIM objects with different levels of geometry and information. Some examples are NBS National BIM Library, BIMcomponents, BIMobject, and SmartBIM. More BIM libraries are presented in Table 2. The product libraries that exist today are primarily software specific and directed to various user groups (Palos et al., 2014 p. 59).

There are several ways how to categorise Product Libraries. Succar (2009) states that interchange can occur in three main ways; proprietary (e.g. Revit file – RVT), open-proprietary (e.g. DWF and many XML schemas), and non-proprietary which is open (e.g. IFC and CIS/2). This paper categorises Product Libraries by the following:

1. **Content** – Products (objects) can be (Stangeland, 2013):
 - a. Generic
 - b. Manufacturer specific
2. **Content's format**
 - a. Libraries containing PDF sheets and/or 2D drawings in e.g. PDF, DWG formats
 - b. Proprietary Product Libraries – 2D & 3D CAD and BIM software specific formats like DWG, RVT etc. Here also the open – proprietary formats can be included
 - c. Non-proprietary Open Standard Product Libraries – e.g. IFC, bSDD formats
 - d. Multiplatform Product Libraries – Proprietary and open formats mixed
3. **Provider**
 - a. Software vendors
 - b. Associations (e.g. ventilation product manufacturers)
 - c. Commercial providers – manufacturers, suppliers, wholesalers
 - d. Private AEC companies – have created in-house Product Libraries

The Manufacturer specific products can be designed and produced in alternative ways, and this influence when they have to be ordered and when they can be delivered to the construction site. MTO (made-to-order) components are usually produced as needed due to the short shelf-life and high inventory costs. ETO (engineered-to-order) elements involve more specific design, while the suppliers of MTS (made-to-stock) and MTO components are rarely involved in installation phase as the components are designed for general use. Generally the elements available on BIM platforms are generic and do not describe specific manufacturer's components and do not include product specific information. Product type from a manufacturing and supply chain point of view is also influencing the accessibility of the product information. They are ETO, followed by MTO, and then ATO (assembled-to-order), finally MTS products, as shown in Table 1

(Zeng et al., 2015). It is based on CODP (Customer Order Decoupling Point) classification thinking.

Table 1: Types of product, according to CODP, after Zeng et al. (2015)

CODP	Product Example	Lead Time	Stock
ETO	Power distribution equipment, Preassembled rebar components	long	no
MTO	cast-in-place concrete, prefabricated panels	long/short	no
ATO	doors, windows	short	yes
MTS	consumables such as bricks, bolts	short	yes

Several countries, including UK and Australia, have set requirements or recommended to adopt BIM in the public projects. This has initiated another form of product libraries supported by national institutions. One example of Open standard libraries is IFC Product Libraries that are supported by product information from templates and bSDD (Stangeland, 2013). Table 2 below is an overview of proprietary and multiplatform Product Libraries. Work by Eastman et al. (2011) has been updated.

Table 2: Overview of Proprietary and Multiplatform Product Libraries

	Modelling environment	Format of content	Portal	Links
Proprietary Product Libraries	Graphisoft ArchiCad	ArchiCad	BIMcomponents	https://bimcomponents.com/
	Autodesk Revit	Revit, AutoCad	Autodesk Seek	http://seek.autodesk.com/
			Arcat	http://www.arcad.com/
			RevitCity	http://www.revitcity.com/
			SmartBIM	http://library.smartbim.com/
			MagiCAD	https://portal.magicad.com/
	Nemetschek Vectorworks	Vectorworks	Vectorworks	http://www.vectorworks.net/
Multiplatform Product Libraries	Bentley Systems	Bentley/AECOSim	MicroStation	http://www.bentley.com/en-US/Products/microstation+product+line/
	Tekla Structures	Tekla	Tekla Warehouse	https://warehouse.tekla.com
		AECOSim, ArchiCad, IFC, Revit, Tekla, Vectorworks	NBS National BIM Library (UK)	http://www.nationalbimlibrary.com/
		ArchiCad, IFC, Revit, SketchUp, etc	BIMobject	http://bimobject.com/

4. Standards

Standardisation is especially important for product libraries, as there often is a change of actors when going from design to supplier specific products in the BIM (Berlo et al., 2015). Palos et al., (2014) state that there is a great need for a product library standard in the construction industry. The purpose of the standard is to determine what products should be contained in the libraries, what properties are required and how libraries are supported by different classification systems (Palos, et al., 2014). Also Nummelin et al. (2011) state that enhanced and standardised libraries would potentially increase sustainability in the construction industry. Three important standards/groups of standards for BIM product libraries are described in the following paragraphs.

4.1 ISO 12006-2

Internationally, the ISO 12006-2:2014 (ISO, 2014) standard is a framework for classification for organising the information about construction works. It defines the granularity of building elements, work results and products to fit the manufacturers' products and their classifications.

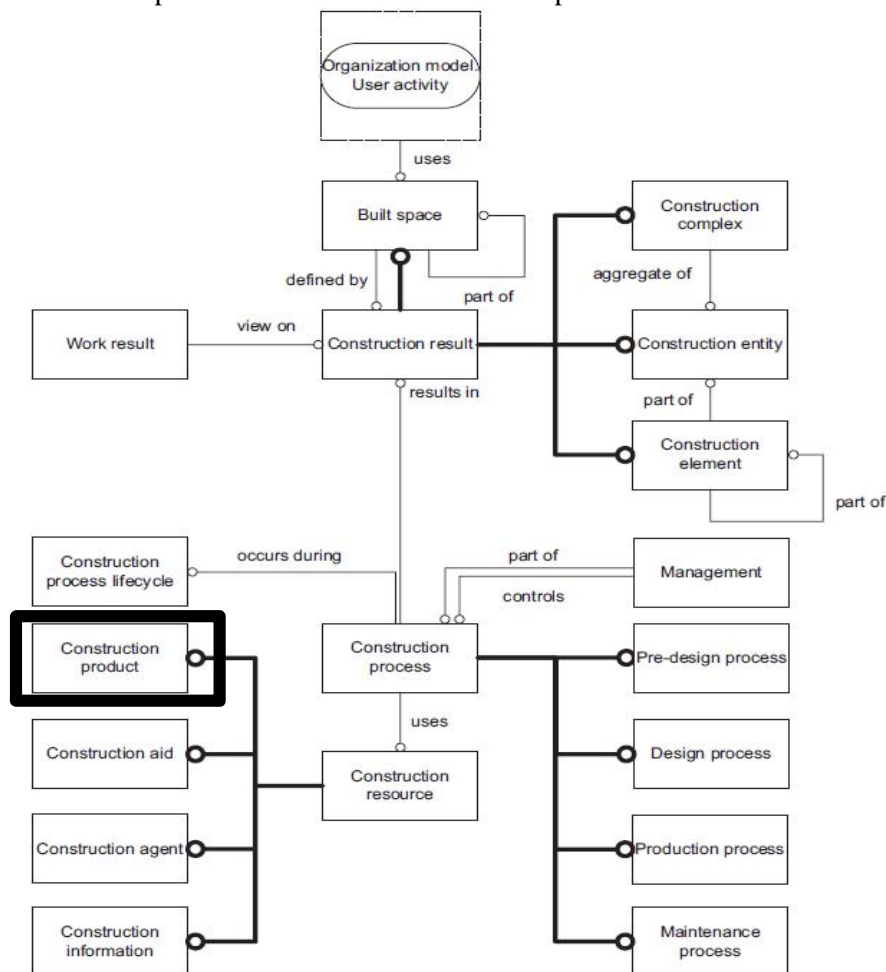


Figure 2: ISO 12006-2:2014 (ISO, 2014) Construction product in relation to Construction resource

The standard is for “Organisation of information about construction works and is implemented in many national classification systems” (ISO, 2014). The Construction product entity is a Construction resource with a relation to the Construction result, which can be a Construction complex (e.g. airport), entity (building) or element (window). In Figure 2 the Construction product is highlighted.

4.2 buildingSMART International open standards

buildingSMART International (bSI) is a worldwide standardisation organisation driving the transformation of the built environment through creation and adoption of open, international standards (bSI, 2015). IFC is a building product data model for building planning, design, construction and management (Eastman, et al., 2011). In addition to IFC and bSDD (IFD), buildingSMART has three other basic methodology standards, Information Delivery Manual (IDM), BIM Collaboration Format (BCF) and Model View Definitions (MVD).

ISO 12006-3:2007 (2007) “Building construction – Organisation of information about construction works – Part 3: Framework for object-oriented information” is known as buildingSMART Data Dictionary (bSDD) and describes the meaning of information that is exchanged.

4.3 PLCS, Product LifeCycle Support

The business objects in PLCS, ISO 10303-239 (ISO, 2012) cover the whole life cycle for products, with the goal to support the maintenance, influence the design, development and production for maintainability and finally influence the requirement improvements for the coming projects.

5. Levels of development, detail and information

While the concept of LOD is gaining popularity as more projects are required to be delivered in BIM, the definition of what LOD levels mean and how they should be used is getting more interest. Moreover, there are different meanings of LOD. This can stand for Level of Development and Level of Detail. One possible view is that Level of Development is better to represent the LOD as it can be thought as a combination of geometry (detail) and non-geometric content (information), while Level of Detail mainly represents the geometry. The need to properly define the concept of LOD is stated by Berlo et al. (2015). Today the industry participants are still asking for different LOD models and everyone has their own idea what the LOD model is. It is not clear what kind of information should be available in a model on a particular level.

“Level of Development is the degree to which the element’s geometry and attached information has been thought through – the degree to which project team members may rely on the information when using the model” (BIMForum, 2013). Berlo et al. (2015) described the Dutch National BIM Levels of Development and the 7 levels of development as having only limited

adoption by the industry. In a new research (Berlo & Bomhof, 2014) the result show that the Levels of Development were used, but the names of the phases they represented could not be agreed upon. In the collaboration between multiple partners it should be required to know exactly what the model can be used for, what data in the model is definite, and what confidence level is appropriate for the model? Level of Development (LOD) is a measure how seriously the information presented by the BIM object can be taken (McPhee, 2013). It is not a measure of the amount or accuracy of graphical information, rather the level on trust of the data that can be assigned to a BIM model. It should be clear what information to have in the model to perform a specific task (Berlo et al., 2015).

Level of Detail is a measure of the amount of information provided (quantity). Level of Development cannot exist without Level of Detail. In reality the Level of Detail might be the highest at the beginning of the project while the Level of Development is the lowest. This is in the stage where the design is being sold to the client and the stake-holders. In documentation phase one usually wants to keep Level of Detail low while Level of Development is high (McPhee, 2013).

Level of Information: UK standard PAS 1192-2 (BSI, 2013) “Specification for information management for the capital/delivery phase of construction projects using building information modelling” (BSI, 2013) specifies the requirements for achieving building information modelling (BIM) Level 2, according to UK BIM implementation. PAS 1192-2 defines two components to the level of definition:

- Levels of model detail (LOD), which relates to the graphical content of models.
- Levels of model information (LOI), which relates to the non-graphical content of models.

In this definition the LOI (information) is developed in parallel with the LOD (detail).

6. Life-cycle model

From a life-cycle perspective it is important to have an unbroken information flow. The different phases of the life-cycle for a construction project and the construction itself need to be represented by several unique objects over time. The designed physical element, fulfilling requirements through its function, the product realising the technical solution and finally the product as realized with its serial number (not for all products). This is studied and realized in the BIM Collaboration Hub at KTH (Tarandi, 2011). This requires interoperability through open standards and effective product data management. The presented Plans of Work in Figure 3 are only to be seen as examples of the life cycle stages. Many development projects are ongoing in UK now, and several examples are taken from these like the “resolving of objects at different levels” by Gelder (2012). The following references have been used for the diagram in Figure 3: RIBA Plan of Work 2007 (RIBA, 2008), RIBA Plan of Work 2013 (RIBA, 2013), A report for the Government Construction Client Group (BIM Industry Working Group, 2011) for the Data

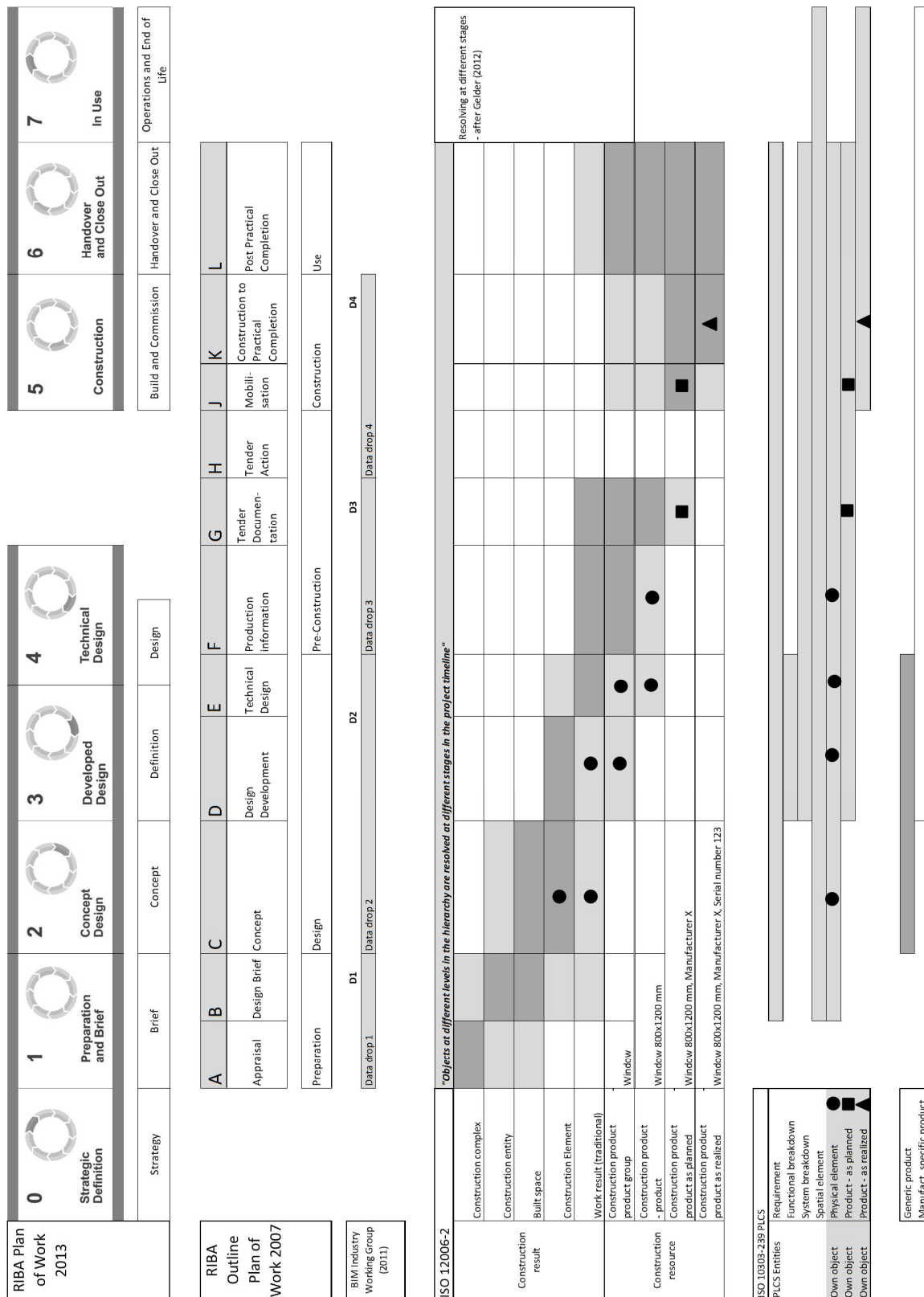


Figure 3: Life cycle framework based on through life support for BIM objects over all the project phases

drops, ISO12006-2 (ISO, 2014), and PLCS ISO 10303-239 (ISO, 2012) for the physical elements, products – as planned and products as realized.

The shaded fields are illustrating the plausible process phases where the different elements in the construction complex from the building (Construction entity) down to the Construction product – as realised - fit. Gelder (2012) explains it as “Objects at different levels in the hierarchy are resolved at different stages in the project timeline”. Darker grey means more plausible than the lighter grey. At the bottom the PLCS entities, based on the studies of implementing them in the BIM Collaboration Hub (Tarandi, 2015), are outlined over time to present where BIM objects for different life cycle phases can be managed. The point in time when they – physical element, product and product as realized – are created and used vary depending on contract and project type.

7. Discussion

In the study, the state of and requirements on BIM product libraries for the construction industry gave the answer, there are many alternative developments without open formats being implemented in a consequent way. The granularity standard is fundamental for linking BIM objects from Product libraries to a life cycle supporting BIM model. Many different library types without common metrics for classification of products and properties. Most of the barriers presented by Amor et al. (2004) are still there. Some of them like *Life-cycle support*, *Mapping between representations*, and *Products’ data representation* can be managed with the life-cycle framework presented in paragraph 6.

Level of Development – geometric and non-geometric information are equally important (Berlo & Bomhof, 2014), but no agreements have been made on international level on how to combine Level of Development and Level of Detail. The information content of the BIM objects which should capture information for different life-cycle phases matching Level of Development both with regards to geometry and properties supporting analysis, simulation and visualisation is not there. The following questions are still open:

- How is transition between different levels of development for BIM object realised?
- What information exists in current libraries?
- How is information delivered to the libraries?

Also these barriers can be eliminated by the life-cycle framework as all these states and definitions can find a place based on granularity, context and life-cycle phase in the framework. The physical element in the design, the product as planned and finally the product as realized on site.

8. Conclusions

The industry should have a clear understanding of what the model should be used for, what data in the model is definite and what confidence level it has in order to have more efficient collaboration between the industry actors. The Level of Development can be seen as the degree to which project team members may rely on the information when using the model. In Level of Development the geometry and non-geometric information are equally important. To make this operative in industry there is, still is, a need for continuing the work on coming to international

agreements on how to structure these concepts and also very important – to link it to the life-cycle of the projects. The proposed framework with through life support based on existing open international standards, life cycle phases and the high level building classification framework standard ISO 12006-2 can be one way of managing the BIM objects over the projects, even before the issue of Levels of D has been resolved. The life cycle platform presented is capable to support the unbroken information flow over all the life-cycle phases!

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Promoting Design of Buildings with Low Carbon Footprint Using Environmental Product Declarations

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Abstract

Nowadays, there is an increasing demand for sustainability in construction industry. As significant efforts have been made on reducing operating energy, the share of embodied energy is increasing from the lifecycle perspective. In order to reduce carbon footprint caused by embodied energy, stakeholders should make more optimized material purchase schemes in the design stage. An environmental product declaration (EPD) provides environmental data of a particular product, thus it can serve as an effective tool to assist decision-makers in selecting environmentally friendly products. The aim of this paper is illustrating how EPDs can be used to assist stakeholders in designing buildings with low-carbon footprint. In addition, the concept of carbon footprint index (CFI) is introduced in this paper. CFI can be used as a threshold in a green building rating system for evaluating the cradle to gate embodied energy of a building. A two-story office building with concrete frame structure is used to illustrate the application of EPD in selection of concrete products. The results show that selection of concrete with low carbon footprint can reduce the CFI by 68%.

Keywords: carbon footprint, environmental product declaration, concrete, cradle to gate

1. Introduction

Construction industry is one of the largest consumers of natural materials. According to the Worldwatch Institute, buildings consume three billion tons of raw materials annually, accounting for 40% of the global consumption (Roodman and Lenssen, 1995). In the United States, the situation is even more severe, the Environmental Protection Agency (EPA) reported that the raw material consumption from construction activities contributes to 60% of the national demand (EPA, 2012). Meanwhile, the proportion of energy use in construction industry is higher than other sectors. According to the National Trust for Historic Preservation (NTHP), the energy used in buildings is about 41% of U.S. primary energy consumption, while the industrial and transportation sectors represent 30% and 29%, respectively (NTHP, 2012).

Echoed with the large resources and energy consumption, construction industry imposes serious impacts to the environment due to unwanted discharging, such as waste, greenhouse gas, etc. In the United States, it is estimated that the amount of waste generated from construction related activities reached 170 million metric tons in 2003, which is equal to 1.45 kilogram per capita per day (EPA, 2009). The large amount of construction waste may cause pollution to air, water, soil, and thus further affect human health (Wu et al., 2013). Greenhouse gas (GHG), which is also a main emission of building operations, is regarded as a significant cause of global warming (Buchanan and Honey, 1994). In 2002, the GHG emission from construction industry in the United States is estimated as 131 million tons CO₂ equivalents. Fuel consumption of on- and off-road construction equipment and electricity used for providing power are regarded as the two main emitters (EPA, 2008). From the above presented figures, it can be seen that construction industry is a significant consumer of resources and energy, and produces a substantial amount of wastes and carbon emissions. Thus, there is an urgent necessity to develop strategies to promote sustainability in construction industry by using less natural resources and energy while producing less waste and carbon footprint (Zhang et al., 2014).

In the lifecycle of a building, the consumed energy can be divided into three main categories according to its usage, namely embodied energy, operating energy, and building transportation energy (NTHP, 2012). Building transportation energy refers to the energy used to transport individuals or materials to and from a building, while operating energy is utilized to make building related facilities work. It has been investigated that operating energy is the most significant component among the three categories, accounting for 80-90% of the lifecycle consumption (Liu et al., 2012). So far, building designers have been focusing on the reduction of operating energy in the design stage. However, as technologies have improved energy efficiency of buildings, the proportion of operating energy is decreasing (Islam et al., 2014). As a result, the share of embodied energy is increasing and its reduction is gradually becoming an important aspect in decreasing building energy consumption. Embodied energy is defined as the energy that consumed to construct a building, involving the processes of extraction, processing, manufacture and delivery (Venkatarama Reddy and Jagadish, 2003). A stage that significantly affects the embodied energy of a building is design stage (Shrivastava and Chini, 2012). Therefore, in order to reduce greenhouse gas emissions caused by embodied energy, stakeholders should focus mainly on material selection in the design stage.

Environmental product declaration (EPD) can serve as a useful tool to assist the decision-makers in selecting environmentally friendly materials in the design stage. An EPD is a standardized, third-party verified document that communicates a product's environmental data, which obtained from lifecycle assessment, in accordance with the international standard ISO 14025 (Type III Environmental Declarations) (NRMCA, 2014b). By providing detailed information about the environmental impacts of a product, EPDs can give designers the information they need to minimize embodied carbon footprint of a building. EPD has been implied in other fields for reducing environmental impacts. For instance, Fet et al. (2009) has utilized EPD to provide stakeholders the environmental performance of furniture. However, the application of EPD for selecting environmentally friendly and economically efficient construction materials is not widespread.

The aim of this paper is to illustrate the application of EPD in reducing buildings' embodied carbon footprint at the design stage. A carbon footprint index (CFI) is introduced to facilitate the design determination. The focus in this study is concrete product selection because it is a main material in construction industry and its production process involves an intensive energy demand and CO₂ emission. The rest of this paper is organized as follows. Section two gives a general literature review of current studies on carbon footprint reduction in construction and concrete. This is followed by introducing the research method used in this study. Results and discussions are subsequently presented, and conclusions are given at the end of the paper.

2. Literature Review

2.1 Carbon footprint reduction in construction industry

Construction industry contributes significantly to carbon footprint due to the large demand of natural resources and energy. Metz et al. (2007) claimed that the CO₂ generated from construction industry increased at an average rate of 2.7% from 1999 to 2004. To have an insightful understanding of greenhouse gas (GHG) contribution of construction industry, many studies have been conducted to quantify the emissions at both industrial and project levels. At the industrial level, an input-output life cycle assessment, which is based on the whole industrial chain, has been widely implemented (Acquaye and Duffy, 2010). At the project level, a process-based life cycle assessment method is very popular (Wu et al., 2012). In addition to the quantity, the sources of GHG emissions were also investigated. It is found that manufacture and transportation of construction materials, on-site electricity use, and disposal of waste are the main activities that produce GHG emissions during construction process (Hong et al., 2014). Moreover, a number of methodological tools have been developed for investigating carbon emissions in construction projects, such as carbon footprint estimation tool (Melanta et al., 2012), management information system (Barandica et al., 2013), and virtual prototyping technology (Wong et al., 2013).

In addition to the quantification methodologies, a series of technologies have been introduced to reduce carbon footprint in construction industry. For example, Hidalgo et al. (2008) compared a solar absorption system with a conventional vapor-compression machine from the aspects of system performance, economic feasibility, energy saving and environmental impact reduction. The outcome of their comparison supported the utilization of the solar absorption system. In the aspect of heating and

cooling, Hacker et al. (2008) conducted a case study and found that the inclusion of thermal mass can reduce building's lifecycle carbon emission by decreasing operational heating and cooling energy. Recently, Zhang et al. (2014) introduced a PV-LED lighting system which produces solar photovoltaic energy in the underground garage to substitute the traditional system. The results proved that the new system can bring benefits in economic effectiveness and CO₂ reduction. A number of green technologies have been introduced to mitigate environmental impact. Johnston et al. (2005) claimed that current available technologies can reduce CO₂ to a large extent by strategic shifts in both energy supply and demand sides. However, most of these technologies focus on reduction of carbon footprint due to operation of the facilities. Researchers from both academia and practice appealed that particular focus should be given to the design stage of facilities (Kim et al., 2013; Zhu et al., 2013).

2.2 Carbon footprint reduction for concrete

Concrete is one of the main materials with high environmental impact in construction industry. It has been widely used in the process of making foundations, structures, infrastructures (e.g., roads, bridges, and dams), etc. (NRMCA, 2008). The consumption of concrete is huge in many countries. For instance, there are approximately 5,500 ready mixed concrete plants in the US, and the value of ready mixed concrete trades is around \$30 billion (NRMCA, 2013). Based on the Portland cement sales, it is estimated that the production of ready-mixed concrete in the US is about one billion metric tons per year (EPA, 2013). In China, the concrete consumption is tremendous as well. It is reported that the amount of concrete production in 2007 was two billion cubic meters with an average annual growth rate of larger than 10% (Li et al., 2007).

Concrete is composed mainly of water, aggregate, admixtures, and Portland cement. The proportion of Portland cement in concrete is about 7% to 15% depending on the performance requirements of concrete (NRMCA, 2008). Although concrete has a lower total energy intensity than other generally used construction materials, cement production is a highly energy-intensive process and entails potentially significant air and water pollution (Chini, 2009). In addition, the natural aggregates have finite resources and concern over environmental issues oppose the production of sand and gravel by dredging huge cavities in traditional landscape. Furthermore, the demolition of old concrete pavement and structures produce large quantities of waste that in most cases are landfilled. It has been reported that concrete waste occupied one third of the total wasted materials in the landfills of the US (Zhang, 2012).

Currently, as the concept of sustainable construction has motivated innovative companies, researchers, and industrial coalitions to be more environmentally responsible, potential solutions have been suggested to reduce the carbon footprint produced by concrete. Some highlights of the prevailing technologies and approaches are listed as follows.

- Use of supplementary cementitious materials. The traditional technologies for manufacturing concrete have required unnecessary quantities of cement, thus consuming less cement in production of concrete is the first step for reducing energy consumption and GHG emissions. One solution to achieve this goal is using supplementary cementitious materials (SCMs). SCMs are industrial byproducts which are usually end up in landfills, however, they can be used to substitute a portion of cement in concrete production, such as fly ash, blast furnace

slag and silica fume (NRMCA, 2008). The appropriate use of SCMs in concrete production can consume less energy and emit less GHG. In addition, a blend of 50% or more granulated blast furnace slag or fly ash can increase the durability of concrete products compared with using pure Portland cement (Mehta, 2001).

- Use of recycled concrete aggregates. So far, the natural resources of the earth have been exploited to a point where the availability of gravel is scarce in some places. Furthermore, disposal problems have risen because of excessive volume of construction and demolition waste generation (Wu et al., 2014). As a result, there is a need to curtail the production of concrete waste. A possible solution is recycling wasted concrete by crushing it into acceptable sizes and removing impurities such as rebar, PVC pipes, etc. Numerous studies have been conducted utilizing recycled concrete waste to substitute natural raw materials (Chini et al., 2001).
- Design innovation of concrete products. The design of concrete products has been improved continuously, such as design of flat slabs and voided slabs. The recent flat slabs were designed without drops and column capitals, which can withstand greater slab loadings and allow thinner slabs in the design (BCA, 2012). In addition, the deletion of beams allows lower floor-to-floor heights, which contributes significantly in concrete reduction. Especially in cases where there is no requirement for a deep suspended ceiling, flat slab construction can minimize floor-to-floor heights (BCA, 2012). Voided slabs are a form of structural slab system in which voids are introduced to reduce concrete usage, and in turn reduce the dead load of the structural slab (BCA, 2012). This design contributes not only to concrete reduction because of the voids, but also to the reduction in size of the supporting columns and foundation.
- Reuse and deconstruction. The best way to preserve the embodied energy of a concrete structure is adaptive reuse. Adaptive reuse is defined as “to leave the basic structure and fabric of the building intact, and change its use” (Langston et al., 2008). Buildings that employ concrete frame structural systems are well suited for adaptive reuse. Deconstruction or disassembly of the structure can be utilized to divert the maximum amount of the structural components from the waste stream (Chini, 2005). It is regarded that the top priority is placed on the direct reuse of the component in new structures (Chini and Bruening, 2003). This approach has been successfully applied in several countries (CCANZ, 2007).

Through the literature review, it can be found that the concrete industry has been dedicated to reducing the carbon footprint of concrete products. However, the current practice is mainly focusing on the manufacture and recycling of concrete, no attempt has been conducted on reducing carbon footprint in the concrete product selection process. Therefore, this paper is attempting to introduce a tool for reducing carbon footprint by optimized concrete product selection.

2.3 Environmental product declaration for concrete products

To facilitate concrete product selection, EPD is utilized in this study. As introduced in the introduction section, an EPD can provide quantifiable data about the potential environmental impacts of a particular

product. The typical procedure for creating an EPD is as follows. Firstly, identify product category rules for describing how to implement life cycle assessment on a particular product. Then, perform the life cycle assessment according to the outlined rules. Finally, input the derived life cycle assessment data into an EPD format and create an EPD for the particular product. Usually, an EPD includes the information about manufacturer, use of the product, and environmental data. Before its publication, a verification must be derived from a third party.

The implementation of EPD has been encouraged in green building rating systems. For example, in the most updated version of Leadership in Energy & Environmental Design (i.e., LEED v4), points can be awarded if a project uses more than 20 products having their EPDs (NRMCA, 2015). As concrete has a wide application in manufacturing construction products (e.g., columns, beams, walls), it is regarded that concrete products with corresponding EPDs can contribute significantly to satisfying this requirement.

In order to help concrete manufacturers meet the new requirements, the National Ready Mixed Concrete Association (NRMCA) of the United States has operated an EPD program for guiding them to develop draft EPDs and conducting corresponding verification. The concrete EPDs verified under this program are all listed on the official website and free for download. An industrial wide EPD which indicates the average environmental characteristics of 48 ready mixed concrete products is provided as well.

3. Methodology

To illustrate the application of EPD in building construction, two scenarios are proposed in this study. The first scenario is designed to explain how to use EPD to make material selection from the environmental perspective. In this scenario, an office building with concrete frame structure is used as an example. This is a two-story building with twenty square reinforced concrete columns (300 mm × 300 mm) located in the grids (4.3 m × 6.1 m). Three concrete slabs which are 100 mm thick are used as floors. The sectional and plan views of this building are presented in Figures 1 and 2.

The second scenario is proposed to introduce the concept of carbon footprint index (CFI) which can be used as an indicator for facilitating carbon footprint reduction at design stage. In this paper, the CFI is defined as the amount of carbon emissions due to the use of concrete to cast a square meter of construction floor area. The calculation scope involves structural and non-structural concrete elements in superstructure, regardless of concrete used in external works and sub-structural works such as basements and foundations. The formula for calculating CFI is shown in Eq. 1.

$$CFI = CV \times CFE / TA \quad \text{Eq. 1}$$

where CFI (kgCO₂e/m²) is the carbon footprint index, CV is the concrete volume (m³) that used in building the superstructure, CFE refers to the carbon footprint emission (kgCO₂e) in one cubic meter of selected concrete material, TA represents the total floor area (m²) of the superstructure.

The different values of CFI indicates various levels of carbon footprint. More specifically, the material with a higher CFI produces more carbon footprint than the material with a lower CFI. In the

determination process of material selection, the material with the lower CFI is preferred from the perspective of environmental protection. This concept can be introduced into green building rating system (e.g., LEED) to provide thresholds for different categories of buildings.

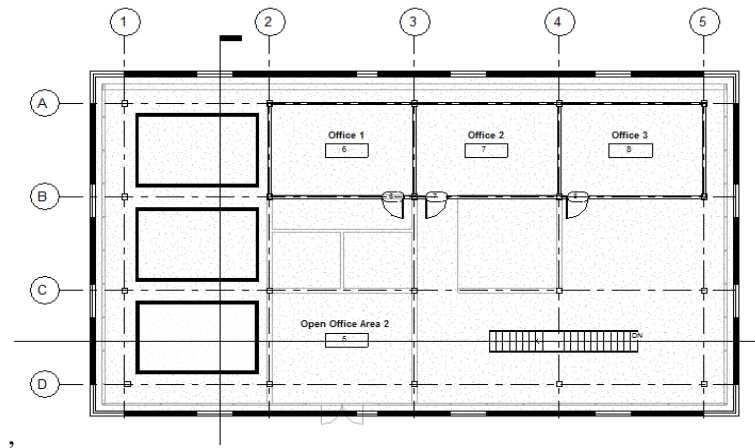


Figure 1 Plan view of the office building

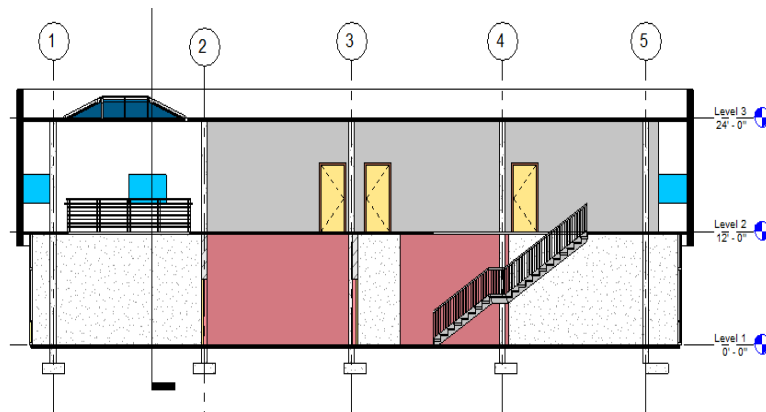


Figure 2: Sectional view of the office building

4. Results and discussions

4.1 EPD application for selecting environmental materials

In terms of the first scenario, the basic information of the office building is shown in Table 1. From Table 1, it can be seen that the concrete strength is various in different floors. Based on the NRMCA member industry-wide EPD for ready mixed concrete (NRMCA, 2014a), the potential concrete products for satisfying different strength requirements and their carbon footprint are abstracted and presented in Table 2.

Table 1 Basic information of the office building

Item	Floor area (m ²)	Concrete volume (m ³)	Required concrete strength (MPa)
Floor 1	391.9	39.19	21
Floor 2	409.3	40.93	34.5
Floor 3	385.4	38.54	34.5
Columns		14.81	28
Total	1186.6	133.47	

Table 2 Carbon footprint of potential concrete products

Strength (MPa)	Range (psi)	Potential products	Carbon footprint (kgCO ₂ e/m ³)
21	3001-4000	4000-00-FA/SL	416.1
		4000-20-FA	357.1
		4000-40-FA	291.6
		4000-30-SL	316.6
		4000-50-SL	250.4
28	4001-5000	5000-00-FA/SL	509.1
		5000-20-FA	435.6
		5000-40-FA	353.9
		5000-30-SL	385.1
		5000-50-SL	302.4
34.5	5001-6000	6000-00-FA/SL	536.1
		6000-20-FA	458.5
		6000-40-FA	372.1
		6000-30-SL	405.1
		6000-50-SL	317.8

Note: the name of concrete product is given according to the following rules: the first section of the product name indicates the range of compressive strength in psi, the second section declares the percentage range of supplementary cementitious materials (SCM) used to manufacture the concrete products, and the third section stands for the components of the SCM (FA is short for fly ash, while SL represents slag).

From Table 2, it can be seen that the most environmental-friendly concrete products for different strength levels are 4000-50-SL, 5000-50-SL, and 6000-50-SL. On the contrary, using 4000-00-FA/SL, 5000-00-FA/SL, and 6000-00-FA/SL produces the most carbon footprint.

Tables 3 and 4 show the total carbon dioxide produced using the mix designs without cementitious materials (66,451 kgCO₂e) and mixes with 50% slag (39,547 kgCO₂e), respectively. Based on the results, it can be found that various schemes of concrete product selection can make a significant difference on carbon emission. While the selected case is just a regular office building with only three floors, the difference can be more significant if it is a high-rise building.

Table 3 Total global warming potential using mix designs without cementitious materials

Member	Floor Area	Material Volume	Mix Design	Concrete Strength	GWP	Total GWP
	m ²	m ³		MPa	Kg Co ₂ e per m ³	Co ₂ Eq. Kg
Floor 1	391.9	39.19	4000-00-FA/SL	21	416.1	16,307
Floor 2	409.3	40.93	6000-00-FA/SL	34.5	536.1	21,943
Floor 3	385.4	38.54	6000-00-FA/SL	34.5	536.1	20,661
Columns		14.81	5000-00-FA/SL	28	509.1	7,540
Total	801.2					66,451
Carbon Footprint Index Kg Co ₂ e/m ²						82.9

Table 4 Total global warming potential using mix designs with 50% slag

Member	Floor Area	Material Volume	Mix Design	Concrete Strength	GWP	Total GWP
	m ²	m ³		MPa	Kg Co ₂ e per m ³	Co ₂ Eq. Ton
Floor 1	391.9	39.19	4000-50-SL	21	250.4	9,813
Floor 2	409.3	40.93	6000-50-SL	34.5	317.8	13,008
Floor 3	385.4	38.54	6000-50-SL	34.5	317.8	12,248
Columns		14.81	5000-50-SL	28	302.4	4,479
Total	801.2					39,547
Carbon Footprint Index Kg Co ₂ e/m ²						49.4

GWP = Global Warming Potential

4.2 EPD application as an indicator for carbon footprint

Equation 1 was used to calculate the carbon footprint index of the building for each case. Tables 3 and 4 show that the carbon footprint index decreased from 82.9 to 49.4 Kg Co₂e/m² when the mix designs without any cementitious materials were replaced by those with 50% slag. Ground granulated blast-furnace slag is a byproduct of steel production and much cheaper than Portland cement. It is highly cementitious in nature, ground to cement fineness, and hydrates like Portland cement. Substitution of ground granulated blast furnace slag for up to 70 percent of the Portland cement in a mix has been used. In addition, Portland cement blends containing 50% or more granulated blast furnace slag can yield much more durable concrete products than the pure Portland cement.

The introduction of CFI can assist designers to measure and benchmark the carbon footprint of building during the design stage to arrive at an optimal design early in the design and construction process. The CFI can also be used as a measure of environmental impact of buildings in building rating systems.

The carbon footprint analysis in an EPD can facilitate manufacturers to understand more about the

effects of their products to the environment, while the CFI can assist construction stakeholders in improving the carbon footprint reduction.

5. Conclusion

The construction industry produces a significant amount of carbon footprint. As energy efficiency of buildings has improved, the proportion of embodied carbon footprint with respect to operational energy is increasing. An EPD of a concrete product can tell the customers how much carbon footprint can be generated from the manufacture of this product, thus provide convenient and useful information on materials selection with the aim of reducing embodied carbon footprint. The research findings in this paper reveal that different schemes of materials selection can make significant difference in carbon footprint reduction. Furthermore, the concept of CFI is introduced in this paper, which can be used at the design stage to arrive at an optimal design as well as in a green building rating system for evaluating the carbon footprint reduction performance of a building.

The paper contributes to illustrating the applications of EPD on carbon footprint reduction in construction industry. Further research can be addressed to integrating building information modeling (BIM) with EPD to simulate the effectiveness of different materials selection schemes, establishing CFI thresholds of different materials for green building evaluation.

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Increasing the Market Penetration of Manufactured Green Buildings: A Research Proposal

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Abstract

This conceptual paper provides a desk-top study of secondary sources to outline a robust program of research to increase the market penetration of high quality green buildings produced in advanced manufacturing facilities. The environmental benefits of such buildings are investigated, a theoretical approach to understanding the drivers of best practice is outlined and a field work-method is proposed to understand the dynamic capabilities that support leading manufacturers. An extended sociotechnical systems view of the firm is developed to guide a program of international case studies. This paper makes a theoretical contribution to the understanding of firm performance in an important empirical setting. Future research by the author will involve execution of the described research program. A limitation of the paper is that the effectiveness of the proposed theory and methods is yet to be tested empirically.

Keywords: Sustainability, buildings, off-site, socio-technical systems, Australia

1. Introduction

There is an urgent need to improve the environmental sustainability and the whole-of-life cost of buildings by increasing the market penetration of green buildings produced in advanced manufacturing facilities. This requires new management theory to understand the latent variables underpinning successful facilities internationally. The building sector represents an urgent environmental problem because of its poor performance in energy, carbon, materials, water and waste. It is the single largest contributor to CO₂ emissions among industry sectors (UNEP, 2014) and produces more greenhouse gases than the transport sector (World Business Council for Sustainable Development, 2009). These significant environmental problems can be efficiently and effectively addressed through a shift to advanced manufacture of buildings and their parts, such as modules, bathroom pods and structural insulated panels.

Advanced manufacture results in a higher quality and more sustainable asset compared to buildings constructed on-site through manual processes (Johnsson and Meiling, 2009, Poon et al., 2003, Monahan and Powell, 2011). However, Australian efforts to develop such an industry, although promising, are hampered by a number of obstacles. These include social stigma, sector resistance to radical innovation and lack of design flexibility (Steinhardt et al., 2014). In Australia, it is estimated that less than 5% of new buildings are produced using advanced manufacturing, while in leading countries, such as Japan, the comparable rate is 15% (Steinhardt et al., 2013a). Although these figures indicate that market penetration is currently low, there is overwhelming evidence that such approaches are the direction of the future (CEDA, 2014). This is because of the strong business drivers for green buildings (WGBC, 2013) and the potential for advanced manufacturing to deliver sustainability benefits (Kibert, 2012).

The Australian manufactured building industry has some competitive advantages, but is relatively undeveloped in a global sense (Steinhardt et al., 2013b). The current paper provides a desk-top study of secondary sources to outline a robust program of research to increase the market penetration of such buildings in Australia. The proposed study aims to benchmark current best practice globally, framed by an integrated conceptual framework. This framework is essential to uncovering the latent drivers of excellence in this field. The proposed study addresses the research question ‘How can factory production of buildings be optimised?’

2. Literature Review

The study will address the: conceptual problem of modernizing the STS view of the firm; the empirical problem of reducing the impact of building engineering and operation on climate change; the management problem of the best way to improve building quality; and the policy problem of encouraging efficient building production and expanding export markets.

The focus of this study is residential buildings, like houses and apartments. The vast majority of such buildings in Australia and elsewhere are constructed manually on-site. A small percentage are produced in a factory and transported to site. The factories might produce whole buildings or their parts. Most of these factories are not employing advanced manufacturing techniques;

however this is the approach that leads to the most significant environmental benefits (Noguchi, 2011). The definition of advanced manufacture adopted here follows that of the Committee for Economic Development of Australia (CEDA). CEDA recently produced an Industry Plan that distinguishes between traditional assembly-line manufacturing based on low-cost, high-volume production and advanced manufacturing which is ‘about variability, complexity and extensive customisation with high value-add’ (CEDA, 2014). Advanced manufacturing directly addresses many of the obstacles to increased market penetration of green buildings by providing (1) flexible and sophisticated designs; and (2) detailed monitoring of whole-of-life outcomes (Noguchi, 2011).

Advanced manufacture of buildings also offers significant efficiency improvements to substantially lift the productivity of construction processes (Kibert, 2012, Manley, 2008), potentially doubling efficiency compared to on-site production (Eastman and Sacks, 2008). The technologies supporting these gains include advanced numerical controlled machinery, robotic assembly, building information models and enterprise resource planning systems. Improved productivity is urgently needed, given that previous attempts to improve the performance of the construction industry have had very limited success (Productivity Commission, 2014). Efficiency improvements are in part reaped through a higher quality product that eliminates re-work (Manley and Miller, 2014, Blismas and Wakefield, 2009). Yet the adoption of advanced manufacture in the building sector has been slower than expected (Middleton, 2014). Recent research suggests that this may be due to inappropriate firm-level management strategies (Brege et al., 2014). The current study builds on those findings by developing a systems approach and employing international comparisons that enable the identification of best practice.

UNEP (2014;16) reports that the building sector is an urgent environmental problem: (1) 30% of energy end-use world-wide takes place within buildings; (2) 10% of the global energy supply is consumed during the manufacture of building materials; (3) 30-40% of CO₂ emissions are generated during the use phase of buildings; (4) 40-50% of the total flow of raw materials globally is used in the manufacture of building products and components; (5) 12% of global water use takes place in buildings; and (6) 40% of solid waste streams in developed countries comes from building engineering and demolition. These issues must be addressed immediately if the ravages of climate change are to be minimised.

Leading international studies show that the average cost premium for a zero-carbon building is 12.5% (WGBC, 2013), yet neither the World Green Building Council, nor the United Nations Environment Program assess how this cost premium might be reduced by extending the use of advanced manufacturing technologies in a factory setting to produce buildings and their parts. For the first time, the current study will compare the cost profiles and environmental outcomes of leading green building manufacturers internationally. By doing so, it will improve the performance of Australian building manufacturers, thus reducing the environmental problems outlined above.

There are persuasive statistics demonstrating the gains to be made if more buildings were produced through advanced manufacture. For example, a recent UK study compared the

performance of manufactured homes with those that were constructed on-site. The figures demonstrated a 34% reduction in embodied carbon (Monahan and Powell, 2011). The proposed study will improve (1) the success of climate change mitigation strategies; (2) Australia's standing in the international community; and (3) the international competitiveness of Australia's manufacturers of buildings and their parts.

As a traditional industry, lacking the glamour of research-intensive industries, the building and construction industry has received limited attention from innovation analysts (Gann, 2000, Kibert, 2012). The study addresses this urgent empirical gap by focussing on a significant innovation (advanced manufacturing) that can reduce the environmental impact of buildings and improve efficiency. This empirical gap has occurred because of an acute shortage of rigorous research in this area. Climate change responses are currently focused on high profile polluters such as the coal or transport sectors, yet the building sector is the biggest polluter amongst all industry sectors (UNEP, 2014). The proposed study directly addresses this important issue.

The proposed study addresses the efficiency and effectiveness of the built environment, where the human population lives and where 95% are employed (Newton et al., 2009). This is achieved by encouraging a shift in market preferences away from 'stick-built' buildings constructed on-site, towards the advanced manufacture of buildings and their parts. Advanced manufacture has the twin benefits of improved environmental and productivity outcomes. Although the focus of this study is on environmental outcomes, productivity is also improved through the ability to (1) utilise advanced manufacturing technologies, (2) work through rain, storms and heatwaves, and (3) recycle waste materials more efficiently. Historical data comparing buildings produced on-site, with buildings produced in advanced manufacturing factories, shows higher labour productivity and faster growth in the factory sector. For example, data on curtain wall production in the U.S. between 1992 and 2002 showed a 32% growth in labour productivity in the factory sector, while the comparable figure for on-site production was 8% (Eastman and Sacks, 2008). Data from another study shows that producing a bathroom pod in an advanced manufacturing facility takes one tenth the time of traditional on-site bathroom construction (Singerman, 2013).

The proposed study is likely to reduce the financial burden placed on owners and taxpayers arising from paying too much for buildings. Cost savings will have significant ramifications for Australian society as a whole given that the building and construction industry contributes 8% of GDP and is the 3rd largest industry division across 19 ANSZIC divisions (ABS, 2014). The industry produces the built environment and thus has a significant impact on living standards, the production of other goods and services, and trade. Yet, it is known as a 'serial productivity under-performer' (PWC, 2013). The scale and ubiquity of the industry means that productivity improvements will have much larger multiplier effects compared to nearly all other Australian industries.

3. Conceptual Framework: Validation of Techniques

Conceptually, the problem at the centre of this study can be framed as inadequate diffusion of a radical innovation (advanced building manufacture) given its potential benefits compared to

established methods. CI Manley is a global expert in innovation systems and has an intimate knowledge of the evolution of systems approaches to the study of innovation (Manley, 2002, Rose and Manley, 2014). Leading approaches include technological regimes (Nelson and Winter, 1977), technological systems (Carlsson and Stankiewicz, 1991), systems of innovation (Edquist, 1997) and STS (Trist and Bamforth, 1951, Cooper and Foster, 1971). The STS view is selected for development here as it is the most promising for addressing the urgent environmental problems at hand. This is because the STS view explicitly combines the linear end-points of ‘technological fix’ on one hand, and ‘behavioural change’ on the other, in framing approaches to sustainability transition problems (Geels, 2012). A STS is a multi-level concept that describes a work system that is typically described as having four components that need to be balanced to maximise performance: (1) goals, (2) actors, (3) technology and (4) structure (Leavitt, 1964). At firm-level, an STS is described here as follows:

- 1) Goals: work is assigned to actors to achieve the goals of the firm
- 2) Actors: employees with different beliefs undertake tasks to achieve goals
- 3) Technology: physical tools are employed by the firm to help actors achieve goals
- 4) Structure: work is designed to help the actors and technology achieve goals

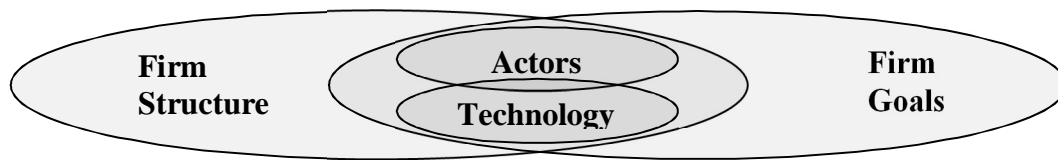


Figure 1: Integrated STS concepts

Figure 1 shows the interconnectedness of STS components. STS theory is more than 60 years old and has been used ubiquitously over the years, yet it is increasingly criticised for being outdated (Eason, 2008), and too focused on information systems (Davis et al., 2014). Key authors are calling for renewal to extend the conceptual basis of the theory and to apply it to new fields (Eason, 2008, Davis et al., 2014). The current study addresses these gaps, building on the integrated concepts encapsulated in Figure 1 by providing theoretical depth and currency for each of them. It challenges the currently limited approaches to understanding STS by developing a highly structured and detailed theory suitable for application to the built environment, based on related management theory, which itself borrows from social psychology theory. The new theory will aid in the understanding of the dynamic capabilities that underpin firm performance (Zollo and Winter, 2002). The application of renewed STS theory to the built environment responds to calls from academics in that field for theoretical approaches that combine technological and social dimensions of change (Schweber and Harty, 2010). The outcome is valid and reliable advice for firms to help them extend market share, based on detailed prescriptions driven by strengthened and streamlined theory.

A taxonomy of dynamic capabilities will be provided by combining the STS literature (Trist and Bamforth, 1951, Cooper and Foster, 1971) with more nuanced management theory, such as planned behaviour (Ajzen et al., 2011), organisational ambidexterity (Patel et al., 2013) and user-

producer interaction (Lundvall and Vinding, 2004). While the STS view provides a very useful organising principle for understanding dynamic capabilities and firm performance, its integration with more nuanced approaches, focused on each of the four individual system components, will provide the depth required to direct real-world change. In this way, the learning routines that underpin dynamic capabilities can be better understood and the operational relevance of the STS view will be vastly improved. The new theory developed by this study makes a significant contribution to the emergent field of sustainability transitions that has developed over the past 10-15 years. A recent summary of this field emphasises the critical need for more comparative studies, as will be undertaken here (Markard et al., 2012).

4. Approach and Methodology

The epistemological approach adopted is ‘realism’ giving rise to modified objectivist findings, through case studies (Healy and Perry, 2000). A deductive approach is proposed, driven by research questions within a rigorous qualitative framework. Based on existing conceptual approaches, an integrated theory is developed to guide the case studies. The proposed study is forecast to take 3 years to complete, as detailed below.

4.1 Stage 1: Theoretical Development: 3 months

Objective: Modernize and improve the operational relevance of the STS view by developing measurable items drawn from related theory for each of the four components.

Method: Development will be based on the procedure pioneered by CI Manley in earlier research funded by the Australian Research Council (LP110200110) (Chen and Manley, 2014). A robust and structured literature search will be undertaken, using directed content analysis (Krippendorff, 2004). CI Manley has extensive experience with this method, leading to many significant journal publications. She will supervise the process of sourcing, classifying and interrogating potentially useful theories, with an RA doing the routine sourcing and classification work, and a Post-doc examining the potential to add value to the predictive power of the initial model. The management literature on topics relevant to the four system components will be reviewed, focussing on highly-cited contributions in leading journals. A two-stage process will be employed, commencing with *general* management literature to establish broad principles and concluding with *engineering* management literature to provide relevant contextualisation. The integrity of the final integrated result will be supported by feedback from a panel of international experts on management theory and firm capabilities sourced from CI Manley’s extensive networks.

Contribution: An integrated theory of STS that better facilitates empirical work in the current context.

4.2 Stage 2: Case Study Logistics: 3 months

Objective: To identify and secure interviewee firms and managers for the 15 cases; and establish the flight, accommodation and interview schedules in each of the five countries sampled.

Method: Three leading firms in each of five countries will be studied, including Australia, resulting in 15 cases. The data obtained will cover the four components of the new STS theory. This data will describe the drivers of firm performance. CI Manley's experience suggests that three firms are sufficient to get a good sample of best practice in each country. Each firm will be a leading advanced manufacturer of green buildings, selected on the basis of advice from our foreign collaborators regarding the firms with the largest market share. The foreign countries themselves were selected because they are considered to be progressive in this area, based on earlier pilot research by CI Manley in late 2014 (Steinhardt et al., 2013b). Using contacts established by CI Manley during that study, the schedules will be developed using phone and email communications. This work will be driven by CI Manley, overseen by the Post-doc and actioned by the RA. CI Manley will secure participation; the Post-doc will establish schedules and the RA will make bookings.

Contribution: A register of 15 leading firms globally in the advanced manufacture of buildings.

4.3 Stage 3: Case Study Performance: 12 months

Objective: To efficiently and effectively conduct the case studies to help grow the Australian green building industry.

Method: Case studies are recommended for analysis of messy empirical contexts (Eisenhardt and Graebnew, 2007). This means contexts that are (1) significantly multidimensional, giving rise to a large number of variables; (2) marked by interactive relationships with unclear cause and effect; (3) impacted by situational factors in the surrounding environment; and (4) being examined from a systems' perspective. These conditions apply to the current research, justifying the use of case studies.

Two senior managers from each manufacturing firm will be personally interviewed for one hour by two researchers at the same time; CI Manley and the Post-doc. This dual approach allows for cross-referencing of information provided by the two managers and cross referencing of observations across the two researchers. Personal interview enables unobtrusive observation, augmenting word responses, particularly in relation to non-verbal cues from interviewees, technological infrastructure and factory lay-out. Company reports will also be collected and consulted, including performance audits, employee opinion surveys, training materials and operation manuals. Pilot study manufacturers have indicated a willingness to share such material. The RA will be responsible for transcribing the interview recordings and pulling salient material from company reports. Triangulation across two managers, two senior researchers and three data sources assures robust findings. CI Manley's extensive interview experience suggests that one hour is sufficient time to reach data saturation point, after which no new material is likely to emerge. Academic and industry partners in each foreign country have been secured to help with the case studies.

Many of the case study firms have already been identified and secured including Broad Sustainable Building (China), Sekisui House (Japan), Baufriz (Germany) and BoKlok

(Ikea/Skanska in Sweden). The interviews will be semi-structured involving two phases. In the first phase, the interviewee will be given a short questionnaire to complete, taking about 15 minutes, based on the four system components. In the second phase, open-ended questions about each component will be discussed with the interviewee.

Contribution: 15 ‘demonstration’ case studies, each describing success factors in advanced manufacture of green buildings, driven by integrated theory.

4.4 Stage 4: Cross Case Analysis: 3 months

Objective: To understand the role of context in the different countries and to isolate common success factors.

Method: Directed content analysis will again be employed to review the 30 interview transcripts and associated company documents and researcher notes, with the RA organising and reviewing these research materials to maximise their accessibility. The identification of key variables and initial coding categories will be driven by the novel STS theory developed earlier in the study. NVivo, a qualitative data analysis software package, will provide a rigorous system to assist with coding. The coding will focus on identifying themes within the theory components and will be undertaken independently by CI Manley and the Post-doc, then cross-referenced to produce the final result. This triangulation process will support the validity and reliability of findings. Care will be taken to ensure that coding categories are mutually exclusive, limited in number and clearly aligned with theory components.

Contribution: The first evaluation of pathways to environmental excellence in advanced manufacture of green buildings internationally.

4.5 Stage 5: Theory Refinement: 3 months

Objective: To improve the value of the theory developed in Stage 1

Method: The explanatory power of the theory is reviewed by reflecting on its usefulness in the field. Did some items seem irrelevant? Were new items indicated? Through such analysis, contemporary empirical findings can improve the current state of theory. Analysis will again be undertaken independently by CI Manley and the Post-doc, then cross-checked to produce an interim result, which will be further cross-checked with an expert panel to improve validity and reliability. The final model will be particularly relevant to the study of advanced manufacturers, which is a very valuable research output as these manufacturers are currently being targeted by the Australian government for development through an Industry Growth Centre. During this stage, the RA will be working on industry magazine articles.

Contribution: A refined and contextualised management theory dedicated to an industry sector that is of strategic significance to Australia’s future industry growth.

4.6 Stage 6: Knowledge Diffusion Program: 12 months

Objective: To provide advice to industry for improving market penetration of advanced manufactured green buildings and extend the academic knowledge base.

Method: Industry publications will provide research results, together with a set of normative guidelines for firms on how to achieve environmental excellence in their advanced manufacture of buildings. Such guidelines will be validated through feedback from an expert panel of industry practitioners. A Capstone Symposium will also be held for industry stakeholders in the three largest capital cities; Sydney, Melbourne and Brisbane; to share knowledge and map future pathways to greater market penetration. The RA will play a major role in framing industry publications and liaising with industry associations to validate guidelines and ensure appropriate distribution, as well as providing logistical support to the Post-doc, who will organise the Symposia under the direction of CI Manley. This industry phase of the knowledge diffusion program will consume six months. The academic publications will focus on the theoretical and empirical work, and target leading management journals, as well as refereed conferences. The Post-doc will generate the first-drafts of many of these articles. CI Manley will draft some articles herself and provide heavy revision for the others. Initial submission of articles will consume six months. See ‘Communication of Results’.

Contribution: Validated industry guidelines, industry publications, Capstone Symposia, conference papers and journal articles.

5. Conclusions

This conceptual paper was based on a desk-top study of secondary sources to justify and design a proposed program of research. The contributions of the paper comprise (1) an assessment of the environmental benefits of manufactured green buildings, (2) a theoretical approach to understanding the latent drivers of best practice and (3) a field work-method to understand the dynamic capabilities that support leading manufacturers.

The extended sociotechnical systems view of the firm developed here is both useful for the proposed study and has more general applicability as a more nuanced approach to assessing the capability of firms and the strength of their socio-technical systems. The current paper makes a theoretical contribution to the understanding of firm performance in an important empirical setting. Future research by the author will involve execution of the proposed study. A limitation of the paper is that the effectiveness of the proposed theory and methods is yet to be tested empirically.

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Conceptual Framework for CIB W114: Construction Materials Stewardship

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Abstract

Construction Materials Stewardship can be thought of as the range of activities that go into the products and materials used in the infrastructure construction and maintenance process with respect to how they impact society. In particular, Materials Stewardship examines both the material manufacturing process and the raw materials used in addition to the deconstruction or demolition process and the disposal of the waste products. The Construction Materials Stewardship focuses on closing the material loop between the demolition process and the materials manufacturing process or product reuse. By reusing or recycling construction waste products, the quantity of raw materials required for future construction can be reduced in addition to diverting waste away from landfills. The Construction Materials Stewardship mission is interested in (1) drastically reducing the extraction and consumption of new non-renewable construction materials, (2) replacing non-renewable materials with renewable ones whenever possible, (3) achieving equilibrium in the demand and supply of renewable materials, and (4) ultimately restoring the renewable resource base. With this framework in mind, the research is intended to carry out these tasks in ways to maximize positive financial, social and environmental and ecological sustainability effects, impacts and outcomes.

This paper discusses the conceptual framework for the Research Roadmap of The CIB W115 and will address the issues related to construction materials stewardship, their interrelation, and the characteristics of the most relevant systems, processes and technologies.

Keywords: Construction, Materials, Waste, Reuse, Design

1. Introduction

Construction Materials Stewardship can be thought of as the range of activities that go into the products and materials used in the infrastructure construction and maintenance process with respect to how they impact society. In particular, Materials Stewardship examines both the material manufacturing process and the raw materials used in addition to the deconstruction or demolition process and the disposal of the waste products. The Construction Materials Stewardship focuses on closing the material loop between the demolition process and the materials manufacturing process or product reuse. By reusing or recycling construction waste products, the quantity of raw materials required for future construction can be reduced in addition to diverting waste away from landfills.

During the construction process, a significant amount of waste can be generated based on the materials selected due to excess supplies, errors in material selection, or damaged products. Material Stewardship is interested in measures that can be taken to reduce these waste streams and improve the sustainability of the facility based upon product selection. An initial aspect of these studies looks at how existing construction materials can be used more efficiently to reduce waste on the construction site and improve performance. A few examples of this type of improvement can be seen in using techniques such as Lean construction to prefabricate assemblies (Nahmens, 2012) and BIM to evaluate material locations (Wong, 2015). In addition, further research is necessary to look at new technologies that can be applied to material production that would result in improved environmental performance. The design of new products has seen tremendous advancements in technologies that improve the life cycle of the individual materials as well as reduce the pollution emissions of the building. An example of this type of improvement is implementation of nanotechnology in concrete that improves durability and facilitates cleaning of the surfaces (Ortiz et.al, 2009). Additionally, the application of sustainable construction materials in which reused or recycled products are incorporated to create an eco-material with an improved life cycle performance can be significant (Nie and Zuo, 2003). By evaluating the individual construction materials from a sustainable stand point, can result in modifications that can improve the life cycle properties of the materials, increase the useful life of the products, and recognize reductions in waste along with other environmental and economic benefits.

The waste stream generated from the life cycle of infrastructure including building, maintaining, and end of life disposal is often referred to as Construction & Demolition (C&D) waste. Due to the large volume of materials, such as concrete, steel, glass, and masonry, most countries track their recycling rate separately. In the European Union, it is estimated that 850 million tons per year or about 30% of the total waste stream is attributed to C&D waste (Fischer and Werge, 2009). This percentage of the waste stream is consistent with other developed countries in the world as reported in previous W115 publications.

Over time, a building's ownership and/or functionality can transition quite often. If the facility does not have the flexibility to adapt to the new needs, the building may be demolished or left vacant. Either case would not provide the most sustainable use of the facility. By extending the

useful life of the facility by planning for the adaptability of new users and occupiers would provide significant economic and environmental benefits. When a building can be initially designed with adaptability in mind, the space and materials would be considered relative to their life cycle and the flexibility that is needed to maximize the building's lifetime while minimizing disturbance to the integrity of the structure. In addition, by designing for adaptive reuse the building owners can more readily adjust the facility at lower costs to account for new technologies. From an environmental perspective, any design for adaptive reuse will demonstrate significant savings in both demolition material being landfilled in addition to the purchase of new structural materials (Saleh & Chini, 2009). Despite the lack of initial designs for building adaptability, a concentrated effort should be made for adjusting existing buildings that have exceeded their current functionality to be altered to permit reuse. The added effort to convert the facility to an adaptable structure will vary depending on the design; but should be considered as a viable option to demolition or the construction of a new facility.

The Construction Materials Stewardship mission is interested in (1) drastically reducing the extraction and consumption of new non-renewable construction materials, (2) replacing non-renewable materials with renewable ones whenever possible, (3) achieving equilibrium in the demand and supply of renewable materials, and (4) ultimately restoring the renewable resource base. With this framework in mind, the research is intended to carry out these tasks in ways to maximize positive financial, social and environmental and ecological sustainability effects, impacts and outcomes.

2. Background

The percentage of Construction and Demolition (C&D) waste that is recycled varies tremendously from country to country. Although a few countries have indicated recycle rates as high as 90%, most countries have less than 50% recycling rates, with several as low as 10%. Recognizing the importance of recycling C&D waste, some national legislative bodies have implemented regulations to encourage more recycling efforts. One of the most stringent new requirements is the EU Waste Framework Directive (European Parliament and Council, 2008) which has established a strategy to handle waste, including a minimum of 70% of C&D waste reuse, recycling, or material recovery by the year 2020 (Hiete, et al, 2012).

C&D waste is generated at four intervals during the life cycle of the facility or structure. First, the site will often require some form of preparation prior to commencing any construction activities. The initial demolition could involve clear and grubbing for an undeveloped site, infrastructure removal for a previously occupied site, or a combination of these methods. Second, during the construction process, excess materials are often discarded as waste. Factors that affect this waste stream include impacts of selected materials and methods, poor workmanship, uneconomical design, and improper material handling. Third, during the operating phase of the building, any renovations or repairs will generate waste from the removal of old material and excess from the new product. Finally, during the building demolition process, all the demolished building materials are often disposed of as waste. Despite attempts to require the recycling of materials during demolition, it is often uneconomical, time

consuming, or impractical to sort the waste for efficient recycling. Ideally, if the building is designed for deconstruction at the end of the life cycle, many of the challenges regarding the sorting of the waste to an acceptable quality for reuse or recycling can be dramatically improved.

The following is a summary of the major drivers that can influence designers to design for deconstruction in the initial design process (Hobbs & Adams, 2012):

- **Environmental driver:**
 - o Reducing the extraction of new materials;
 - o Diverting waste away from landfills
- **Socio-economic driver:**
 - o Employment: Jobs may be lost in primary manufacturing, but some will be created in the refurbishment of equipment and in the processing of reclaimed materials;
 - o Social benefits: Benefits from reduced loss of land due to materials extraction and landfill sites
- **Political driver:**
 - o Government policy on sustainability (minimization of waste, maximization of recycled and reclaimed materials)
- **Risk management:**
 - o Legislation, health and safety, fiscal measures encouraging minimization of primary materials extraction and waste generation;
 - o Reclassification of materials and waste
- **Economic driver:**
 - o Design for deconstruction increases the flexible use and adaptation of property at a minimal future cost;
 - o Reducing the whole-life environmental impact of a project and diverting waste away from landfills
- **Ethical Responsibility:**
 - o There is a moral responsibility to protect the natural environment and ensure social equality when selecting products for construction.
 - o Product selection and waste handling can play a significant role in the ecological and social impacts of a business.

3. Issues

Despite the numerous advantages, the barriers to designing for deconstruction often make it difficult for architects to incorporate material recovery procedures into the initial building design. The following are some of the challenges faced to design for deconstruction (Hobbs & Adams, 2012):

- **Lack of legislation:**
 - o At present there are no legal requirements in any country for clients or contractors to consider deconstruction at the design stage or require that waste materials from construction or demolition be sorted for recycling.
- **Human barrier:**

- Habits: It is easier for people to carry on what they have been doing;
- Mindset: People tend to prefer new materials to second hand ones.
- **Additional design cost:**
 - Additional time is often required for architects and engineers to include the added features to make the building deconstructable.
- **Procurement and contractual responsibilities:**
 - The design agents may be hesitant to specify products that are not normally used by contractors since they may become liable for the quality of the installation due to their proprietary control of the contractor's choice of products.
 - Likewise, contractors may be hesitant to select products that are not normally recognized by the design agents since they could become liable for any variations from the standard specifications.
- **Technical barrier:**
 - Jointing systems, for example between pre-cast concrete beams, are usually stronger than the actual beam and are very difficult to deconstruct.
- **Economic barrier:**
 - Cost of individual units (tiles, paving slabs etc.) is usually low, so it is more cost effective to buy new ones.
- **Dimensional barrier:**
 - Structural units (beams, columns, etc.) are normally for one-off custom elements with unique dimensions.
- **Physical barriers:**
 - Pre- and post-tensioned beam/ floors, jointing systems, natural ageing of concrete, reinforcement corrosion, presence of coatings.
- **Contamination and aesthetics of components issues:**
 - Contamination with pollutants (petrol, grease, grime)
- **Perception and education:**
 - Perception that composite and strongly bonded elements are more durable and stronger structurally. In reality, a well-designed building that incorporates design for deconstruction elements should pose no increased risk of structural failure.
- **Problem of storage and double-handling of materials:**
 - Transportation between sites and locations can increase reuse costs.
- **Lack of markets for reusable elements or components:**
 - The reusable parts are perceived as being more inferior to newly constructed elements or components in terms of performance and quality.
- **Lack of design codes/ standards/ guidelines:**
 - Without consistent codes that include deconstruction, it is difficult to provide specifications that can be met by a large variety of contractors.
- **Lack of expertise:**
 - To carry out deconstruction and/or supervise the deconstruction process.
- **Lack of project references:**
 - Without good examples to follow that demonstrate the effectiveness of design for deconstruction, it may be difficult for both design agents and contractors to have a reference project to emulate.

An essential element in the evaluation of construction products to reduce waste and minimize the depletion of natural resources is the initial selection of the appropriate materials. In some

cases, existing products can be modified or used in alternative methods and thereby improve their performance while minimizing their ecological effect. Additionally, new products should be evaluated to ensure that their manufacture, use, and disposal will not result in further environmental impacts. Life Cycle Analysis tools are one method that can be used to assist in performing these evaluations. By examining the full life cycle of a product it is possible to determine the environmental, social, and economic impact that is expected from the processing, operation, and end of life or recycling. This method of analysis can prove useful in determining which materials are considered sustainable. Construction Materials Stewardship is concerned with the developing methods, strategies, and initiatives to promote the use of more sustainable products.

Churn rate has been used to measure how often a business or building changes its operation. When the old tenant vacates the facility, there can often be a complete demolition of the interior and the installation of new finishes and furnishings. A significant tool in the minimization of material waste is the design for a facility to readily transform and adapt to new tenants and operational requirements. A critical aspect in the success of these transformations is the initial design of the building to facilitate the easy turn over. Additionally, the appropriate materials need to be selected that are durable and can withstand the periodic displacement. By planning in advance to design the building for the eventual churn, significant amounts of construction waste can be reduced.

As communities transition, often there are buildings that outlive their original design and become vacant or abandoned. In many cases, the site will be completely demolished prior to subsequent facilities being constructed. This building demolition results in a tremendous amount of material being landfilled that otherwise could have been reused. The renovation or adaptable reuse of the existing structure would provide a significant improvement from complete demolition and additionally minimize the amount of raw materials needed for new construction. However, changing the functional classification of a building may introduce new regulatory conditions and perhaps require zoning consent (Langstom, 2008). Again, the early planning for the potential adaptable reuse can have significant impacts on the economic, ecological, and social aspects of a building.

4. Stakeholders

With regards to the construction industry, there are two groups of major stakeholders: Internal and external stakeholders (figure 1). The internal stakeholders refers to the groups that have a direct impact on the construction process, while the external stakeholders have more of an impact on the internal stakeholders than they do on the actual infrastructure construction. The internal stakeholders include project owner, clients, project leader, and core team members such as designers, contractors, suppliers, and subcontractors. The external stakeholders include regulators (both local and national), public community groups, financiers, the media, end users, and special interest groups (Chinyio & Olomolaiye, 2010).

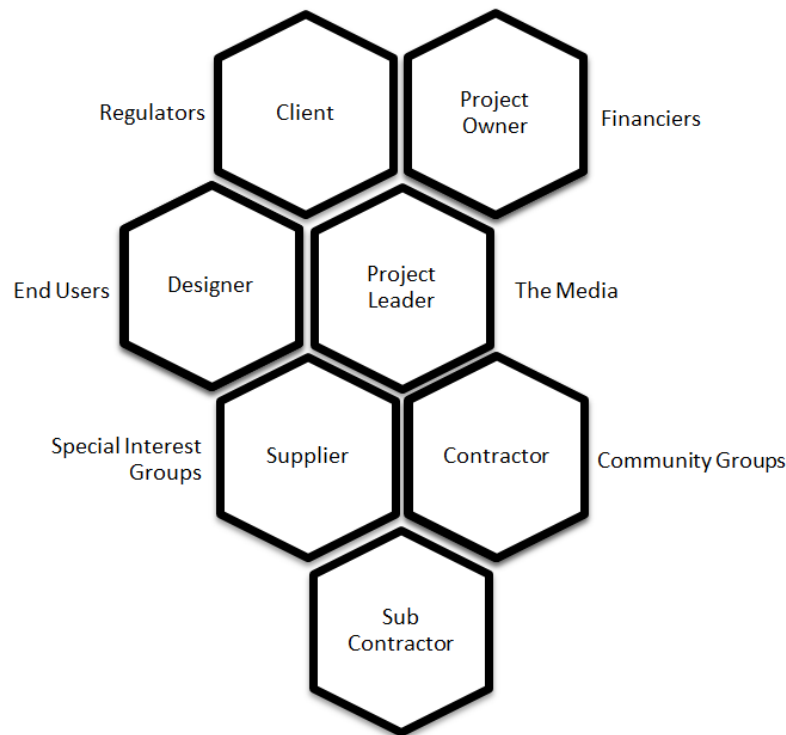


Figure 1: Internal and External Stakeholders

With regards to Construction Materials Stewardship, the following list describes the influences provided by the stakeholders and the perceived barriers for recycling or reuse:

- **Project Owner:**
 - As the primary group or individual responsible for the project, the owner sets the tone and establishes the priorities for the entire construction process. However, the owner may argue that designing for deconstruction or requiring more source sorting recycling programs will increase the cost of the project and not be economically feasible. If only a small portion of the owners are implementing these programs, it may be difficult to sell or lease the more expensive property unless the clients demonstrate a greater need for these requirements or the designers/contractors can perform the material recovery at the same cost.
- **Client:**
 - The group that will lease the spaces or purchase the property. In some cases, the clients may also be the project owners. The group may argue against the materials stewardship principles since they do not want to incur the added costs. Unless, there is government regulations that require that they operate from an environmentally responsible facility they will not have an even playing field from their competition and the added costs for materials stewardship will add an unnecessary expense.
- **Project Leader:**
 - Depending on the contractual situation, the project leader is often the individual responsible for coordinating design and construction efforts with the owner. With regards to materials stewardship, the project leader recognizes the need

for added costs from the design and construction team and thus passes these costs along to the owner. However, if the owner does not desire to pay for these added services, then the project leader normally will not require these services.

- **Designer:**

- The design team is normally comprised of the architects and engineers responsible for developing the drawings and specifications for the project. They often feel that the limitations of including design for deconstruction are from two other groups. First, is that the material suppliers do not provide enough material options using recycled material that is of equivalent quality to virgin products. Second, the owner may not be interested in paying the added cost to enhance the drawings to the level needed for a structurally sound design that can be readily deconstructed at the end of life. Thirdly they may not want to bear additional responsibilities or risks for being the first movers to adopt design for deconstruction concepts in view of the current lack of project references, design codes/ standards/ guidelines.

- **Contractor:**

- The contractor is responsible for the physical assembly of the infrastructure in accordance with the design and specifications provided by the architect/engineer. The limitations regarding infusing materials stewardship principles into the construction are directly limited by the design, the regulatory environment, and the market for recycled products. In other words, unless the construction specifications specifically require the recycling operations, the regulating authorities have policies for mandatory recycling, or there is a financially viable market for recycled products, the contractor does not have a strong incentive for capturing the material waste. Another common issue is that obtaining a higher grade of recycled product can be very labor intensive or delays the project; thereby further increasing the construction costs.

- **Suppliers:**

- The suppliers include all of the material manufacturers that provide the products necessary for the construction. This group has often argued that developing new products using recycled materials can be costly and often there is not an adequate consumer market to justify the expense. Additionally, when the quality of the recycled material is inadequate, it is more difficult to develop better quality products that would be comparable to virgin materials.

- **Subcontractors:**

- Many of the basic trades that demolish or install the building materials are conducted by subcontractors. The common barrier for subcontractors is due to the uncertainty in performance of new products from recycled material. If the quality is inadequate, the project may require substantial rework and incur significant additional costs.

- **Regulators (both local and national):**

- This group includes the legislative bodies and government officials that establish the codes and standards along with the tax laws that are applicable for the region. Although it has been demonstrated in many countries how effective legislation can make a significant difference in implementing materials stewardship principles, there is often resistance from industry on excessive legislation in a free market society. Additionally, many of the laws that would

implement the environmentally friendly programs may require higher revenues to administer the policies and this may be politically challenging to acquire.

- **Public Community Groups:**
 - These groups refer to the locally organized citizens organizations that have jurisdiction over the area of the construction project. They can provide a very positive impact on the materials stewardship of the project by specifying that certain demolition and recycling practices be implemented within the community. However, if they see the recycling and reuse practices as unnecessary expenses, then they may also have a negative impact by not encouraging the materials stewardship practices.
- **Financiers:**
 - This group includes the various funding sources that provide the revenue for the project. When sustainable practices can demonstrate a financial benefit for the project, then they are interested in encouraging implementation of the materials stewardship policies. However, if the financial institution is not concerned with the environmental principles then they may not be interested in the extra costs that may be involved in recycling or reuse operations.
- **The Media:**
 - This group includes the various news and public information agencies for a community. In some instances if the owner feels that the media's positive publicity on the material stewardship principles of the project will assist the marketing of the project, there is a greater likeliness that recycling or reuse operations will be implemented. However, depending on the media service, if there is an impression that the materials stewardship principles are adding excessive costs to the project, then it may have a negative impact on publicity.
- **End Users:**
 - The final users of the constructed project are often referred to as the end users. Their impact on material stewardship is often through their willingness to shop or use the appropriate infrastructure. If the recycling or reuse operations created added cost for the users beyond competitive service, it may cause a loss of end users and similarly a decline in revenues for the owner.
- **Special Interest Groups:**
 - Organizations that are interested in promoting various causes and agendas can be referred to as special interest groups. Depending on the environmental preferences of the group, they can have a very positive impact on influencing the implementation of material stewardship principles. Although, there are likewise other groups that are more concerned with fiscal responsibility and reducing costs that may be just as likely to have a negative impact on recycling or reuse practices.

5. Conclusions

The expertise needed to solve these issues includes researchers and policy makers that can collaborate with the stakeholders. The mission of Construction Materials Stewardship is to provide the framework for this collaboration by encouraging the additional research that practitioners need to implement the changes. By working with the policy makers, schemes can be developed to encourage adoption of the procedures that will close the loop of the infrastructure's material life cycle.

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Reinforcement Corrosion Modelling in Renovation Strategy for Concrete Facades

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Abstract

Starting from the 1960s, concrete structures have become prevalent in Finnish construction. This is a result mainly from urbanization and domestic housing policy in Finland which triggered the production of prefabricated concrete buildings. Because of the huge volume of this building stock, its renovation is also challenging in terms of resources. Approximately 11–40 % of the repair costs of prefabricated concrete facades result from corrosion-induced damage.

A subjective methodology is required to compare different repair options technically as well as economically including instant and life cycle costs. Essential information on the durability properties of single buildings and their repair possibilities is gathered in condition assessments but to estimate the residual service life of a concrete structure or to provide strategies for a large number of buildings it is necessary to utilize predictive models. At present, a methodology to assess the residual service life of existing buildings in practice is not available. The propagation of corrosion on concrete facades in Finnish environmental conditions was studied by a series of field and laboratory studies conducted on twelve residential concrete buildings located in different parts of southern Finland. In addition, corrosion rates in concrete facades were evaluated by long term field measurements on concrete facades under natural conditions. The experimental results were contrasted to statistical information on 947 case buildings. This information was used in determining critical parameters in service life modelling.

In the rising trend of renovation in the construction sector, this research will provide information on when to initiate repairs and in what extent. Thereby, the results will enable deciding the order of importance of renovation projects and change from reactive to proactive maintenance. Future applications could include the establishing of alliance type contracts between building owners and renovation specialists covering the long time span upkeep of a large building stock.

Keywords: Concrete facades, service life, modelling, renovation strategies

1. Introduction

Corrosion of reinforcement affects concrete structures basically either by cracking of concrete cover caused by corrosion products or by reduction of effective steel cross-section. The functionality of reinforcement (structural/non-structural) and the corrosion mechanism are decisive for which effect is dominating service life. However, cracking is typically the first sign of corrosion damage visible to the structure's surface. Corrosion is responsible for approximately 11–40 % of the repair costs of prefabricated concrete facades in Finland depending on the surface finishing, and along with insufficient frost resistance, carbonation induced corrosion is the most significant degradation mechanism of concrete buildings in Finnish environment. The damage caused by the both mechanisms accounts for €3.5 billion in repair need and is increasing. It alone makes 1.8 % of the 2013 GDP of Finland. This is an issue that cannot be solved instantly, but requires a rehabilitation plan over several years.

Private and public buildings built of concrete make up 34 % of the whole building stock in Finland, of which almost 40 % is now 30-50 years old. The majority of the existing concrete facades in Finland have been built in time when service life design practice was not yet established (compared to a common service life requirement today of 50 years). The reinforcement service life is in Finnish guidelines (by50 2012) defined as only corrosion initiation. This means that the target service life should be achieved by carbonation resistance alone. This strategy withholds additional safety since no damage at all has happened yet at the chosen end of service life. In addition in new construction carbonation can be fairly easily accounted for by engineering concrete composition and reinforcement cover depths accordingly. Concerning existing buildings a problem is formed since these properties are already fixed. Also, the initiation phase is in many cases already passed. This makes the assessment of the residual service life of these structures problematic in two ways: (i) the residual service life is, by the definition, zero even though no damage at all has happened, (ii) there is no methods available to evaluate the residual service life.

This research entity focuses on the service life design and maintenance strategies of existing concrete facades in Finland. Service life extension is gained by defining the end of service life in a new way and reliably modelling the corrosion propagation phase. It is a practical issue since many of these concrete buildings have poor quality and ongoing degradation due to freeze-thaw and corrosion. The residual service life of these facades cannot be estimated by carbonation resistance since this phase has already passed. The motivation is to find a way to compare renovation projects and to manage the ever growing renovation needs. The aim is to be able to combine a carbonation model and an active corrosion phase model to form a larger picture of the service life of these structures.

2. Background

2.1 Renovation strategy for concrete facades

Renovation strategy of a built asset is tied to the business/maintenance strategy, financial situation and future prospects of the owner. The renovation project should begin with a project planning phase where the owner sets the requirements (technical, visual, etc.) and the budget for the project. In particular, the owner should define the target service life for the renovation.

The options available for renovation projects can be divided into (SFS-EN 1504-9):

- a) do nothing & monitor
- b) re-analyse & downgrade in function
- c) prevent & reduce further degradation
- d) repair & protect
- e) replace with new
- f) demolish.

The first two options can be used in delaying and budgeting for a larger project in the future. If utilized, these options require comprehensive survey/investigation of the condition of the structure (Lahdensivu et al. 2013). The optimal renovation on the point of view of economy and sustainable use of resources would include options c (prevent & reduce further degradation) and d (repair & protect). In practice, it is however far too common for the owner to only focus on repairing visual damage without analysing properly the need for protective/preventive measures. Cases showing high degree of degradation or obsolescent facilities or technical systems may have to be replaced.

Another way of classifying the repair options is (by41 2007):

- a) do nothing
- b) preserving renovation
- c) altering renovation
- d) renewing of the whole structure
- e) special methods.

The repair options are followed by the choice of (a set of) renovation principles. The renovation of concrete structures in general can follow several main principles (SFS-EN 1504-9) shown in Table 1. The selection of the renovation principle is often guided by technical, financial, valuation and social aspects.

Table 1: Renovation principles in SFS-EN 1504-9.

Repair principle
1. Protection against ingress
2. Moisture control
3. Concrete restoration
4. Structural strengthening
5. Increasing physical resistance
6. Resistance to chemicals
7. Preserving/restoring passivity
8. Increasing resistivity
9. Cathodic control
10. Cathodic protection
11. Control of anodic areas

2.2 Reinforcement corrosion modelling

A widely accepted description of the corrosion process of steel in concrete withholds the phases of initiation and propagation (Tuutti 1982). The both phases can be analysed as separate entities or combined to form a holistic view of the structure's lifetime for the service life design purposes. The assessment of the residual service life of corroding concrete reinforcement requires detailed information on the corrosion mechanism, initiation, corrosion rate and conditions which are regarded as the end of service life. The diameter and cover depth of the corroding reinforcement as well as the type of products (rust) formed in the corrosion process have been found to have significant impact on the formation of corrosion cracking. These factors are critical in modelling of the residual service life of structures in active corrosion state.

Carbonation of concrete cover is behind the corrosion phenomenon in many outdoor concrete structures, such as facades and balconies. Carbonation of concrete is a chemical reaction between the alkaline hydrates of concrete and carbon dioxide gas, both of which are dissolved in concrete pore water. Because carbonation is mainly controlled by the diffusion of carbon dioxide within concrete, it is commonly modelled using the square root of time relationship, derived from Fick's diffusion law.

Many models have been proposed for depicting carbonation, all of which make use of the square root of time relationship (Parrott 1987). However, empirical measurements have indicated it to overestimate carbonation especially in cases where the concrete is exposed to rain (Tuutti 1982, Huopainen 1997). Therefore, the square root equation should be regarded as an upper limit for carbonation in such cases. The carbonation coefficient k is used to adjust the model to describe the carbonation of different concretes in different environments. (Tuutti 1982).

Another approach has been to incorporate the effect of different environments by modifying the exponent of time (Parrott, 1987). A number of studies e.g. (Thiery et al. 2007, Hyvert et al. 2010) have been concentrated on the reaction kinetics of carbonation by utilizing physical models. The square root equation has also been improved to distinguish between the influences of different individual internal and external factors affecting carbonation (Neves et al. 2012), and to isolate the influences of specific factors (fib 2006) opposed to the one parameter in Eq. (1). A statistical analysis of a carbonation coefficient based on field measurements has been recently presented in Portugal (Monteiro et al. 2012) and in Finland (Lahdensivu 2012).

The main difference between the carbonation model proposed in fib model code (fib 2006) and the one and two parameter models by Tuutti (1982) and Neves et al. (2012) is the requirement for a specific accelerated carbonation test performed in a laboratory environment to determine the carbonation resistance parameter. The latter models, on the other hand, are applicable in practice based on natural carbonation measurements conducted on site.

Corrosion propagation can be modelled by (i) empirical, (ii) numerical or (iii) analytical approaches. (Otieno et al. 2011) Empirical models are sub-divided into three types i.e.: expert Delphic oracle models, fuzzy logic models and models based on electrical resistivity and/or oxygen diffusion resistance of concrete. Empirical models are based on experimentally achieved relationship between corrosion and controlling parameters (e.g. DuraCrete 2000). Three different approaches can be used to develop numerical models: finite element method (FEM), boundary element method (BEM) and resistor networks and transmission line method. Numerical models rely on computational solving of larger entities by dividing them into small elements connected to each other by boundary conditions (FEM, BEM) (e.g. Gulikers and Raupach 2006). Analytical models apply usually thick-walled cylinder approach. Division into cracked inner cylinder and an uncracked outer have also been developed. Analytical models are based on the closed-form solving of mathematical equations derived from the geometry of the problem such as concrete cracking (e.g. Goltermann 1994).

A traditional way of modelling corrosion propagation is by the corrosion rate modified by the diameter of reinforcement and the concrete cover. (Siemes et al. 1985) The corrosion rate itself is related to the wetness and temperature of the structure and is modelled e.g. by the potential electrolytical resistivity of concrete (DuraCrete 2000). A way of finding information on the corrosion propagation phase by statistically calculating backwards the age and initiation time on existing concrete structures subjected to condition assessments has been proposed by Köliö et al. (2014).

3. Research material and methods

The propagation of corrosion on concrete facades in Finnish environmental conditions was studied by a series of field and laboratory studies conducted on twelve residential concrete buildings located in different parts of southern Finland. The studies were conducted in tandem with the normal condition assessment inspections for these buildings. In addition, the extent to which the corrosion rates in concrete facades are affected by the outdoor environment was

analysed using long-term (25 months) field measurements from concrete facades under natural weather conditions. These experimental results were compared with statistical information on 947 buildings.

The condition assessment database was used in studying statistically the realized service life of concrete facades in regard of visual damage caused by reinforcement corrosion (Köliö et al. 2014). The age at which visual corrosion damage is generally observed in concrete facades was studied using visual damage ratings given in condition assessments. This damage rating was used together with the age of buildings to study the time it takes for corrosion damage to propagate.

The type and critical amount of corrosion products were studied by electron microscopy and X-ray diffractometry on concrete and reinforcement samples from existing concrete facades on visually damaged locations. This information was utilized in creating a service life limit for concrete facade panels in regard of visual corrosion damage occurrence. Corrosion rate was determined as a combined effect of weather parameters on already carbonated concrete structures exposed to natural outdoor environment. A long term corrosion rate measurement data was combined with weather data from the location of the measurements from the same time period.

These in-depth studies were used to model the probable extension in residual service life given by the active corrosion phase for existing concrete facades. The modelling approach counts among the empirical models with statistical experimental data.

Ways of utilizing the knowledge on the corrosion propagation phase in the renovation strategy were analysed based on acknowledged renovation intervention options or principles (SFS-EN 1504-9; by41 2007). The possible benefits from the propagation phase were analysed in regard of timing, budgeting and prioritizing of renovation projects.

4. Results and discussion

4.1 Reinforcement corrosion modelling

This chapter discusses the service life of concrete facades in Nordic climate including the initiation of corrosion and corrosion propagation until visual corrosion cracking occurs. The discussion is based on studies described in chapter three.

During initiation phase the concrete cover is carbonated as a barrier and finally reaching the steel initiating the actual corrosion process. Until this point, no actual damage has occurred at all. In the propagation phase, as the corrosion proceeds it will eventually induce visual damage to the concrete structure's surface as cracks or spalls. The rate of this process depends on many things, such as cover depth, diameter of the reinforcing steel as well as temperature and the availability of moisture. A statistical distribution over time was produced for the formation of visual damage after consecutive initiation and propagation phases on concrete facade and

balcony structures (Fig. 1). Because the information about the age of the building is linked to the time of condition assessment these examinations do not take into account the fact that visual cracks or damage have, in fact, emerged some time before the assessment date. This time before the condition assessment is in this study unknown. Thus, the visual damage is likely to be formed even earlier than the results indicate, and the results of this study should be treated accordingly.

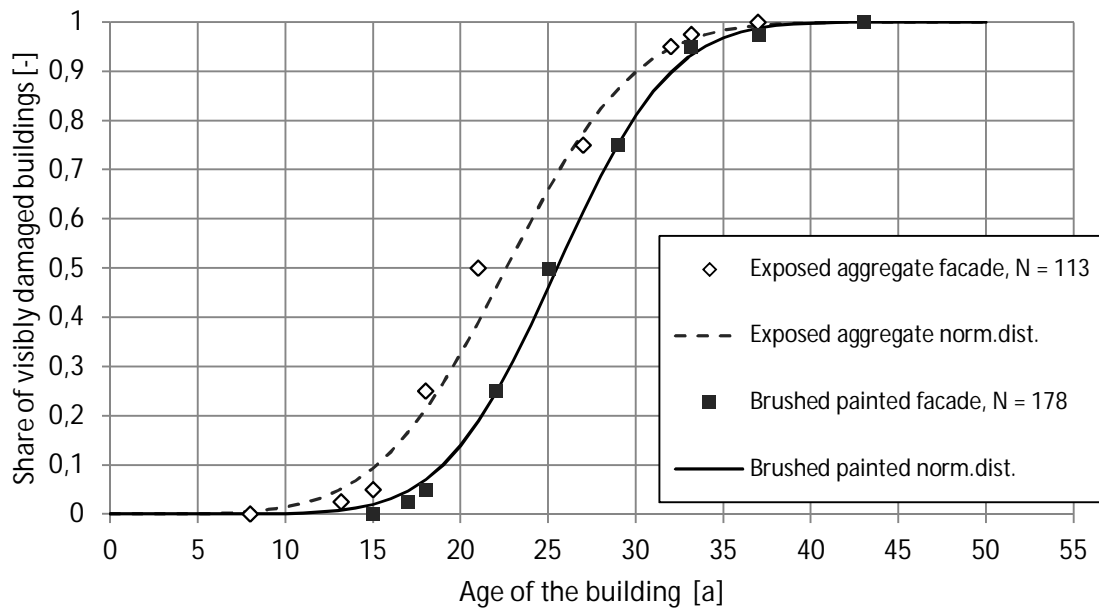


Figure 1: Statistical model for the evolution of corrosion damage after consecutive initiation and propagation phases based on condition assessment data.

The first visual damage had occurred after 15 years from construction in brushed and painted concrete facades and after 8 years in exposed aggregate facades. By median, visual corrosion damage has formed on concrete facades after 21 to 25 years from construction (exposed aggregate and brushed painted respectively). The propagation phase was estimated by extracting from the total age (Fig. 1) a known initiation phase based on carbonation depth measurement data. According to the calculation, the length of the propagation phase is 0.6–1.4 years when adopting a commonly used 5 % safety level. It relates to corrosion of reinforcement with extremely small cover depth or in very capillary concrete. However, this safety level may be too strict compared to empirical knowledge. On average, the length of the propagation phase has been 6–10 years depending on the type of structure.

Concrete structures studied by characterization methods (SEM, EDS, XRD) were on average 38.8 years old. The average time under active corrosion was for the cracked locations 26.0 years. It should also be noted that for all of the samples corrosion has been initiated quite fast (by average 12.6 years) which indicates that both concrete resistance against carbonation has been poor and the environmental conditions favourable to carbonation (somewhere between exposure classes XC3 and XC4). Corrosion products associated with carbonation initiated corrosion on the studied concrete facade panels were mostly hydroxide type of rusts with a unit

volume of roughly 3 times the volume of iron. Taking the determined relative volume of the rust layer into account the required corrosion penetration to initiate visually observable cracks in the studied facade panels was by average 67.5 μm (total range of 22.2–119.1 μm) with a corresponding rust thickness of 202.5 μm .

Measured corrosion current densities show high scatter but are in general rather high (Fig. 2). The wind-driven rain amounts on the structures have during the monitoring period been 47 % higher inland than in the coastal region. Inherently, the corrosion rates have been 11–18 % higher inland than in the coastal region. This observation stresses the importance of the micro climate around the building along with the geographical location in regard of degradation rate. Current densities measured as a reference from the bottom surface of a balcony slab (sheltered from rain) were very low. In a regression analysis between corrosion rate and weather parameters all seasons showed high correlation between wind-driven rain and corrosion rate.

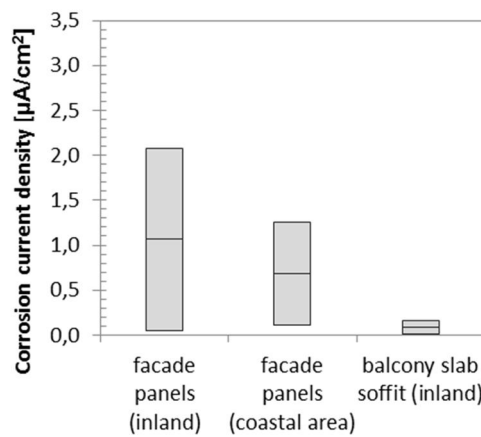


Figure 2: Monthly averaged corrosion current densities recorded in field measurements in inland and in coastal area of Finland.

Corrosion rates during the lifetime of the concrete structures at inland and coastal area locations were estimated using the model with a record of 30-year weather data from 1979–2009. The weather data was available for coastal site from Helsinki-Vantaa airport (distance to site 15 km) and for inland site from Jokioinen observatory (distance to site 79 km). On a long time scale the corrosion rate on concrete facades were relatively steady at the both locations.

The overall average level was 1.2 $\mu\text{A}/\text{cm}^2$ at inland and 1.7 $\mu\text{A}/\text{cm}^2$ at coastal area site. These corrosion rates correspond to a steel loss of 14.6 $\mu\text{m}/\text{year}$ and 19.6 $\mu\text{m}/\text{year}$, respectively, derived from the Faraday's law. These corrosion levels can be considered high (Andrade & Alonso 2001) in carbonation initiated outdoor concrete structures. Based on the modelled corrosion rate and the measured critical corrosion penetration, the length of the propagation phase is estimated to be approximately 1.5–8 years in inland and 1–6 years in the coastal area in south facing facades.

4.2 Active corrosion phase in renovation strategy

The studies presented in this paper aim to enhance the knowledge on the corrosion propagation phase in reinforced concrete facades as a part of their service life. The research project confirmed that the propagation phase can provide a considerable extension to the service life of concrete facade panels in Nordic climate. This extension can be from ten to even 30 years. However, it varies considerably due to material, structure and environmental factors.

Table 2: The relationship of initiation and propagation phases in concrete facade panels (average in brackets)

structure surface	share of the initiation phase in the total service life, average in parenthesis (%)	share of the propagation phase in the total service life (%)
brushed painted concrete facade	85–98 (88)	2–15 (12)
exposed aggregate concrete surface	91–99 (94)	1–9 (6)

It appears, from Table 2, that the potential for extending a structure's service life with the propagation phase is in some cases considerable (by average 6–12 %). Although, majority of the service life of concrete is accounted for already in the initiation phase. Therefore, when assessing the total service life of a building, it is critical to ensure the structures have the required resilience to carbonation in terms of concrete composition, concrete quality and cover depths. If the properties of the initiation phase are already fixed (as is the case in existing structures) it seems clear that accurate information about the propagation phase will have to be utilized to extend a structure's service life.

The ability to model or forecast corrosion rates on concrete facades will enhance the capability of realtors to react on upcoming repair needs. This kind of model would be able to predict the residual service life of a certain structure, but it could also be used in creating renovation strategies for a larger building stock by revealing the order of importance or the urgency of single renovation projects. The knowledge on active corrosion phase will enhance the capability of the owner to utilize the delaying options with more confidence. Especially this knowledge will help in pointing out the cases where these options are applicable and where they are not (Table 3). It also illustrates clearly the influence of the delaying of renovation, which will in eventually render lighter repair options not applicable due to increasing degradation.

The occurrence of visual damage is a natural way of judging the service life of these structures since all of the renovation and maintenance decisions are made based on investigations usually commissioned based on these visual signs. This, however, means that lighter remedial actions are not anymore available and repair & protect options have to be considered to some extent. In order to be able to utilize only protective options, the service life should not include propagation phase. The intervention should in this case be taken directly in the end of the initiation phase.

Corrosion induced damage occurred on the studied structures commonly on the lap splicing locations of rebars, in the edges and window openings of the panels and in locations with pronounced moisture load due to poorly functioning flashings and rain water runoff control. If the ratio of concrete cover to reinforcement diameter was small (below 1.5) corrosion related damage had emerged as spalling. If the ratio was well over 1.5 the damage more probably emerged as cracking. Careful design of the above mentioned details will allow longer propagation phases to be taken into account in service life.

Table 3: Renovation options contrasted to different renovation strategies.

Repair option	Early intervention (up to initiation)	Early intervention (up to first visual damage)	Need-based-repair (intrusive)	Maximized service life
a) do nothing & monitor	Available	Available	Not available	Not available
b) re-analyse & downgrade in function	Downgrade not required	Downgrade not required	Available	Not available
c) prevent & reduce further degradation	Available	Available	Not available	Not available
d) repair & protect	Available	Available	Available	Not available
e) replace with new	Not reasonable	Available	Available	Available
f) demolish	Not reasonable	Not reasonable	Available	Available

The available repair options (Table 3) illustrate the importance of early intervention. At this point the available options are many and they are in general fairly light. A need-based renovation strategy already requires some level of intrusive repair. A strategy aiming at maximizing the available service life of the existing structure will lead to heavy renovation, replace or demolition eventually. A conventional limit for the early intervention strategy is the initiation of corrosion. However, it is visualized that this strategy is not compromised even when the service life is extended to the propagation phase. Same set of renovation options will be available until the occurrence of damage as cracking or spalling. This information can be utilized in planning of the renovation of structures, where the initiation phase has already

passed. Modelling the length of the propagation phase will allow a time-span of up to 8–10 years for planning and budgeting of the renovation work without compromising the choice of strategy.

5. Conclusions

Renovation strategy of a built asset is tied to the business/maintenance strategy, financial situation and future prospects of the owner. The options and principles available for the renovation of concrete facades are many. However, all of them have specific uses and preferable conditions where they perform best. It should be acknowledged that the decisions of the owner in the timing of the repairs greatly affect which renovation options and principles are applicable. Protective renovation options usually perform best when applied in the initiation phase of degradation whereas delaying intervention will force the use of repair/renew options.

The knowledge on active corrosion phase will enhance the capability of the owner to utilize the delaying options with more confidence. Such a tool could be used also in moving towards a predictive upkeep of realty and the confidence of making long term contracts between realty owners, renovation engineers and contractors.

The research project confirmed that the active corrosion phase can provide a considerable extension to the service life of concrete facade panels in Nordic climate. This extension can be from ten to even 30 years. However, a probable extension is 8–10 years in high environmental stresses. This time period may well provide the necessary latitude for the renovation budget and planning.

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Integrating Building Information Modeling Technology, Facility Management System and Maintenance Cost Database in Predicting Building Life Cycle Maintenance Cost

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Abstract

In building operational phase, facility management problems such as the deferral of critical repair, replacement or renovation of building structure or equipment are often observed in Taiwan due to inadequate annual maintenance funding. Building owners and facility managers are in great need of a method or tool to predict the maintenance costs over the life spans of their facilities in order to allocate adequate maintenance funding to sustain their facilities. To solve this problem, this study adopts and integrates existing technologies such as building information modeling (BIM), facility management system (ArchiBus[®]), and local construction and maintenance cost database (PCCES) to establish the Building Life Cycle Maintenance Cost Prediction method (BLCMCP) to predict annual maintenance costs over building life span based on a set of predefined maintenance plans. It is proposed that (1) BIM software such as REVIT is used to create all the components (each with a CSI's MasterFormat code) of each building subsystem of a building, from which a 'component list' of a building subsystem with quantity takeoff can be generated; (2) Facility management system such as ArchiBus[®] is used to specify the schedules of various maintenance tasks (inspection, repair, renovation, or replacement) for each component of a building subsystem over building life span such as 30 years; (3) local construction and maintenance cost database such as PCCES in Taiwan is used to provide updated construction and maintenance cost data (labor and material costs) for each component of a building sub-system. The annual maintenance cost of a component of a building subsystem in a particular year can be estimated by retrieving the maintenance tasks scheduled from the ArchiBus[®] as well as the unit cost data of each maintenance task from the PCCES according to its MasterFormat code. The 'elevator' subsystem of the Taiwan Building Technology Center (TBTC) building located on the NTUST university campus is used as a case to demonstrate how the established BLCMCP method can be used to estimate the annual maintenance costs of this subsystem and its components over a 25-year life span.

Keywords: MasterFormat code, maintenance schedule, construction and maintenance cost database

1. Introduction

1.1 The Problems

The structure and various building control equipment of a building have their design service lives, and they are expected to degrade or breakdown sometime during the building life span. Facility management plays an important role in operating and maintaining building components and keeping them in reliable conditions. Nevertheless, facility management problems such as the deferral of critical repair, replacement or renovation of building structure or equipment are often observed due to inadequate annual maintenance funding. Building owners and facility managers are in great need of a method or tool to predict the maintenance costs over the life spans of their facilities in early operational phase in order to allocate adequate maintenance funding to sustain their facilities.

1.2 Potential Technologies as the Solution

To solve this problem, this research argues that existing potential technologies such as building information modeling (BIM), facility management systems, and local maintenance cost database can be adopted and integrated to establish a building life cycle maintenance cost prediction tool.

Building Information Modeling (BIM) has recently attained widespread attention in the architectural, engineering and construction (AEC) industry worldwide. Many researches have been dedicated to demonstrate the applications of BIM's responsive quantity takeoff capability in cost estimation in building design and construction phases (Eastman et al., 2008; Meadati and Nelabhotla, 2011; Lu et al., 2016; Popov et al., 2006; Smith, 2014). This study argues that the same capability is potentially applicable to maintenance cost prediction during operational phase as well by producing quantity takeoff for those building elements to be maintained.

Facility management systems or computerized maintenance management system have been used to plan and manage maintenance tasks during building operational phase. To predict building life cycle maintenance cost in early operational phase, it's critical that cost estimations are based on a set of pre-planned maintenance tasks to be conducted on various building subsystems and their components over a certain life span, which can be effectively assisted and scheduled by facility management systems.

To further estimate the cost of each maintenance task, it is necessary to acquire the unit costs of the labor, material, or equipment involved in that task. Local construction and maintenance cost databases, such as RS Means cost data (Plotner, 2013), have been established in many regions or countries, and can provide cost data required for maintenance cost estimation purpose.

1.3 Research objectives

This research intends to develop a building life cycle maintenance cost prediction method to be used in early operational phase. To be more specific, the objectives of this research are:

1. To establish a Building Life Cycle Maintenance Cost Prediction method (BLCMCP) that integrates BIM, ArchiBus^{○,R} facility management system and a local construction cost database (PCCES) to predict the annual maintenance costs of a building over its life span given a set of maintenance plans specified in early operational phase;
2. To demonstrate how the developed BLCMCP framework can be applied in the Taiwan Building Technology Center (TBTC) Building on NTUST university campus to predict the life cycle maintenance costs of its elevator subsystem.

2. Literature review

Compared to the construction cost estimation methods devised for new building construction, relatively few researches have been dedicated to developing effective building life cycle cost estimation methods. In their book *Life Cycle Costing for Facilities*, Dell'Isola and Kirk (2003) not only present the methods for economic analysis (ROI, etc.) and life cycle cost analysis (NPV, etc.), but also suggest a framework for estimating life cycle costs, in which decomposing a whole building into several levels of hierarchical elements and adopting MASTERFORMAT or UNITFORMAT that link to cost databanks appear to be the key concepts. Stanford (2010) proposes effective building maintenance as a way to protect capital assets. He not only addresses the importance of budgeting for various types of maintenance taking place during building life span, but also presents budgeting methods adopting the ideas of decomposing a building into four levels of elements as well as remaining design service life for maintenance cost estimation. Kim et al. (2010) employed similar decomposition structure to develop a life cycle cost estimate system for structures of light rail transit infrastructure. The notions underlying the life cycle cost estimation methods proposed above are to decompose a building into several levels of components and then to estimate the life cycle costs for all components individually, which represent great amount of work if done manually.

BIM seems a reasonable technique to be adopted for life cycle cost estimation, considering its capabilities in structuring building components and automatic quantity takeoff. In fact, numerous studies have proposed the 5D concept and applied BIM in building cost estimation to be used during design and construction phase (Cheung et al., 2012; Lu et al., 2016; Popov et al., 2010; Smith, 2014). In these applications, BIM involves more than just 3D modeling and is also commonly defined in further dimensions such as 4D (time) and 5D (cost). 4D links information and data in the 3D object model with project programming and scheduling data and facilitates the simulation analysis of construction activities. 5D integrates all of this information with cost data such as quantities, schedules and prices.

Literature review conducted by this study reveals that little research has been done in applying BIM in predicting long term building life cycle costs. Whyte and Scott (2010) employed statistics and probability, fuzzy set logic, artificial neural networks and objected orientated analysis to develop a life-cycle-cost system in order to assist design decisions, which require advanced techniques to implement. This study argues that the 5D BIM concept, although mainly applied in new building construction cost estimation, linking the 3D BIM model, quantities, schedules, and prices is still a feasible approach to be explored in life cycle cost prediction.

3. The Building Life Cycle Maintenance Cost Prediction (BLCMCP) Methodology

3.1 BIM Model and the MasterFormat Code

This study proposes that building information modeling (BIM) technology be used to organize a building in the following ways for the purpose of life cycle maintenance cost prediction:

1. Each building is decomposed into ten building subsystems: structure, enclosure, interior, HVAC, electrical, telecommunication, fire safety, water/plumbing, conveying, and landscape sub-systems (Table 1).
2. Each building subsystem is decomposed into two levels of elements. A subsystem is first categorized into several major 'assemblies' (level one element), which is then further decomposed into several 'components' (level two element). BIM software such as REVIT can then be used to establish the BIM models for all the 'components' of each subsystem (Table 1). For each 'component' of a subsystem, the maintenance schedules or frequencies of various types of maintenance task can be further specified by facility management software.
3. For each component of a building subsystem, a CSI's MasterFormat code is assigned (Table 1). The MasterFormat code of a component is a unique number or 'key' used to link to and retrieve its maintenance cost data stored in a local maintenance cost database.

Once the BIM models of all subsystems of a building is established, the 'bill of quantity' of all components of ten subsystems can be generated automatically. The 'quantity' of each component is an important parameter for estimating its long term maintenance cost.

3.2 Facility Management System for Long Term Maintenance Tasks Planning

Over the life span of a building, various maintenance tasks (planned or unplanned) are often conducted on individual subsystems and their components to sustain their performance and achieve their service lives. To predict the long term maintenance costs of a building, it is imperative to plan ahead (in early operational phase) for the planned maintenance tasks to be conducted on each component of each subsystem at different time during a certain building life span. The planned maintenance tasks typically conducted are preventive maintenance (inspection/ testing, repair) as well as planned renovation and replacement (Stanford, 2010). The labor (man-hour) and material (or equipment) involved in a particular maintenance task on a component can be assessed, based on which the maintenance cost can be further estimated.

Given the decomposition-structure of a building described in the previous section (3.1), this study suggests that facility management systems (such as ArchiBus^{○,R}) be used to plan and specify the frequencies (or the schedules) of each type of planned maintenance task (inspection, repair, renovation, and replacement) to be conducted annually for each component of a subsystem over building life span such as 30 years (Frequency columns in Table 1).

Table 1: Data to be specified by BIM model, FM system and local maintenance cost database for building life cycle maintenance cost estimation.

Building Subsystems	Level 1 Assembly	Level 2 Component	Master Format / PCCES code	Spec. Info	Quantity	A. Inspection			B. Repair			C. Renovation			D. Replacement		
						Freq- uency	Man-day	LUC MUC	Freq- uency	Man-day	LUC MUC	Freq- uency	Man-day	LUC MUC	Freq- uency	Man-day	LUC MUC
1. Structure	S1 Foundation	S1-1 Structural concrete	03 31 13														
		S1-2 Concrete Reinforcing	03 20 00														
		S1-3															
	S2 Column	S2-1 Structural steel for bldg.	05 12 23														
		S2-2 Steel Joist Framing	05 21 13														
		S2-3															
	S3 Beam	S3-1 Structural concrete	03 31 13														
		S3-2 Concrete Reinforcing	03 20 00														
		S3-3															
	2. Enclosure	E1 Roof	E1-1 Mortar-based ceramic tile	09 32 13													
E1-2 Toolled concrete finishing			03 35 29														
E1-3 Built-Up asphalt waterproof			07 12 13														
E2 Exterior wall		E2-1 Masonry stone cladding	04 42 13														
		E2-2 Grooved concr. surf. finish	03 35 26														
		E2-3 Heavyweight arch. concrete	03 33 13														
I1 Ceiling		I1-1 Acoustic panel ceiling	09 51 13														
		I1-2															
		I2 Flooring	I2-1 Wood block flooring	09 64 16													
I3 Wall		I3-1 Curtain Wall	08 44 00														
	I3-2 Sheet Metal Wall Cladding	07 64 00															
	I3-3 Faced Panels	07 44 00															
4. HVAC	H1 Central cooling equipment	H1-1 Centrif. refrig. compressor	23 61 13														
		H1-2															
		H2 HVAC air distribution	H2-1 Metal Ducts	23 31 13													
	P1 Electrical distribution	P1-1 Dry-type transformers	26 12 16														
		P1-2															
		P2 Lighting	P2-1 Interior lighting fixtures	26 51 13													
	T1 Communications	T1-1 Communications Cabling	33 82 13														
		T2 Wireless	T2-1 Transmitters and Receivers	33 83 16													
		F1 Fire Pumps	F1-1 Centrifugal Fire Pumps	21 31 00													
	7. Fire safety	F2 Fire-Suppression	F2-1 Fire-Suppression Water	21 41 00													
8. Water / Plumbing		W1 Plumbing Piping	W1-1 Facility Water Distribution	22 11 00													
		W2 Plumbing Equipment	W2-1 Water Filtration Equipment	22 32 00													
	9. Conveying	C1 Guideways/Railways	C1-1 Rail Tracks	34 11 00													
C2 Traction Power		C2-1 Traction Power Distribution	34 21 00														
10. Landscape		L1 Paving	L1-1 Rigid Paving	32 13 00													
	L2 Planting	L2-1 Turf and Grasses	32 92 00														

Note: PCES = Public Construction Cost Estimation System (Taiwan construction cost database); LUC = labor unit cost (NTD/man-day); MUC = material unit cost (NTD/unit)

3.3 Local Construction Cost Database for Providing Updated Maintenance Cost Data

The unit cost data of the labor and material (or equipment) involved in a particular maintenance task performed on a particular component of a subsystem are required for the estimation of this maintenance cost. In many regions or countries, local building related cost data (in hardcopy or online) have been investigated and updated periodically. For example, the Gordian Group Inc. offers RS Means facilities maintenance cost data in the US, which are organized by using the Construction Specifications Institute's MasterFormat (Plotner, 2013). In Taiwan, the Public Construction Cost Estimation System (PCCES) is a cost estimation system developed by the government to be used by the contractors to prepare the construction cost estimation of a building project. The PCCES contains an updated construction and maintenance cost database (labor, material and equipment unit cost data) for various components of building subsystems which are given with individual MasterFormat codes.

This study suggest that the unit cost data of labor and material (or equipment) involved in four types of maintenance tasks (inspection, repair, renovation, replacement) performed on components of all subsystems be retrieved from the local construction or maintenance cost database in order to further estimate the maintenance cost of all subsystems year by year over a certain building life span (labor cost and material unit cost columns in Table 1).

3.4 Building Life Cycle Maintenance Cost Estimation Model

3.4.1 Total Building Life Cycle Maintenance Cost

To predict the total building life cycle maintenance cost over a certain life span of a building, this study proposes that the total costs of planned maintenance conducted on all ten subsystems and their components are estimated year by year, as indicated in Eq-1.

$$BLCMC_n = \sum_{i=1}^n (STRUCTURE_i + ENCLOSURE_i + INTERIOR_i + HVAC_i + POWER_i + TELECOM_i + FIRE_i + PLUMB_i + CONVEY_i + LANDSCAPE_i) \quad (Eq-1)$$

where:

BLCMC _n =	total long term maintenance cost over a <u>n-year</u> building life span
STRUCUTRE _i =	total maintenance cost of <u>structure</u> subsystem in year-i
ENCLOSURE _i =	total maintenance cost of <u>enclosure</u> subsystem in year-i
INTERIOR _i =	total maintenance cost of <u>interior</u> subsystem in year-i
HVAC _i =	total maintenance cost of <u>HVAC</u> subsystem in year-i
POWER _i =	total maintenance cost of <u>power/electrical</u> subsystem in year-i
TELECOM _i =	total maintenance cost of <u>telecommunication</u> subsystem in year-i
FIRE _i =	total maintenance cost of <u>fire safety</u> subsystem in year-i
PLUMB _i =	total maintenance cost of <u>plumbing</u> subsystem in year-i
CONVEY _i =	total maintenance cost of <u>conveying</u> subsystem in year-i
LANDSCAPE _i =	total maintenance cost of <u>landscape</u> subsystem in year-i

3.4.2 Annual Maintenance Cost of a Subsystem and its Components

To predict the annual total maintenance cost of a subsystem and its components in a particular year, this study proposes that the total costs of four major types of planned maintenance (inspection, repair, renovation and replacement) conducted on the subsystem and its components in that year are estimated. For example, to predict the total annual maintenance cost of HVAC subsystem in year-i ($HVAC_i$), the total costs of inspection, repair, renovation and replacement tasks conducted on all HVAC components in year-i can be estimated individually and added up, as indicated in Eq-2.

$$HVAC_i = H-inspect_i + H-repair_i + H-renovate_i + H-replace_i \quad (Eq-2)$$

where:

$HVAC_i$ = total cost of four types of maintenance on all HVAC components in year-i

$H-inspect_i$ = total cost of all inspection tasks conducted on all HVAC components in year-i

$H-repair_i$ = total cost of all repair tasks conducted on all HVAC components in year-i

$H-renovate_i$ = total cost of all renovation tasks conducted on all HVAC components in year-i

$H-replace_i$ = total cost of all replacement tasks conducted on all HVAC components in year-i

3.4.3 Annual Maintenance Cost of a Particular Component of a Subsystem

To predict the annual total cost of four types of planned maintenance tasks conducted on a particular component of a subsystem in a particular year, this study proposes that the monthly costs of each type of planned maintenance conducted on that component in that year are estimated and added up, as shown in Eq-3.

$$HVAC_{k,i} = \sum_{j=1}^{12} (H_k-inspect_{i,j}) + \sum_{j=1}^{12} (H_k-repair_i) + \sum_{j=1}^{12} (H_k-renovate_i) + \sum_{j=1}^{12} (H_k-replace_i) \quad (Eq-3)$$

where:

j ranges from 1 to 12, representing 12 months;

k represents the k^{th} component of the HVAC subsystem.

To further estimate the annual 'inspection' cost conducted on the k^{th} component of HVAC subsystem ($H_k-inspect_{i,j}$), the frequency of inspection and the labor and material required in year-i planned earlier can be retrieved from the FM system, and then the labor and material unit costs can be retrieved from local construction cost database, whose multiplications yield the monthly inspection costs and thus annual inspection cost. Similarly, annual 'repair', 'renovation' and 'replacement' costs for the k^{th} component of HVAC subsystem can be estimated.

By adding up the annual total maintenance costs of all components of HVAC subsystem in year-i, $HVAC_i$ can be estimated. Similarly, the annual total maintenance costs of all other subsystems can be estimated. Likewise, the annual total maintenance cost of a 'whole building' can be estimated year by year, and finally the total building life cycle maintenance cost.

4. Demonstration Case

4.1 The Subject - TBTC

The Taiwan Building Technology Center (TBTC) building is a relatively new but small building (in operation since 2011.1) located on the NTUST university campus (Figure 1). TBTC is a steel structure with a curved facade assembled from triangular punched aluminium panels, and a seven-story facility (plus B1) with a total floor area of 1,400m². It's mainly a research building with functional uses of research lab, conference room, and office. Its 'elevator' subsystem is used as a case to demonstrate how the established BLCMCP method can be used to estimate the annual maintenance costs of this subsystem and its components over a 25-year life span.

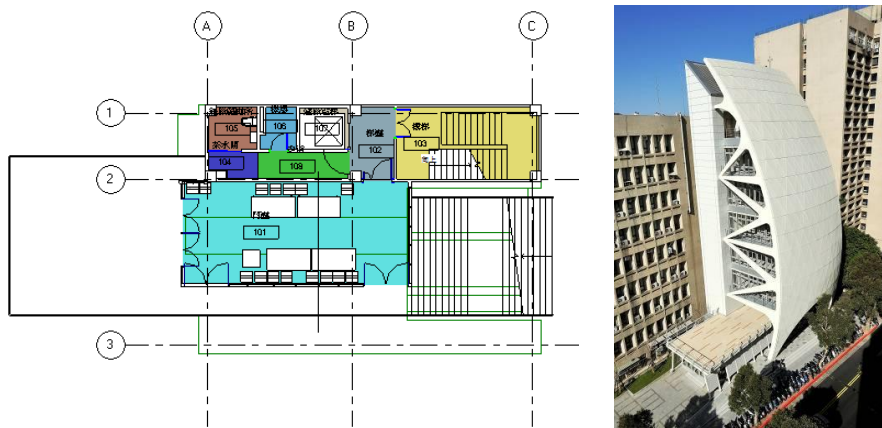


Figure 1: First floor plan and exterior view of TBTC.

4.2 The BIM Model of TBTC

Autodesk's REVIT[®] was used to build the BIM model for TBTC (Figure 2). BIM models were built for each of the ten subsystems with two levels of elements according to the decomposition structure specified in Section 3.1. Each component of a particular subsystem is given a MasterFormat code. The exemplary 'elevator' subsystem consists of four assemblies (machine, car, control and hoistway) and 18 components (Figure 2, Table 2).



Figure 2: The established BIM models of a certain floor and the elevator subsystem of TBTC.

4.3 ArchiBus^{○,R} for Maintenance Planning

Facility management software ArchiBus^{○,R} was used to establish the maintenance plans of all the components of the ten subsystems of TBTC over a 25-year life span. In the case of TBTC's elevator subsystem, the schedules or frequencies of four types of maintenance tasks to be conducted on each of the 18 components were planned year by year. Table 2 shows conceptually the maintenance schedules of all 18 components planned for 2026 (to be 16 years old). It's noteworthy that five components are scheduled to be replaced in January, 2026 (Ds in Jan. column in Table 2). Besides, the labor and material required for each type of maintenance tasks are specified by ArchiBus^{○,R}, as indicated by the MD and Mat. columns in Table 3.

Table 1: The maintenance schedules of all components of elevator subsystem planned for 2026.

Level 1 Assembly	Level 2 Component	Master Format / PCCES code	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
C1 Elevator Machine	C1-1 Prim. veloc. transducer	14210T	D	A	B	A	A	B	A	A	B	A	A	B
	C1-2 Traveling cable	14210E	A	A	B	A	A	B	A	A	B	A	A	B
	C1-3 Counterweight	14210X	D			A	B	A	B	A	B	A	B	A
C2 Car	C2-1 Elevator car	14210V		A		A		A		A		A		A
	C2-2 Door drive	14210R	D			A	A	B	A	A	A	A	A	B
	C2-3 Take gate	14210J	A	A	A	A	A	B	A	A	A	A	A	C
	C2-4 Guider rail fixing brckt	14210M	B	A	A	C	A	A	C	A	A	C	A	A
	C2-5 Elevator rail	14210U	A	A	A	A	A	A	A	A	A	A	A	C
	C2-6 Car safety System	14210N				A	A	B	A	A	B	A	A	B
	C2-7 Slide guide & oil	14211w	A	A		A	A		A	B		A	A	
	C3-1 Control system	14210c	A	A	B	A	A	B	A	A	B	A	A	B
	C3-2 Operator panel	14210L		A			A			A			A	
C3 Control	C3-3 Control cable & wiring	14210E			A		A	B		A		A	B	
	C4-1 Roller guides	14210F	D			A	A	B	A	A	B	A	A	B
	C4-2 Side guide rail	142100	D			A	A	B	A	A	B	A	A	B
C4 Hoistway	C4-3 Tension pulley	14210G	B			A	A	B	A	A	B	A	A	B
	C4-4 Car buffer	14210P	A	A	A	A	A	B	A	A	A	A	A	B
	C4-5 Counterweight buffer	14210b				A	A	A	A	A	A	A	A	A

Note: A = inspection; B = repair; C = renovation; D = replacement.

4.4 PCCES: The Maintenance Cost Database

The Public Construction Cost Estimation System (PCCES) is a local construction cost estimation system and construction cost database in Taiwan. For each component of all ten subsystems of TBTC, the labor and material unit cost data for each type of maintenance task were retrieved from PCCES according to the MasterFormat code of the component. Table 3 shows conceptually the labor and material unit cost data for each type of maintenance task retrieved from PCCES for all 18 components of the elevator subsystem.

4.5 The Building Life Cycle Maintenance Cost Prediction for TBTC

For the elevator subsystem of TBTC, the annual total cost of each type of maintenance tasks conducted on a certain component (say 'inspection') were calculated as: $CONVEY_{k-15} = \text{quantity} * INSPECT_{\text{freq}} * (INSPECT_{\text{labor}} * INSPECT_{\text{lab-unit cost}} + INSPECT_{\text{material}} * INSPECT_{\text{mat-unit cost}})$. Three other types of maintenance tasks conducted on this component were calculated similarly. Table 4 shows the monthly maintenance costs for all components of the elevator subsystem in 2026 (inflation rate not considered in this study for simplicity reason). In most of the months in 2026, periodical inspection and repair are to be conducted, resulting in 1441~2936 NTD

monthly maintenance costs; whereas five components are scheduled to be replaced in January, resulting in 238,224 NTD replacement cost. The annual total maintenance cost for elevator subsystem in 2026 is estimated to be 263,574 NTD. Figure 3 exhibits the annual and accumulated maintenance costs of TBTC's elevator subsystem over its 25-year building life span. Most of annual maintenance costs of the elevator subsystem range from 20,000~30,000 NTD and the accumulated maintenance cost over 25 years is estimated to be 1,362,415 NTD.

Similarly, the annual total maintenance costs of nine other subsystems of TBTC over 25-year life span can be estimated and added up to generate the building life cycle maintenance cost at the whole building level for TBTC.

Table 2: The labor and material required for each type of maintenance task are specified by ArchiBus and their unit cost data retrieved from PCCES for all elevator subsystem components.

Level 1 Assembly	Level 2 Component	Master Format / PCCES code	A. Inspection				B. Repair				C. Renovation				D. Replacement			
			MD	LUC	Mat	MUC	MD	LUC	Mat	MUC	MD	LUC	Mat	MUC	MD	LUC	Mat	MUC
C1 Elevator Machine	C1-1 Prim. veloc. transducer	14210T	0.013	2500	1	10	0.125	2500	0.25	4000	0.188	2500	0.2	2000	0.500	2500	1	70000
	C1-2 Traveling cable	14210E	0.038	2500	1	5	0.375	2500	0.25	800	0.188	2500	0.2	800	0.188	2500	1	80000
	C1-3 Counterweight	14210X	0.013	2500	1	5	0.250	2500	0.07	1200	0.125	2500	0.2	1200	0.125	2500	1	19000
C2 Car	C2-1 Elevator car	14210V	0.044	1800	1	15	0.025	1800	0.05	1200	0.125	1800	0.1	1200	0.250	1800	1	150000
	C2-2 Door drive	14210R	0.125	1800	1	10	0.025	1800	0.15	400	0.025	1800	0.1	400	0.063	1800	1	38000
	C2-3 Take gate	14210J	0.063	1800	1	15	0.025	1800	0.02	3600	0.031	1800	0.02	3600	0.250	1800	1	56000
	C2-4 Guider rail fixing brckt	14210M	0.125	1800	1	5	0.025	1800	0.07	1600	0.063	1800	0.1	1600	0.188	1800	1	46000
	C2-5 Elevator rail	14210U	0.063	1800	1	5	0.100	1800	0.07	3000	0.063	1800	0.1	3000	0.188	1800	1	24000
	C2-6 Car safety System	14210N	0.063	1800	1	5	0.025	1800	0.25	600	0.125	1800	0.2	600	0.125	1800	1	35000
	C2-7 Slide guide & oil	14211w	0.094	1800	1	5	0.025	1800	0.07	1500	0.031	1800	0.1	1500	0.125	1800	1	36000
C3 Control	C3-1 Control system	14210c	0.125	2500	1	15	0.313	2500	0.25	400	0.125	2500	0.2	400	0.188	2500	1	55000
	C3-2 Operator panel	14210L	0.031	1800	1	10	0.106	1800	2	240	0.031	1800	2	240	0.188	1800	1	120
	C3-3 Control cable & wiring	14210E	0.013	2500	1	5	0.188	2500	3	170	0.125	2500	2	170	0.250	2500	1	85
C4 Hoistway	C4-1 Roller guides	14210F	0.025	1800	1	5	0.025	1800	0.25	500	0.063	1800	0.2	500	0.125	1800	1	50000
	C4-2 Side guide rail	142100	0.063	1800	1	5	0.025	1800	0.25	600	0.125	1800	0.2	600	0.125	1800	1	35000
	C4-3 Tension pulley	14210G	0.025	2500	1	5	0.250	2500	0.07	4800	0.125	2500	0.1	4800	0.250	2500	1	68000
	C4-4 Car buffer	14210P	0.031	1,800	1	20	0.031	1,800	0.02	50000	0.031	1,800	0.02	50000	0.063	1800	1	25000
	C4-5 Counterweight buffer	14210b	0.050	1800	1	5	0.025	1,800	0.02	16000	0.025	1800	0.02	16000	0.063	1800	1	35000

Note: MD = man-day; LUC = labor unit cost (NTD/MD); Mat = material; MUC = material unit cost (NTD/unit).

Table 3: Monthly maintenance costs (in NTD) in 2026 for all elevator subsystem components.

Level 1 Assembly	Level 2 Component	Master Format / PCCES code	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
C1 Elevator Machine	C1-1 Prim. veloc. transducer	14210T	82469	41	366	41	41	366	41	41	366	41	41	366
	C1-2 Traveling cable	14210E	99	99	358	99	99	358	99	99	358	99	99	358
	C1-3 Counterweight	14210X	37225			36	330	36	330	36	330	36	330	36
C2 Car	C2-1 Elevator car	14210V		79		79		45		79		79		45
	C2-2 Door drive	14210R	69625			235	235	20	235	235	235	235	235	20
	C2-3 Take gate	14210J	113	113	113	113	113	50	113	113	113	113	113	41
	C2-4 Guider rail fixing brckt	14210M	198	230	230	198	230	230	198	230	230	198	230	230
	C2-5 Elevator rail	14210U	118	118	118	118	118	118	118	118	118	118	118	193
	C2-6 Car safety System	14210N				174	174	174	65	174	174	174	174	65
	C2-7 Slide guide & oil	14211w	1513	313		313	313		313	313		313	313	
C3 Control	C3-1 Control system	14210c	328	328	348	328	328	348	328	328	348	328	328	348
	C3-2 Operator panel	14210L		66			66			66			66	
	C3-3 Control cable & wiring	14210E			36		36	246		36		36	246	
C4 Hoistway	C4-1 Roller guides	14210F	20113			50	50	75	50	50	75	50	50	75
	C4-2 Side guide rail	142100	25913			118	118	80	118	118	80	118	118	80
	C4-3 Tension pulley	14210G	458			68	68	366	68	68	366	68	68	366
	C4-4 Car buffer	14210P	56	56	56	56	56	66	56	56	56	56	56	510
	C4-5 Counterweight buffer	14210b				90	90	90	90	90	90	90	90	90
.....	Total		238224	1441	1624	2113	2462	2667	2327	2139	2936	2149	2672	2822
	Annual Total							263574						

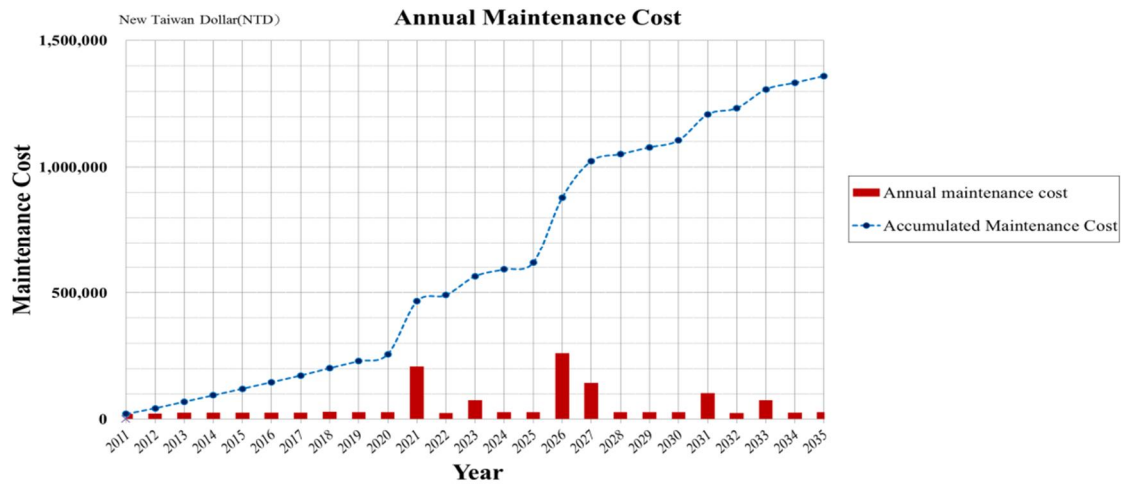


Figure 3: Annual and accumulated maintenance costs of TBTC's elevator subsystem over its 25-year building life span.

5. Conclusions

Building owners and facility managers need a method or tool to predict the maintenance costs over the life spans of their facilities in early operational phase to allocate adequate maintenance funding to sustain their facilities. Responding to this need, this study adopts and integrates existing technologies such as building information modeling (BIM), facility management system (ArchiBus[®]), and local construction and maintenance cost database (PCCES) to establish the Building Life Cycle Maintenance Cost Prediction method (BLCMCP) to predict annual maintenance costs over building life span according to a set of maintenance plans specified in early operational phase. The 'elevator' subsystem of the Taiwan Building Technology Center (TBTC) building located on the NTUST university campus is used as a case to demonstrate how the established BLCMCP method can be used to estimate the annual maintenance costs of this subsystem and its components over a 25-year life span.

This research focuses more on elaborating the concepts and the framework of the developed Building Life Cycle Maintenance Cost Prediction method (BLCMCP). The life cycle maintenance cost estimation for the exemplary elevator subsystem of TBTC was done manually in Excel. Further research effort is required to make the BLCMCP a working tool in predicting building life cycle costs. For example, building utility cost and custodial cost should be included as the major items of life cycle costs as well as the prediction methods should be researched. In addition, inflation rate should be considered when making long term cost estimations. Finally, software engineering effort is required to provide a functional system architecture, database, and user interface that integrate BIM model, FM system, and local construction and maintenance cost database so that life cycle cost estimation can be performed automatically.

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The Utilization of BMS in BIM for Facility Management

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Abstract

The emergence of BIM in the construction industry has come with promises of improving efficiency in project delivery and asset management. BIM concerns the digitization of the building project by depending on information technology capabilities already achieved in various professional domains associated with different stages of the building life cycle. While the utilisation of BIM in the various professional domains and project stages is increasing, research suggests that the building operation and management stage is being left behind. Exploring BIM applications that encompass the building operation are therefore important to improve efficiency during use and coordination with other stages in the project life cycle. As such a framework for utilizing feedback loops on building energy consumption to inform and improve design and facility management in a BIM environment is proposed. In this paper, the authors present the prototype from the implementation of the framework which is interfaced with a BIM-enabled tool. The paper concludes that the framework is useful in contributing to bridging existing gaps between the design, construction and operation phases of a building's life-cycle.

Keywords: BIM, data acquisition, facility management, energy consumption

1. Introduction

A considerable amount of research has been conducted on digitizing the various aspects of a typical building project since the advent of building information modelling (BIM). Most of these efforts leverage on the BIM/computer-aided capabilities already achieved in the various professional domains associated with the different stages of the building life cycle. The overall aim is to provide consistent digital information that can be reused by stakeholders throughout the building life cycle (Eastman et al., 2008; Arayici et al., 2012). It is predicted that BIM will help to drastically reduce errors, fast-track project delivery time and save implementation costs, as well as assisting with asset management. Benefits in the latter sphere can only be accrued if feedback loops can be established so that the information in a BIM is used to inform future design of similar buildings and facilities management. This paper illustrates how such feedback loops can be established by incorporating building management system (BMS) data into BIM to inform the designer and the facility manager.

Section 2 provides a background on the role of data acquisition in facility management integration with BIM. The challenges associated with the utilization of acquired data from building management system are presented in Section 3. The proposed framework is discussed in Section 4 before presenting a test-case of the prototype from the framework implementation in Section 5. Section 6 concludes the paper.

1.1 Research Problem

The existing multi-disciplinary nature of the construction industry offers advantages entrenched in the division of labour. However, it presents challenges such as the lack of interoperability between IT tools used by different professionals resulting in barriers to seamless information exchange. One aspect that is common in these different domains is design specifications, where materials are specified for production/construction according to anticipated performance mainly based on laboratory tests in order to meet the relevant standards. In this context, the design stage offers the best opportunity to influence cost and sustainability through design specification (Ding, 2008; Kohler and Moffatt, 2003). However, professional domains have not sufficiently explored even this clear opportunity (Wang et al., 2013; Oti and Tizani, 2015). Concerning the area of facility management (FM), BIM deficiencies are partly due to the fact that projects are being delivered with little or no considerations for FM integration unless a Client specifically requires this to be done. FM is particularly peculiar as it covers the building operation stage when the performances of all facilities in the building are tested against the building as designed. In addition, the efficient management and integration of resources in the form of people, places, processes and technology are panaceas to ensuring optimum functionality of the built environment. Thus, the facility manager is confronted with location of the property/project, type of facility vis-à-vis users, quantity of workspace and associated requirements, quality and performance of workspace, and the impacts of content layout and space allocation on work performance (Tay and Ooi, 2001). The advent of BIM promises to greatly lighten up the seeming complexities inherent in the tasks assigned to the facility manager as well as other professionals. Despite this potential, the results from a recent survey (Becerik-Gerber et al., 2011) in the USA suggests that the operation and management stage appears to be the least explored, compared to design and construction, in adopting BIM applications to execute requisite project tasks. By implication, the process of leveraging on BIM to close up the feedback loop of learning from best practice examples inherent in the project life cycle stages is equally at the lowest ebb. As the scope of

BIM application gradually expands, there is therefore the need to learn from performance histories of projects via feedback loops to the appropriate stages in the project life cycle.

1.2 Research methodology

Review of literature has been carried out to establish research gaps and further employed to ascertain appropriate methodologies for achieving the aim of this research. The review covered aspects relating the modelling of building energy consumption histories from building energy management systems and areas such as BIM enabling systems, building design and construction and facility management. This helped in identifying research gaps associated with modelling building performance feedback to BIM and possible process options for such communication. The Rapid Application Development (RAD) information modelling approach (Maner, 1997) was used to develop and implement a framework for utilizing performance histories in BIM and facility management. The RAD methodology employs cycles of re-specify, re-design and re-evaluate on the prototype system from its conception to when it achieves a high degree of fidelity and completeness. The prototyping process is therefore characterized by increased speed of development and experiences of series of births rather than deadlines. It informed the implementation of the prototype which entailed the interfacing of a BIM-enabled tool with object oriented representation of information in a contemporary computer programming language.

2. Data acquisition in FM and integration with BIM

There exist potential areas for BIM application in facility management where feedback can be useful. Some areas already identified by Becerik-Gerber et al (2011) include locating building components, facilitating real-time data access, visualization and marketing, considering ease of maintenance, creating and updating digital assets, space management, planning and feasibility studies for noncapital construction, emergency management, controlling and monitoring energy, and personnel training and development. While the modalities of BIM implementation may differ in all these areas, what will perhaps be common to all is the process of harnessing feedback from the model to inform and improve asset performance. This process will require more than just engaging the facility manager in the design stage as suggested in Wang et al (2013). It will require careful planning, mapping and integration of the facility management operations into the BIM approach, including the operations data acquisition, analysis and management strategy. This research stems from this premise. Its aim is to present a framework focused on the integration of energy performance data as an option in BIM implementation.

Energy consumption in the building operation stage is higher than other life cycle stages (Clarke et al., 2008). Obviously, one of the reasons behind such high energy consumption is the cumulative consumption over the long building life-cycle, usually in decades. It is therefore important that efforts are directed towards keeping energy consumption at a very low level during the operation of the building. This requires active participation of facilities management personnel in decision making regarding regular building operation and maintenance tasks. As such facility management personnel need to be better informed about the performance of building systems. A means for enhancing informed decision making and effective management of facilities is through context sensing and data capture from applications or entities in the building (Taneja et al., 2010). Context sensing operations

may cover the monitoring of information on the environmental state, behaviour and situation of an application or a device (Dey, 2001).

The use of building energy consumption data to improve the design and operation of buildings is an active area of research. This process has been commonly called building energy management system (BEMS) or simply building management system (BMS). It is concerned with the active control of energy-dependent systems in the operation phase of the building (Doukas et al., 2007). The technological advances in BIM offer opportunities to integrate BMS data. This area needs to be fully explored. The existing gaps in linking BMS data to BIM has been noted for contributing to the inconsistencies in graphical energy data generated from manual input of repetitive energy management system data (Becerik-Gerber et al., 2011). It is therefore necessary to integrate data acquisition systems into BIM to facilitate real-time monitoring and automated control of building facilities.

2.1 Approaches to the integration of BMS data to BIM

A key goal of this paper is to facilitate the understanding of how BMS data can be analysed to inform design iterations taking advantage of technological trends of using BIM. This encompasses identifying how to provide feedback loops from the building in-use to successive design iterations of proposed building projects. The integration of facility management with BIM that particularly relates to the aim of this paper has two basic approaches to linking BMS data to BIM. The approaches include (1) BIM – Energy Analysis Tool – BMS link and (2) BIM – Energy Consumption Viewer Plugin link.

• BIM – Energy Analysis Tool – BMS Link

In this approach (Figure 1), it is envisaged that BMS data can be sent to Energy Analysis tools to carry out requisite analysis before feeding the outputs to building models in a BIM-enabled tool. This approach can take advantage of database management systems, open file formats and common data environments. The linking of DAT to Onuma Planning Systems (Ozturk et al., 2012) falls into this approach. It is also possible to have the Energy Analysis Tool in a single module with BIM tool or integrated with BMS data collection. For example Autodesk Project Dasher, as a visualization tool, can overlay BMS data on 3D BIM for the monitoring of historical and real-time analysis of building performance data (Attar et al., 2010; Khan and Hornbæk, 2011). In a BIM environment, meaningful visualisation of energy consumption profiles becomes possible which can aid the quick understanding of non-experts including occupants and so may influence their behaviours.

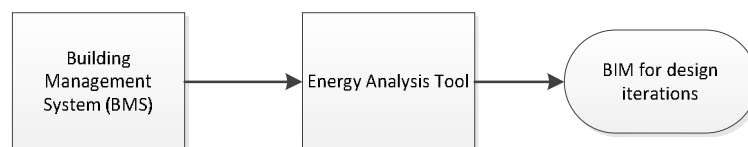


Figure 1: BIM - Energy Analysis Tool Link

• BIM – Energy Consumption Viewer Plugin Link

Here, a BIM tool is bolted with an external application such as Energy Consumption Plugin to enable the viewing of energy consumption profiles of buildings (Figure 2). A plugin is an external

application which can be continuously improved in sophistication through computer programming. Refined BMS data is uploaded into the plugin linked to a BIM-enabled tool through associated application programming interface (API). Depending on the sophistication of the plugin, aspects of consumption data analysis could also be carried in the plugin environment. The result is addition of a new external tool to the BIM environment that can be called up for the visual presentation of historical energy performance to ease understanding of non-experts such as building occupants. For our research, this approach offers us a flexible way to input refined BMS data into the prototype system for display in a BIM environment that is beneficial to standardized building designs.

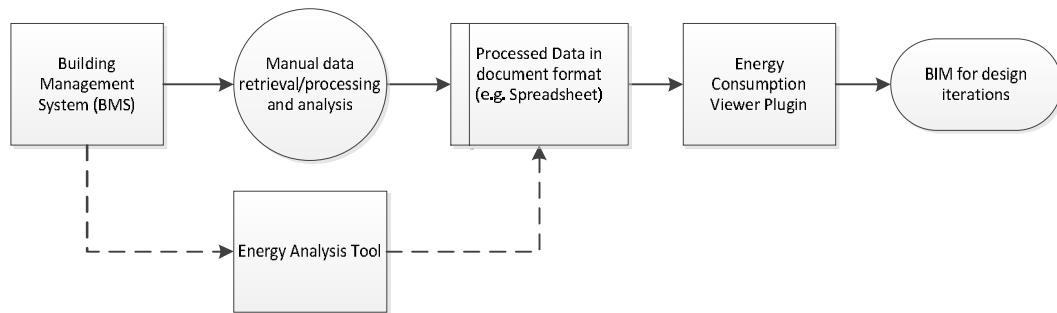


Figure 2: BIM - Energy Viewer Plugin Link

3. Challenges in the use of BMS data

The technological advances made in the development of building data acquisition systems are well acknowledged (Taneja et al., 2010; Becerik-Gerber et al., 2011; Ozturk et al., 2012). However, there have been challenges in utilizing such data to meaningfully inform and improve subsequent project design and delivery. The Big Data syndrome is also associated with the streaming of data from such acquisition systems (Olsson et al., 2015). More often than not, data collected from acquisition systems grow very large in size and is too unstructured to put to immediate beneficial use without some form of structuring and analysis. Thus, the technological advances in BIM offer opportunities to overcome a number of these challenges by integrating BMS data and learning from energy performance data as feedback to various building life cycle stages.

One obvious objective of measuring building energy consumption such as through BMS is to ascertain how the building performs in use. It also helps in determining what the user needs to pay for the services provided. Besides the collective responsibility to reduce environmental pollution, “the polluter pays” approach (Owen, 2006; Bürger et al., 2008) has been a major driver compelling energy consumers to explore avenues to reduce their quotas of pollution arising from energy use. The monitoring and acquisition of energy consumption over a period provide opportunities for strategising various means to achieving reductions in costs that accrue from energy bills. This is especially important as energy is used for a wide range of activity categories including air conditioning and heating, heating and pumping of water, lighting, powering of ICT, and the plethora of personal electronic devices etc. Ascertaining the various proportions of consumption attributed to these categories could be beneficial. BIM-BMS linkage may prove useful for the facility manager in achieving desired energy consumption reductions. Such linkage will provide opportunity for harnessing feedback from the model to inform and improve asset performance and vice versa. It will

entail careful planning, mapping and integration of the facility management operations into the BIM approach. This includes the use of BMS to improve the design and operation of buildings concerned with the active control of energy-dependent systems (Doukas et al., 2007). Research suggest that the existing gaps in linking BMS data to BIM are contributory to the inconsistencies in graphical energy data generated from manual data input of repetitive energy management systems (Becerik-Gerber et al., 2011).

4. Proposed framework for utilizing data from BMS in BIM

Figure 3 summarises the overall research context. It shows the proposed schematic framework of the BIM implementation process to improve building design. As illustrated in the figure, existing drawings, textual information and specification are reproduced as BIM generic systems which can be combined with various site models. These combinations can then be further tailored as site – specific building information models for building construction and operation purposes. These processes produce progressive as-designed BIM, as-built BIM and the live BIM which are used for actual building construction operations and the building operation. They also serve as channels to supply feedback information as a learning process to Model Preparation stage for the development of the generic building design model. Also highlighted in Figure 3 is the aspect of BIM - BMS data interaction for which the BIM - Energy Viewer Plugin Link proposed. This achieves the requirement of users (designers) being able to graphically visualize and compare energy consumption histories of completed buildings in BIM environments. Also such system should allow appreciable degree of flexibility in configuring the input of data from BMS. Lastly, the linkage system should leverage on automating the process of entering BMS data into the system.

5. Case illustration of framework implementation

The framework of data acquisition utilization in BIM is implemented using a prototype as a demonstration of proof concept. The technicality involved in developing the prototype is briefly explained in this section including a scenario of using the prototype in a real- life project.

5.1 Description of prototype for data acquisition utilization in BIM

The approach adopted in developing the prototype for data acquisition utilization in BIM is the BIM – Energy Consumption Viewer Plugin Link. The BIM platform used in developing the prototype for data acquisition utilization is Revit 2014. The prototype can be configured to work in Revit 2015 or new versions to come. The implementation of the prototype system was carried out in C# using .NET and linked to the BIM enabled software (Revit 2015). The prototype plugin can be accessed via the external tools link in Revit 2014 IDE. It functions as an extension of plugin application of the earlier research work on the sustainability appraisal of structural steel framed building (Oti and Tizani, 2015).

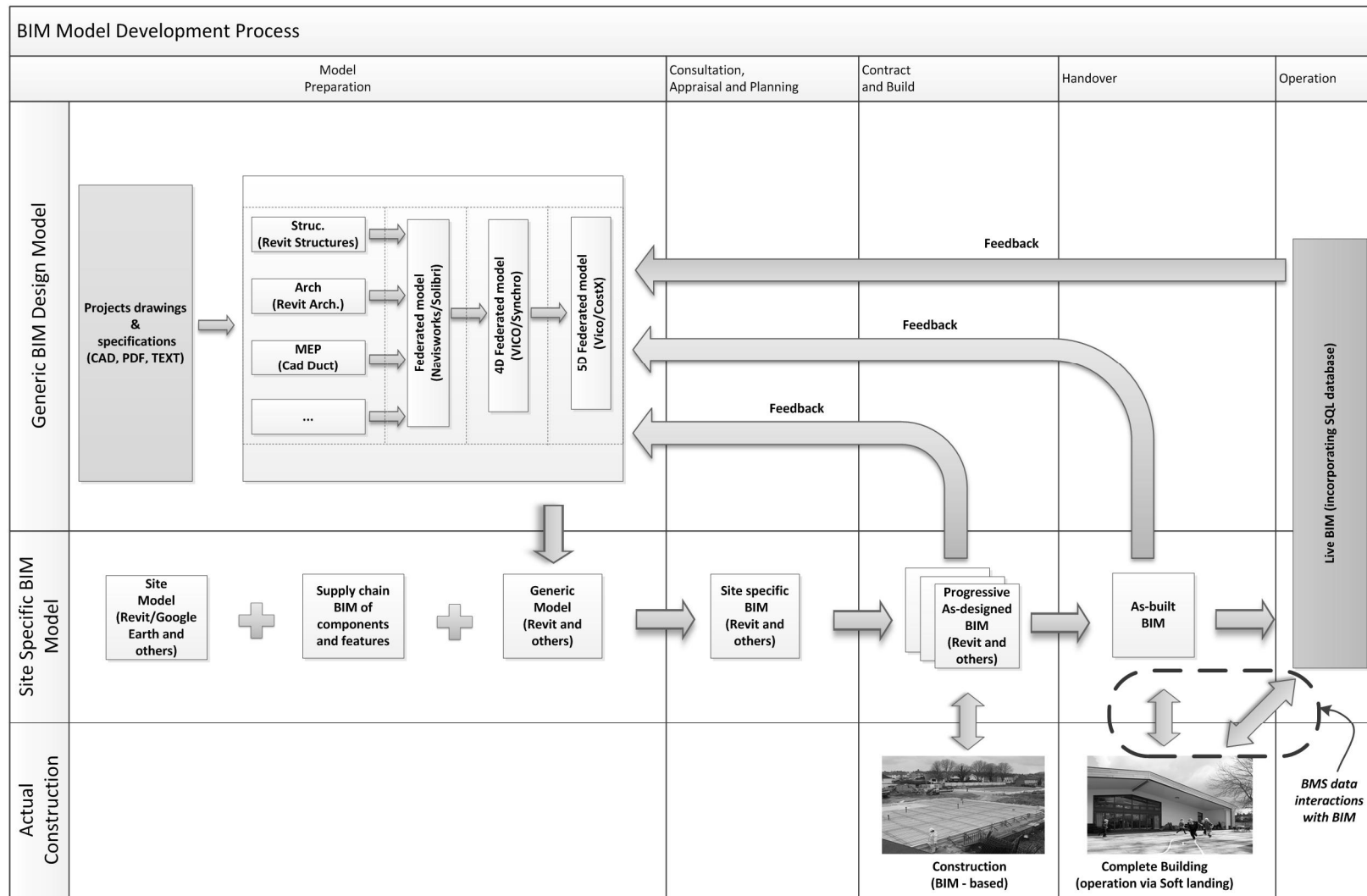


Figure 3: Framework for using BIM to improve the project delivery process

The prototype has been developed through the iterative testing of system components following the RAD approach. It leverages on the characteristic increased speed of development and progressive system refinement to achieve early usability. The flowchart illustrating the actions and processes captured in the prototype system is given by Figure 4. The programme is called through the Energy Use History option of the sustainability Estimation Programme from a BIM enabled environment. On the selection of the project (by name) to examine, the type of information to further explore can then be specified. This offers the option of comparing Design benchmarks and Actual Consumption records or examining various energy consumption categories. These information records are extracted by the system from spreadsheets saved in the various project names and containing pre-defined data. The consumption categories can be examined for a single project or a combination of projects. The intention of such combination is to compare and contrast trends of the same consumption categories of different projects. The system then displays corresponding output charts; from this point, reports can be produced. The user can switch back and forth different projects and consumption categories or quit the programme.

The prototype accesses design data and processed BMS (energy consumption) data saved in MS Excel file formats and expresses abstracted information on energy consumption in terms of 'Design' and 'Actual' for buildings. These values are compared at various levels of granularity to investigate wastes and encourage the use of appropriate measures to reduce consumption levels and save costs. At the moment, the input data into the plugin need to be provided in Excel file format which requires manual processing of the BMS data. However, there is a possibility that this function of processing BMS data and saving in Excel Format can be done by an appropriate Energy Analysis Tools if available.

5.2 Test case of using the prototype

Three projects have been used to illustrate the testing of the prototype. The data from one (Oakfield Project) of the projects have been obtained from a collaborative research project platform on low impact school procurement. The data from the other two projects were generated as a variant of the Oakfield project in order to demonstrate the operation of the prototype. The Oakfield Project is a primary school building in the UK completed and opened for use in October 2012 with a data acquisition system in place and running. Energy consumption levels have been collected and processed in spreadsheets serving as ready input for the prototype. The relevant information were extracted from the spreadsheet and recorded in formats for easy abstraction by the prototype. Since the prototype can be called in a BIM-enabled environment, the operation history of consumption levels and design benchmarks of buildings can be compared.

Figures 5 and 6 show alternative chart views of the design and actual energy consumption figures of the Oakfield project from November 2012 to February 2014. Similar charts can be obtained for the other listed projects. Thus, project information need to be entered in prescribed Excel format and loaded into the prototype to appear in the list of Project and Analysis listBox. The advantage of these charts to designers is that they will help to provide opportunity for quick

review of design and performance benchmarks for more critical examination and analysis where required. For example, the designers' attention may be drawn to the Heating, Hot water and ICT sub-consumption category for further investigation if the respective charts reveal some unexpected outputs. The plug-in neither extracts data from nor feeds data/information to BIM objects but serves as a visualisation tool for historical building energy performance as a starting point. Further, the prototype can compare information on energy costs for design and actual consumption of projects. This can be done for any of the listed projects and also compared on project basis. These charts and the underlying data can be viewed and printed for hard copy recording.

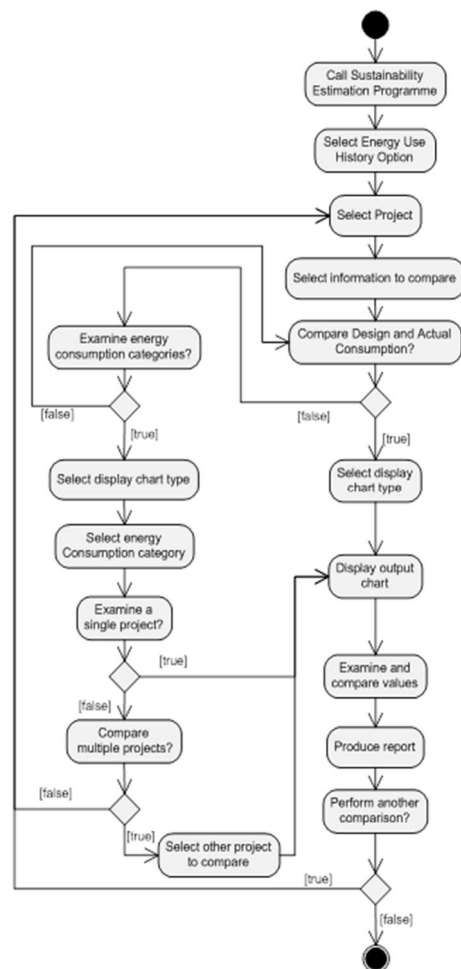


Figure 4: Prototype implementation flowchart

6. Conclusion

One aspect of concern in the emerging BIM applications is how to influence overall project costs and improve sustainable construction practices right from the planning and design stages. This requires the integration of existing work stages and processes into BIM. The incorporation

of FM issues into BIM have seen the least patronage even though it is one of the key stages where all the outputs of the concerted efforts of planning, design and construction of the building is put to test by use. There is the existing gap of how outcomes from such tests are fed back to the planning, design and construction processes to contribute to improving the overall project delivery.

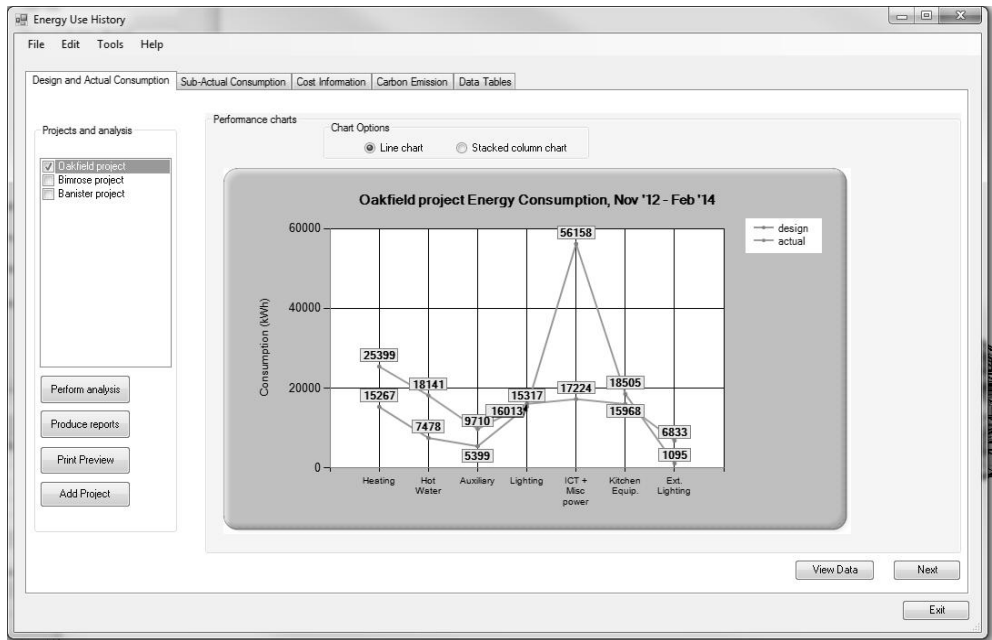


Figure 5: Comparison of Oakfield project design and actual (line chart)

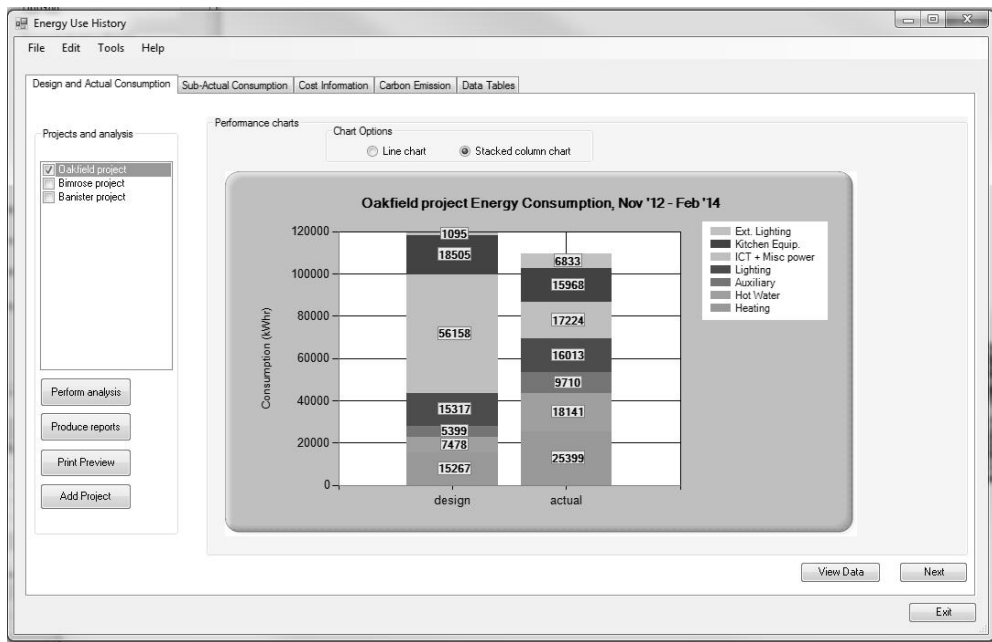


Figure 6: Oakfield project design and actual stacked column comparison

We therefore proposed a BIM-BMS data linkage plugin as feedback to enable designers learn from building energy performance histories. Thus, current energy analysis and design tools utilize conceptual design information such as volumetric and spatial data. These tools are lacking in achieving the aim of establishing requisite feedback of performance histories to BIM. Thus, it is difficult to input raw or refined BMS data in these tools for the purposes of analysis and linking such data back to a building information model. The reason are that (i) large volume of data will usually be involved, (ii) the process of entering data into such tools lack flexibility and (iii) facility management tools do not carry out energy design and analysis at the early project phases but have the capability of capturing and reporting data generated in the field or during building operation. In this paper we detailed the approach to meeting the requirement of utilizing sensing and automated data acquisition technologies (BMS data) in building information models (BIM). Also, we identified available approaches for integrating BMS data to BIM and described the adopted approach of using plugins. The work described a framework that utilizes feedback loops on building energy consumption to inform and improve design and facility management to explore adequate building digitization. The demonstrated approach including the process flow chart and information representations utilized in this work are useful in bridging existing gaps of harnessing historical data from the building operation phase to assist in building information modelling and design.

Acknowledgement

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The Role of Live Energy Modeling in the Integrated Design Process

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Abstract

The integrated design (ID) process has received numerous endorsements across many disciplines as an effective way to design and build more sustainably. Countless reports, papers, journal articles and lectures have demonstrated the many benefits inherent to the ID process; however, rarely do these accolades provide concrete numbers. Energy modeling is becoming common practice, especially for buildings seeking green certifications or improved performance. However, energy modeling is often done too late in the process, after nearly all design decisions have been made. As a result, the process of modeling after design negates the possible benefits and does little to improve the energy performance of the building. Energy modeling professionals have the capacity to provide concrete predicted energy use numbers throughout the design process that can lead to informed design decisions.

This research outlines how to effectively utilize the ID process in order to build a more sustainable building. Additionally, it looks at the role of live energy modeling during the ID process and identifies the benefits of providing design teams with predicated energy use information early in the design process.

The purpose of this research is to identify the benefits of interactive live energy modeling during the ID process over the use of energy modeling simply to show code compliance. The research consists of a comparative analysis using case studies, data analysis and expert interviews with energy modeling professionals. This research demonstrates how the use of live energy modeling within the context of an ID charrette can reduce the predicted energy use of new schools.

Keywords: Integrated Design, Live Energy Modeling, Energy Conservation Measures, ID Charrette, Case Study

1. Introduction

In his book *Sustainable Energy – Without the Hot Air* author David MacKay outlines the need for ‘numbers, not adjectives’ when it comes to our conversations about energy efficiency. He writes,

“In public debates, people just say ‘Nuclear is a money pit’ or ‘we have a huge amount of wave and wind.’ The trouble with this sort of language is that it’s not sufficient to know that something is huge: we need to know how the one ‘huge’ compares with another ‘huge,’ namely our huge energy consumption. To make this comparison, we need numbers, not adjectives (MacKay 2009, p.3).

We often look for the ‘silver bullet’ or ‘low hanging fruit’ that will dramatically improve the energy performance of our buildings. But in order for us to come up with effective solutions, we need numbers on which to base our decisions and not mere adjectives. Energy modeling is one tool that provides designers with numbers to demonstrate building performance though it can be utilized in many different ways.

The purpose of this research is to identify the benefits of interactive live energy modeling during the integrated design (ID) process, over the use of energy modeling simply to show code compliance. The research consists of a comparative analysis using case studies, data analysis and expert interviews with energy modeling professionals. The quantitative methods include case studies and data analysis, while the qualitative methods include expert interviews with energy modeling professionals. This research demonstrates how the use of live energy modeling within the context of an ID charrette can reduce the predicted energy use of new schools.

Additionally, this research establishes a road map for future design teams looking to effectively design and build more sustainable K-12 schools. This research focuses on schools in particular because they are often owner-occupied and directly concerned with operating costs. By focusing on schools that have utilized energy modeling during the early design stages, specifically during ID charrettes, and comparing the predicted energy use results and various modeling inputs with schools that did not participate in charrettes, this research will show the tangible benefits of live energy modeling.

2. Integrated Design and Live Energy Modeling

In order to gain a better understanding of the relationship between integrated design and live energy modeling, below an overview of the ID process is outlined along with how it benefits the design process.

2.1 Overview of the Integrative Design Process

The design and construction industry has long struggled with being efficient, collaborative and cost effective (Latham 1997; Gallaher et al. 2004). These drawbacks have made it challenging to produce high performance buildings that meet the needs of the occupants and the environment. Over the years, a number of approaches have been developed to address these drawbacks such as “Building Information Modeling” or “Integrated Project Delivery,” yet these approaches still lack the holistic methods inherent in an ID process (Owen et al. 2010).

In 2001, the [British Columbia Green Building Roundtable](#), comprised of public sector and non-profit organizations in the province of British Columbia, Canada, came together to develop a “Roadmap for the Integrated Design Process.” This roundtable led to a number of publications and reports designed to advance green building principles and practices across the sector. One of the early roundtable reports established a working definition of the ID Process, which is described as:

[a] method for realizing high performance buildings that contribute to sustainable communities. It is a collaborative process that focuses on the design, construction, operation and occupancy of a building over its complete life-cycle. The ID Process is designed to allow the client and other stakeholders to develop and realize clearly defined and challenging functional, environmental and economic goals and objectives. The ID Process requires a multi-disciplinary design team that includes or acquires the skills required to address all design issues following the objectives. The ID Process proceeds from whole building system strategies, working through increasing levels of specificity, to realize more optimally integrated solutions (BC Green Building Roundtable, 2007).

Excerpt from “The Integrated Design Process: Report on a National Workshop” held in Toronto in October, 2001.

We are still designing buildings the way we have for decades, but the ID process offers a more sustainable building by design as evident from the definition above. In order to have a clearer understanding of what the ID process is, it is important to recognize how it differs from conventional design. Table 1 outlines the primary difference between a conventional design process and an integrated design process. The simplest way to understand the difference is to think of conventional design as **linear** and integrated design as **iterative**.

Table 1: Integrated Design Process vs. Conventional Design Process

Integrated Design Process	Conventional Design Process
Inclusive	Involves team members only when necessary
Front-Loaded	Less time and energy early on
Decisions made by team	More decisions made by fewer people
Iterative	Linear
Whole-system Thinking	Systems considered in isolation
Allows for full optimization	Constrained optimization
Seeks synergies	Few opportunity for synergies
Full life-cycle costing	Emphasis on up-front costs
Process continues post-occupancy	Process ends with construction completion

There is nothing exceptionally revolutionary about the ID process, rather it benefits from a holistic and principled approach that can lead to a better built building. By combining a set of attitudes, principles and strategies, the ID process can result in more sustainable buildings (BC Green Building Roundtable 2007). These attitudes and principles set the tone for the project and allow for the creation of measurable goals.

3. Types of Modeling Processes

For this research, two types of modeling processes were identified and formalized based on the first author's professional experience and familiarity in Canadian K-12 energy modeling requirements. These modeling processes are *compliance modeling* and *integrated design*. Together they form the energy modeling processes that establish a framework for the selection and analysis of case studies. In mapping out the two processes, key factors contributing to the design processes and energy performance outcomes emerged and allowed for comparisons and conclusions to be drawn.

3.1 Compliance Modeling Process

The first process identified is a *compliance modeling* process. For the purpose of this research, the compliance modeling process is defined as: energy modeling completed using Issued for Construction (IFC) drawings and specifications with the modeling team having had no input during the design stages of the

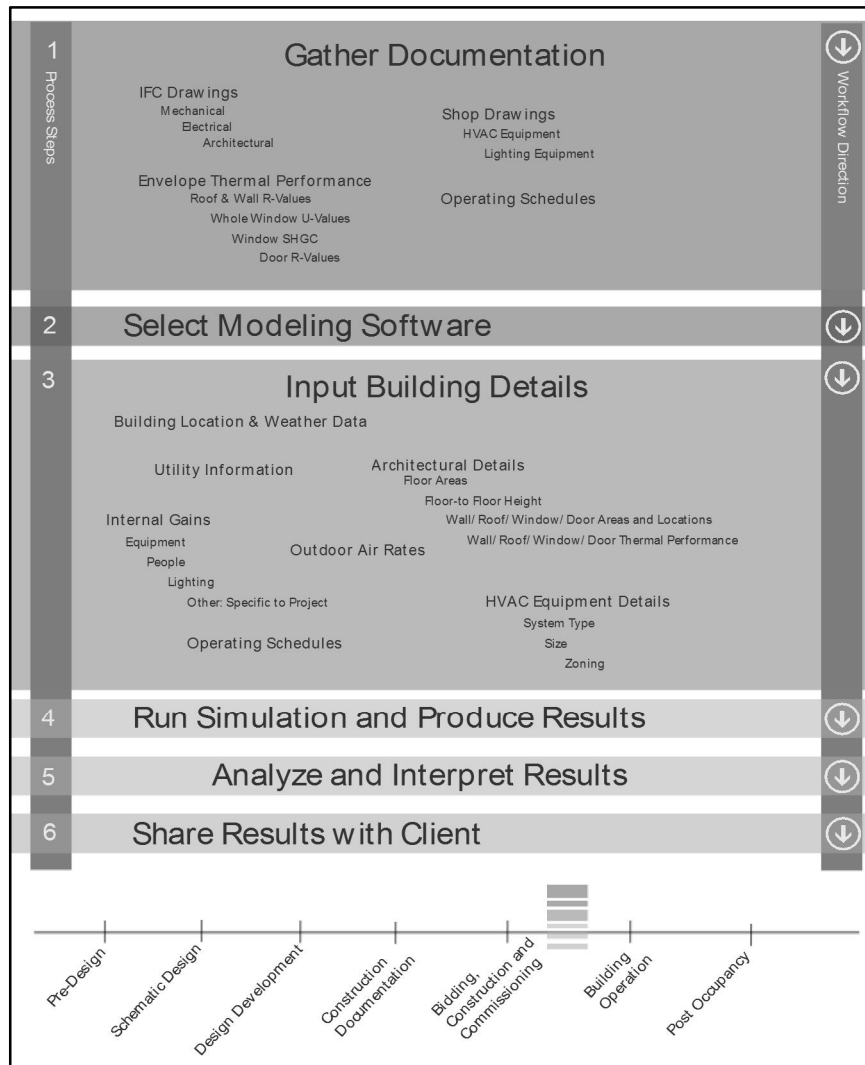


Figure 1: Compliance Modeling Process

project. During the compliance modeling process, an energy model that includes predicated energy use and energy cost numbers is produced; the results are often used to indicate if the building complies with specific requirements such as building code, LEED, or other industry standards. The steps of the process are visually represented in Figure 1 below.

3.2 ID Charrette Modeling Process

The second process was modeled using an *integrated design (ID) charrette modeling* process. For the purpose of this research, an ID charrette modeling process is defined as: energy modeling that takes place live during an ID charrette where design team members are present and are provided with energy use results based on the discussion and suggestions made during the actual charrette. During an ID charrette modeling process, an energy model that includes predicated energy use and a number of discussed Energy Conservation Measures (ECMs) is produced; the results are often used to indicate if the building achieves established energy performance goals. The steps of the process are listed below and a visual representation can be found in Figure 2.

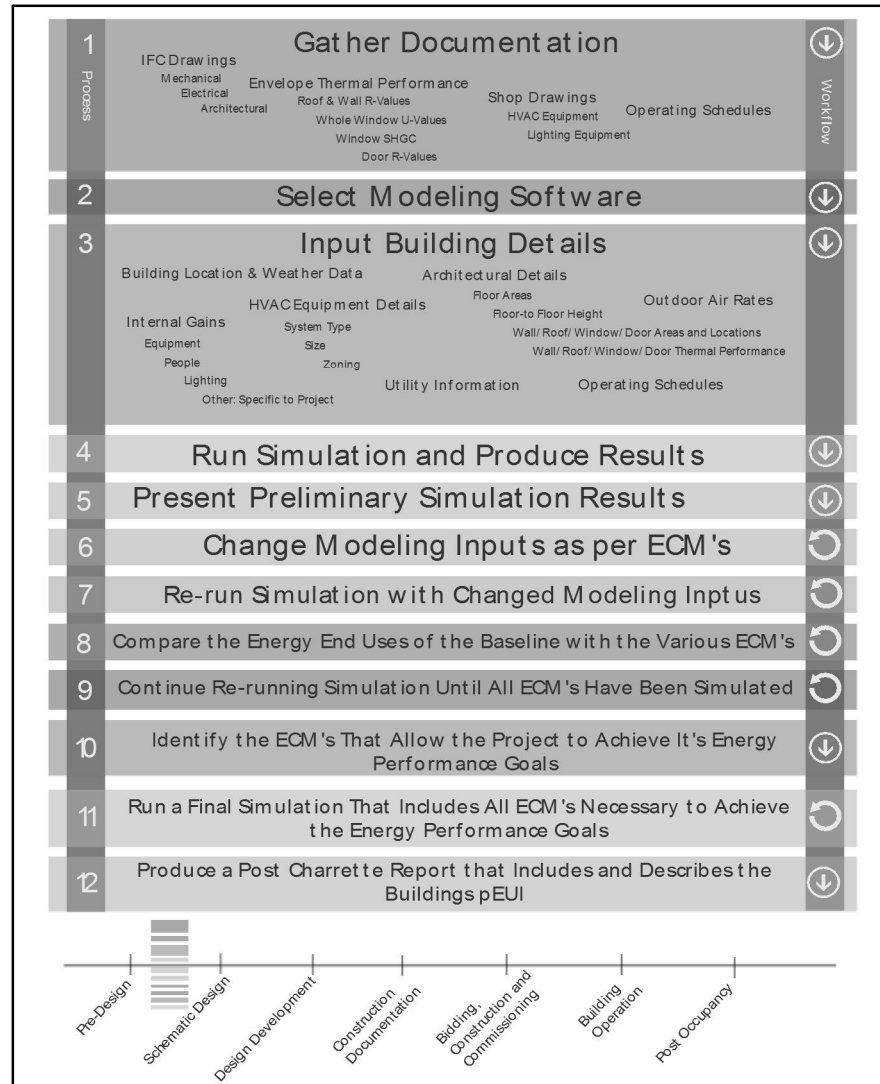


Figure 2: ID Charrette Modeling Process

4. Case Studies Analysis

Buildings utilizing the ID process should use energy simulation early and often. This provides the design team with the necessary information and adequate time to make informed energy related design decisions. The purpose of this research is to demonstrate how the use of live energy modeling can lead to predicted energy savings in new K-12 schools. As such, the following six case studies were analyzed in order to identify the different variables that lead to improved energy performance. All six schools are located in Eastern Ontario, Canada and are publically funded. All Ontario publically funded schools are subject to the same funding formula used to determine the schools operating budget and construction budgets for new builds. Since all six schools are proposed new builds, they are subject to the same funding formula, which in turn means no school within the data set has a budgetary advantage. Schools A1, A2 and A3 serve as the compliance modeling data set, while schools B1, B2 and B3 serve as the ID Charrette modeling data set. The model inputs and energy performance results can be seen in Table 2.

4.1 Case Study Results

Drawing causation conclusions based on an analysis of the case study results is very difficult. The modeling results (energy end use and performance) for each school are the result of a single simulation, as isolating the impact of a single variable (model input) is nearly impossible because there is no point of reference. However, comparing the modeling results of each school helps identify trends, which are further explained through the expert interviews. A more accurate picture emerges only when the quantitative data (modeling inputs) is examined next to the qualitative data (interview findings).

The analysis of the case studies revealed that the ID charrette modeling schools use 58% less energy than the compliance modeling schools, on average. Additionally, the ID charrette schools have an average Predicted Energy Use Intensity (pEUI) that is 11.1 ekWh/ft²/yr less than compliance modeled schools. A deeper analysis of the modeling inputs helps identify what impacts these predicted energy savings, but it does not tell the whole story. No individual variable or modeling input alone can be linked to the significant reduction in predicted energy use, however, averaging each input and comparing them between the two data sets tells a different story.

In nearly every case, the average input variables for the ID charrette modeling schools are better than the compliance modeling schools; however, in a few cases the reverse is true. Focusing only on the averages for each input is deceiving since the averages are not generalized; it is important to drill down on some of the outliers in order to better understand how these two data sets compare. For example, the compliance modeling schools average glazing U-value is 0.36 verses 0.38 for the ID charrette schools; the poorer glazing performance for the ID charrette modeling schools is directly due to the fact that school B1 has a U-value of 0.44 and pushes the average down to 0.38. Looking a bit closer at all the inputs for school B1 shows that the design is not particularly high performing. The primary energy savings measure for school B1 is its outside air rate of 0.16 cfm/ft², which is significantly less then all of the other schools. School B1 has a much lower outside air rate partially because it was a discussion topic during the ID charrette and the design team was able to test assumptions and develop a design that specifically addressed the schools needs. Comparing the average values for each input is important, however, understanding the differences and strengths of the two modeling processes is equally important.

Table 2: Case Study Model Inputs and Results

Project Details	A1	A2	A3	B1	B2	B3
Location	Kingston	Cornwall	Ottawa	Ottawa	Ottawa	Ottawa
Climate Zone	6A	6	6A	6A	6A	6A
Modelling Software	IES-VE 2014	IES-VE 2014	EE4	eQuest	eQuest	eQuest
Weather file	CAN_ON_Ottawa.CWEC	CAN_ON_Ottawa.CWEC	CWEC\Ottawa.bin	CWEC\Ottawa.bin	CWEC\Ottawa.bin	CWEC\Ottawa.bin
Total Building Area (ft²)	56,474	50,600	44,014	58,477	36,201	48,074
Number of Storeys	1	1	1	2	2	1
General Building Characteristics						
Insulation Values						
Roof (average weighted R-value)	R-30	R-30	R-25	R-37	R-37	R-47
Walls (average weighted R-value)	R-20	R-23	R-18.5	R-17	R-27	R-20
Windows						
Window-to-Wall Ratio	16%	9%	13%	19%	12%	5%
Frame type	Aluminum	Aluminum	Aluminum	N/A	N/A	N/A
Glazing type	Double Pane - Air filled	Double Pane - Air filled	Double Pane - Air filled	N/A	N/A	N/A
Glazing U-value	0.36	0.36	0.35	0.44	0.33	0.36
Glazing SHGC	0.40	0.40	0.30	0.40	0.42	0.54
Lighting Power Density (W/ft²)						
	1.17	1.24	0.86	0.89	0.66	0.61
Misc. Equipment (W/ft²)						
	0.90	0.86	0.46	0.28	0.32	0.30
Outdoor Air Rate (CFM/ft²)						
	0.63	0.31	0.29	0.16	0.32	0.29
Operating Schedule						
Weekdays	7am-6pm	7am-5pm	7am-10pm	8am-4pm +	7am-6pm	8am-4pm +
Weekends	Closed	10am-1pm Sat	Closed	Closed	Closed	Closed
Holidays	Closed	Closed	Closed	Closed	Closed	Closed
System Set Points						
Heating (degrees F)	70	70	70	72	72	72
Cooling (degree F)	75	75	74	75	75	75
Mechanical Equipment						
Heating Plant	HE gas-fired boilers	HE gas-fired boilers	gas-fired boilers	Condensing HW Boiler	Condensing HW Boiler	gas-fired boilers
Heating Plant Efficiency	91%	91%	80%	91%	93%	85%
Cooling Plant	DX office, CW Vent	Chilled Water	DX Cooling	DX Cooling	Chilled Water	DX Cooling
Ventilation Heat Recovery	60%	60%	60%	60%	88%	75%
Energy End Use						
Lighting (kWh/year)	187,235	177,537	123,617	135,342	88,989	62,090
Space Heating (ekWh/year)	475,173	569,027	558,593	224,702	87,959	200,881
Space Cooling (kWh/year)	85,188	50,788	27,461	11,076	28,151	9,793
Pumps (kWh/year)	3,266	4,171	7,473	3,956	10,642	2,740
Heat Rejection (kWh/year)	21,167	10,298	0	0	0	0
Fans (kWh/year)	80,188	65,736	168,252	125,920	60,329	68,112
Misc. Equipment (kWh/year)	140,123	122,182	82,294	43,380	41,242	34,421
Energy Performance						
Annual Electrical Use (kWh/year)	517,167	430,711	409,097	319,674	229,353	177,156
Annual Nat Gas Use(ekWh/year)	475,173	569,027	558,593	224,702	87,959	200,881
Total Energy Use (ekWh/year)	992,340	999,738	967,690	544,376	317,312	378,037
EUI (kWh/ft².yr)	17.6	19.8	22.0	9.3	8.8	7.9

5. Expert Interviews

The primary goal of the interviews was to identify how live modeling is done in practice and link the benefits of this process with possible energy savings. Interview participants were selected based on their level of experience with live energy modeling within the context of ID charrettes. Five interviews were completed with professional energy modelers from across Canada. Two of the interviewees were from Ottawa, Ontario (in Eastern Ontario), two from the greater Toronto, Ontario area, and one from Vancouver, British Columbia. Additionally, two of the interviewees had direct experience with the models for the three ID charrette modeling case studies. Despite there being countless professional energy modelers around the world, the selected experts represent a group of modelers who have spearheaded the use of live modeling for the purpose of identifying energy savings within a Canadian context. Each interview participant was asked the same series of questions especially designed to get a better understanding of the live energy modeling process.

The interviews were broken down into four main sections in order to outline the process of live energy modeling. The first section focused on background experience and knowledge; this series of questions was used to collect information about the knowledge areas needed to be successful at energy modeling as a profession. The second section focused on charrette preparation; this series of questions addressed the groundwork leading up to a live energy modeling session within an ID charrette. The third section looked charrette activity; these questions focused on what the live modeling expert was doing during the actual charrette. The fourth section focused on post-charrette activity and lessons learned; these questions addressed what the modeling experts did after the charrette and how the knowledge acquired during the charrette works its way back into the practice.

5.1 Background Experience and Knowledge

The first series of interview questions focused on the background experience of the interview participants and identified the necessary knowledge areas to effectively run live modeling within an ID charrette. Each interviewee was a professional modeler or energy efficiency expert that had between 4 to 30 years' experience. In addition, they collectively have administered more than 200 ID charrettes that incorporated live energy modeling with projects dating back more than 10 years. It is clear that the interviewees are highly experienced professionals working to find innovative ways to use energy modeling to improve performance.

Each participant was asked the question: 'What skills or knowledge areas do you believe to be essential to successfully run a live energy modeling session?', and several themes emerged. First, some key areas of understanding were identified that included thermodynamics, building science, and relevant energy codes. It was also identified that modelers should be familiar with current state-of-the-art building technologies and be highly experienced with the selected software used in the charrette.

Finally, interviewees were asked what software they use and what about that software makes it ideal for live modeling. The most common software was eQuest, which uses the DOE 2.2 engine, while another group of charrettes utilized DOE 2.1e. It was indicated that these software programs were used primarily because of their ability to complete simulations quickly, but also because they are well-

supported and fairly simple to use. During a live energy modeling session, simulation run time is critical since the entire discussion hinges on the speed at which results can be produced. Although being able to produce simulation results quickly does not directly impact the performance of the building, it allows the ID charrette to run more smoothly, which in turn improves the quality of the charrette.

5.2 Charrette Preparation

Like most complete processes, a key element of a smooth charrette is preparation. Each interviewee was asked what information they required for charrette preparation, as well as how much time they spend preparing and what assumptions are made at the onset. There was little variation about what information is required in preparation. Generally, every modeling expert required a complete set of preliminary mechanical, electrical and architectural drawings as well as a complete set of preliminary shop drawings or specifications. Or as one modeler said, “any information available concerning the building program, design information (which varies depending on how advanced the design is), and intended use of the facility,” is requested for preparations.

A lot of information is still missing when the team begins preparing for an early stages ID charrette. To get a better understanding of what information is still missing at this stage, the modelers were asked ‘What assumptions need to be made in order to move the project forward while remaining accurate?’ Because projects can vary so dramatically, no consistent list of assumption beyond using standard ASHRAE 90.1 defaults whenever information is missing was identified through the interview process.

Finally, the amount of preparation time varied between 20-60 hours within the 2-week period leading up to the charrette. Several modelers identified that part of the preparation included either scripting or pre-running a number of generic ECMs in order to make the actual live modeling sessions run smoother. There is a lot of pressure on the modeler during the actual live modeling session, so good preparation is key.

5.3 Charrette Activity

By the time the actual charrette is underway, the modeler’s role is fairly focused. When asked what they do during the actual charrette, each modeler described a fairly similar process. It begins with participating in the team discussion with a greater emphasis on listening; this way they are fully aware of the charrette goals and innovative ideas being discussed. They also each described how, working in tandem with the charrette facilitator, they start to run each ECM discussed by the team while the facilitator keeps the conversation focused and moving. As they begin to get results, the modelers provide the energy use changes of each discussed ECM to the group so that the process can continue forward. At times, certain ECMs require additional input from the team; this is where other experts can support the modeler. Several modelers described scenarios where fenestration experts or envelope experts were able to provide more accurate thermal performance numbers rather than relying on software defaults for example. As a result, more team members were involved and the charrette model calculations were more accurate while also offering an opportunity for collective learning.

Several of the modelers described charrette processes that involved cost consultants. In the first section of this research, the importance of including a cost consultant was addressed. It was identified that the financial information that cost consultants are able to provide leads to greater buy-in from the team members and also connects the energy performance goals with the project budget. Although there is clear value in ID charrettes as a whole, it is important that cost consultants are always involved.

Finally, each modeler identified the need for taking notes on the various ECMs discussed. This aided in the development of the report after the charrette and ensured the spirit of the conversation was incorporated into the model as well as the report. Additionally, each modeler described a charrette process that involved multiple team members, this generally included a facilitator and note taker in addition to the dedicated modeler.

5.4 Post Charrette Activity and Lessons Learned

The lessons learned and post charrette activities part of the interviews provided the most insight in the process, as each of the modeler had a lot to share. There was a wide range of lessons learned, yet there was still quite a bit of consistency between responses. Every modeler identified that live modeling sessions are stressful and that good preparation is key. Because live modeling requires expert knowledge of the modeling software and engineering principles, it was identified that experienced modelers should always be involved. However, several modelers identified that live modeling sessions is a great way for a less experienced modelers to learn. Actively participating in the charrette process is a great way for inexperienced modelers get a better understanding of how to successfully run an ID charrette with live modeling.

Another lesson learned was the need to run the ID charrette as early in the process as possible; a best practice identified earlier in the ID charrette process section. A charrette runs smoother earlier in the process for several reasons, as identified in the interviews. First, during an early charrette fewer decisions have been solidified and the design team members are more willing to consider changes. In turn this leads to more innovation and willingness to participate from all of those attending the charrette since there is less need to defend certain decisions.

Keeping the model as simple as possible was another lesson learned. As one practitioner put it, ‘we should aim to make our models accurate rather than precise.’ The more complicated the model is, the longer the simulation run times will take; when performing energy simulation live, speed is almost as important as accuracy. For example, a recent project the first author was working on required collaboration with the mechanical designer to provide deeper analysis. The project was still in the schematic design phase, however, the model received from the design team already had every room defined, all 346 rooms. As a result the model took roughly 1 hour to simulate on a fairly robust computer. In an ID charrette, this run time would ruin the entire process. Had the model been created with larger thermal blocks rather than every room, the simulation time would have been much quicker. Keeping a model simple and selecting software capable of quick simulations is key to a successful charrette.

5.5 Key Interview Findings

Running a live modeling session is not an easy task, however, if done correctly it can yield superior energy performance and improve the design process and outcomes. The expert interviews led to a number of key findings that allow for a successful live modeling session. The key findings are:

- Schedule the modeling session as early in the design process as possible.
- Ensure that all of the necessary documentation has been collected in order to prepare. This includes a complete set of preliminary mechanical, electrical and architectural drawings as well as a complete set of preliminary shop drawings or specifications.
- State assumptions and ask design team to confirm inputs and ensure assumptions are correct.
- Allow for enough preparation time, somewhere between 20-60 hours. During that time, try to run likely ECM's so that the modeling session runs smoother allowing for certain trends to be identified early.
- Select software capable of running simulations quickly.
- Do not over complicate the model.
- Take lots of notes.
- Ensure a cost consultant is present.
- Invite other experts to the session, i.e. fenestration, building envelope, landscape, lighting, etc.
- Have a dedicated session facilitator, someone other than the modeler, so that things continue to move forward.

6. Conclusion

An improved process almost always leads to an improved outcome, and as this research indicates the same is true for the ID charrette modeling process over the compliance modeling process. ID charrette modeling schools have significantly less predicted energy use than compliance modeling schools, as indicated by a 58% predicted energy use reduction. This research clearly indicates that participating in live energy modeling during the ID process can lead to significant predicted energy use reduction for new K-12 schools in Ontario, Canada. Live energy modeling provides design teams with concrete number necessary to make informed design decisions and allows for participation in the process by all design team members. It should be noted that this research is limited in its generalizability due to a small sample size of six schools located in Eastern Ontario.

An area for further research is the variation of predicted energy use versus actual energy use. Based on the findings, concluding that live modeling during an ID charrette results in a better performing occupied building is inaccurate. Predicted energy use is based on simulation results and actual energy use is based on metered data and it is important that distinction be made when interpreting the results of this study. Additional research needs to be completed in order to state the effect of live modeling during ID charrettes on actual energy use. Are larger sample size across a verity of geographic locations would allow the research to be more generalizable. Once all of the schools in this study are fully constructed and occupied, an analysis of the actual metered energy use of each school could be analyzed in order for additional conclusions to be made.

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Investment Value of Long-Term Building Adaptability

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Abstract

Physical adaptability of buildings has a major role in creating competitiveness for property investors as well as creating a sustainable built environment. Current real estate investment analysis methods do not value investments into long-term adaptability because the discounting effect gives less weight to cash flows further in the future. This paper attempts to apply a newly developed investment theory for justifying the investor value of long-term adaptability. The theory, which combines of real options valuation, investment analysis and building component lifecycle design, proposes that physical asset characteristics can create valuable real options (i.e. building adaptability) for the real estate investor. This paper applies this theory into a real life property development case and evaluates the value of real options for the investor. The results try to explain in economic terms why investors should invest into long-term adaptability. The study found that the value of real options ranges from 0,0 % to 221,4 % compared to the initial investment cost of the building component. The extra investment costs for creating these real options ranges from 0,0 % to 5,0 %. The real option values exceed the costs in most of the cases. As can be seen from the results, it is important to recognize valuable options from the ones that do not provide value in the long-term. More research and discussion regarding the practical usability of the results is needed, as the topic is quite complex.

Keywords: Building adaptability, real options, investment analysis, technical lifecycle, economical lifecycle

1. Introduction

Average lease lengths have decreased rapidly and in major markets are now under 5 years (IPD, 2014; Titman and Twite, 2013). The shortened interval for lease break points requires more active management from the property owner. Since tenant requirements are changing rapidly, the buildings have to be adaptable into different scenarios of best use in the future. Physical adaptability of buildings has a major role in creating competitiveness for property investors as well as creating a sustainable built environment. However, current real estate investment analysis methods do not value investments into long-term adaptability.

Real estate investment analysis is mainly done with discounted cash flow (DCF) valuation method (KTI and IPD, 2012; Shapiro, Mackmin and Sams, 2013) where predicted net rental cash flows are discounted to the present value. The discount rate effect gives less weight to cash flows further in the future. Many authors, such as Hayes and Garvin (1982) and Myers (1984), have noted that the use of DCF results in short sighted decision-making because short-term cash flows can make up the best part of the investment value. In the property sector, this short sightedness is especially problematic as buildings are constructed for lifecycles of 50+ years and initial design plays a key role on how the buildings can be used in different market conditions.

Many of the opportunities in active real estate management are constrained by the physical asset characteristics (PACs) of real estate investments, which are in turn determined in design processes. Vimpari and Junnila (2015) define PACs as *“the limitations and opportunities that the physical attributes of buildings impose on assets’ economically best use... In other words, PACs express the extent in which the real estate manager has to operate during the lifecycle of a building investment.”* They also noted *“it appears that PACs do not have a large role in property analysis as they are mainly assessed through their negative effect on rent and on capital expenditures that is not as a source of value creation, per se.”* Vimpari and Junnila (2015) developed a theory for valuing building lifecycle investments that can justify the investor value of long-term adaptability. The theory, which combines of real options valuation, investment analysis and building component lifecycle design, proposes that PACs can create valuable real options for the real estate investor. Real options are originally defined as *“opportunities to purchase real assets on possibly favourable terms”* (Myers, 1977). In the context of this paper, real options enable that the PACs can adapt into new use when the best use of the building requires it, in economically favourable terms.

This paper applies this theory into a real life investment case and evaluates the value of real options for the investor. The results try to explain in economical terms why investors should invest into long-term adaptability. The study found that the value of real options ranges from 0,0 % to 221,4 % and the extra investments into adaptability ranges from marginal to a maximum of 5,0 %. This paper aims to discuss the reliability and practical usability of the numerical findings.

The paper is organized as follows. The next section describes the relationship between economical and technical lifecycle as well as presents the Vimpari and Junnila (2015) framework. The following section presents an applied case study of the framework. Then discussion and conclusions are provided.

2. Aligning economical and technical lifecycles of buildings

Arge (2005) found that short-term owners, such as developers, invest less into long-term adaptability because the extra investment may be hard to justify in the transactions. On the contrary, long-term owners, such as owner-occupiers, invested more into adaptability. This is an interesting observation because construction literature argues that the cost of adding adaptability into PACs is only marginal. Slaughter (2001) analysed 48 commercial renovation projects and found that interaction between building systems (i.e. structure, enclosure, services and interior finish) *“strongly influenced the building’s adaptability, and that the structural and exterior enclosure systems, as well as the services and interior finish, should be designed with respect to anticipated changes.”* The study found out that different design strategies that increase the adaptability often requires only, on average, 2 % extra investments into initial construction costs.

These small extra investments can have an important impact on the building’s economical lifecycle. To understand the economical value of adaptability, the connection between the market demand of project (economical lifecycle) and the actual lifecycle of the building components (technical lifecycle) needs to be examined. In principle, sustainable use of built environment resources would expect that both the economical and technical lifecycles are as close as possible. Often this is not the case because the economical lifecycle changes faster than the technical lifecycle, which results into inefficient occupancy rates or premature demolition.

The importance of aligning economical and technical lifecycles is explained through technical lifecycle measurement. A building component (i.e. PAC) has an expected technical lifecycle based on the design requirements for the project. Building components can be divided into two categories, fixed and movable, with an expected average technical lifecycle. The fixed category

includes components, such as heating (technical lifecycle of 40 years), ventilation (40), sewage and water (40), air conditioning (40), electricity (50), structures (200), windows (35), façade (40), roof (40), balconies (40) and fixed devices and systems (40). The movable category includes components, such as surfaces of walls (12), roofs and floors (12), fittings (40), partitioning walls and doors (40). These lifecycles are used as a basis for building design as well as for calculating the future renovation costs.

However, since the economical lifecycle of the first best use can be much shorter, the technical lifecycle cannot be exploited fully if there is no adaptability, i.e. investments into technical value is lost because the PAC cannot adapt into the new economical demand. This effect of this is more dramatical in the building components that have longer lifecycles, such as HVAC, electricity and building structures. The lost or gained value with adaptability is pointed out numerically in the Vimpari and Junnula (2015) framework presented in Figure 1. The NPVs in the framework “represent the amount that is lost or gained due to the length of the lifecycle that is, if the lifecycle lasts only n_{min} years, NPV_{min} is lost because the PAC has to be replaced $n_{stan}-n_{min}$ years earlier compared to the standard lifecycle. On the other hand, if the lifecycle lasts n_{max} years, NPV_{max} is gained for the opposite reasons. Therefore, if the PAC reinvestment has to be made early, the X cannot be invested elsewhere with the hurdle rate and it is lost because the PAC does not produce any profits, per se. The higher the hurdle rate, the higher the amount lost/gained and vice versa.”

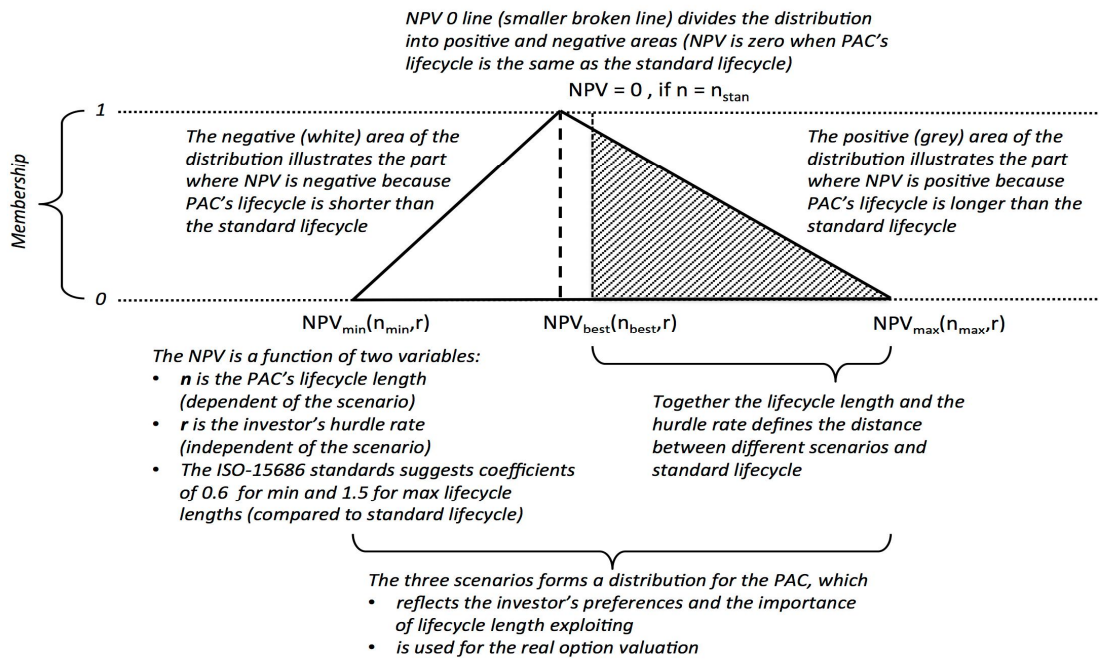


Figure 1: Conceptual framework for valuing lifecycle investments (Vimpari and Junnula, 2015)

The framework is used to form a single distribution of the PAC's lifecycle. A distribution is used because the technical lifecycle defines the limits for the economical lifecycle, i.e. at best the economical lifecycle has the same distribution as technical lifecycle. At worst, a short economical lifecycle transforms the distribution in a way that the positive area has a much smaller proportion (this is illustrated in Figure 2) because there is no adaptability. The framework uses a triangular distribution because it is much easier to use in practice, as there is often limited information to form a probability distribution in property context. The framework suggests that the ISO-15686 standards can be used to define the minimum and maximum lifecycle lengths to form the triangular distribution. The standards suggest that a coefficient of 0.6 can be used for the minimum lifecycle and the 1.5 for the maximum lifecycle, compared to the standard expected lifecycle. For example, a façade has a standard expected lifecycle of 40 years, but the coefficients suggest that the range for the lifecycle is from a minimum of 24 years to a maximum of 60 years. In practice, wear and tear, different conditions, etc. can have an effect on the length of the lifecycle.

The technical lifecycle distribution (which gives the upper boundaries for the economical lifecycle) is rather straightforward to measure, but defining the economic lifecycle is not as straightforward. However, it is more important because it dictates how efficiently the technical lifecycle can be exploited. The economical lifecycle distribution is affected by uncertainty in space demand during the technical lifecycle. Figure 2 presents the relationship of time and demand uncertainty.

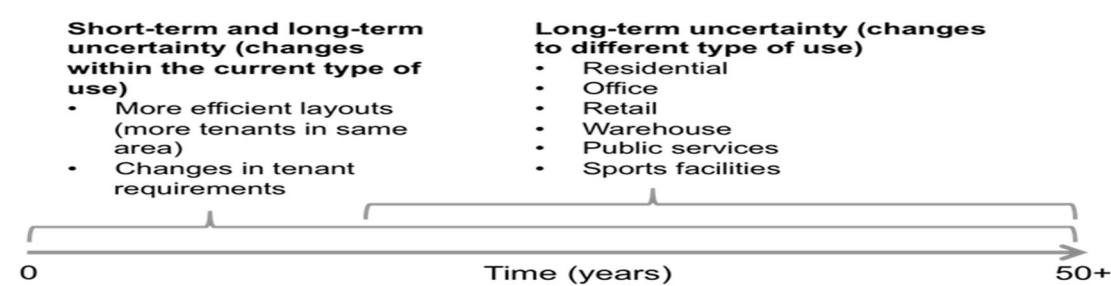


Figure 2: Relationship of time and demand uncertainty

The figure presents what kind of uncertainty can incur to the property owner during the technical lifecycle of the building. The longer the expected same use of the building, the smaller the amount of uncertainty is during the technical lifecycle. For example, a very long lease agreement reduces the uncertainty dramatically and thus reduces the need for adaptability investments, from the property owner's perspective.

If the PACs cannot adapt to the uncertainties, the economic lifecycles for the PACs will be shorter than the technical lifecycles. The value of adaptability comes from the fact that the economic lifecycle is aligned with the technical lifecycles. Therefore, to value adaptability we need to define the technical lifecycle and economical lifecycle. If these are not aligned, we need to identify real options (adaptability investments) for aligning the lifecycles. Then the options are valued with the framework and the values are compared to the cost of the extra investments. This is attempted in the following case study.

3. Case Study

AINOA is a 4-story shopping centre development in Tapiola, Espoo, Finland. It is part of a larger urban development project that transforms the old centre of Tapiola into new use. A lot of older buildings from the 1970's and 80's are demolished, as they cannot be used anymore. Additionally, a new metro line will connect the area to the metro grid of Helsinki Metropolitan Area (HMA). The shopping centre will be ready in 2017.

The investor in AINOA is LähiTapiola that is one of the largest institutional investors in Finland. LähiTapiola plans to own the centre for a long holding period and thus can be considered as an owner who is interested in the long-term lifecycle performance of the building. Even though the building has better construction quality than average and is in a great location, there is uncertainty regarding the economical lifecycles of rentable space within the centre. The main tenant is renting majority of the premises. In addition to the main tenant, there are a few large and several smaller retail spaces in each floor. While the main tenant is a very reputable tenant, the owner cannot expect that it will occupy the premises indefinitely.

In order to value the adaptability strategies for different PACs, technical and economical lifecycles are defined. Let us assume that the best-guess estimate for the building's technical lifecycle is 40 years (in Finland, the average life of shopping centres before demolition has been 39 years according to Huuhka and Lahdensivu, 2014). Based on the ISO standards, the minimum technical lifecycle would be 24 years and maximum 60 years. The minimum lifecycle can feel very short but the triangular distribution gives only a very small weight to it - see Vimpri and Junnila (2015) for more details. For the economical lifecycles, let us use the following lengths presented in Table 1.

Table 1: Economical lifecycle distributions

Tenant	Min	Best	Max
Main tenant	10	25	60
Large tenants	5	10	60

The economic uncertainty can have the largest effect to the main tenant and the larger tenants. The smaller retail spaces are so small that it is unnecessary to include them into the analysis. The table presents the economic lifecycles for the tenant categories. The maximum lifecycles are based on the maximum technical lifecycles, i.e. in the most optimistic scenario the economic demand is in line with technical lifecycle. The minimum lifecycles are based on hypothetical first lease agreements (the owner does not want to disclose the real lengths). The best-guess lifecycles are the most likely scenario for how long the tenant will remain in the building. Figure 3 illustrates the economical distributions the large and main tenants with and without adaptability.

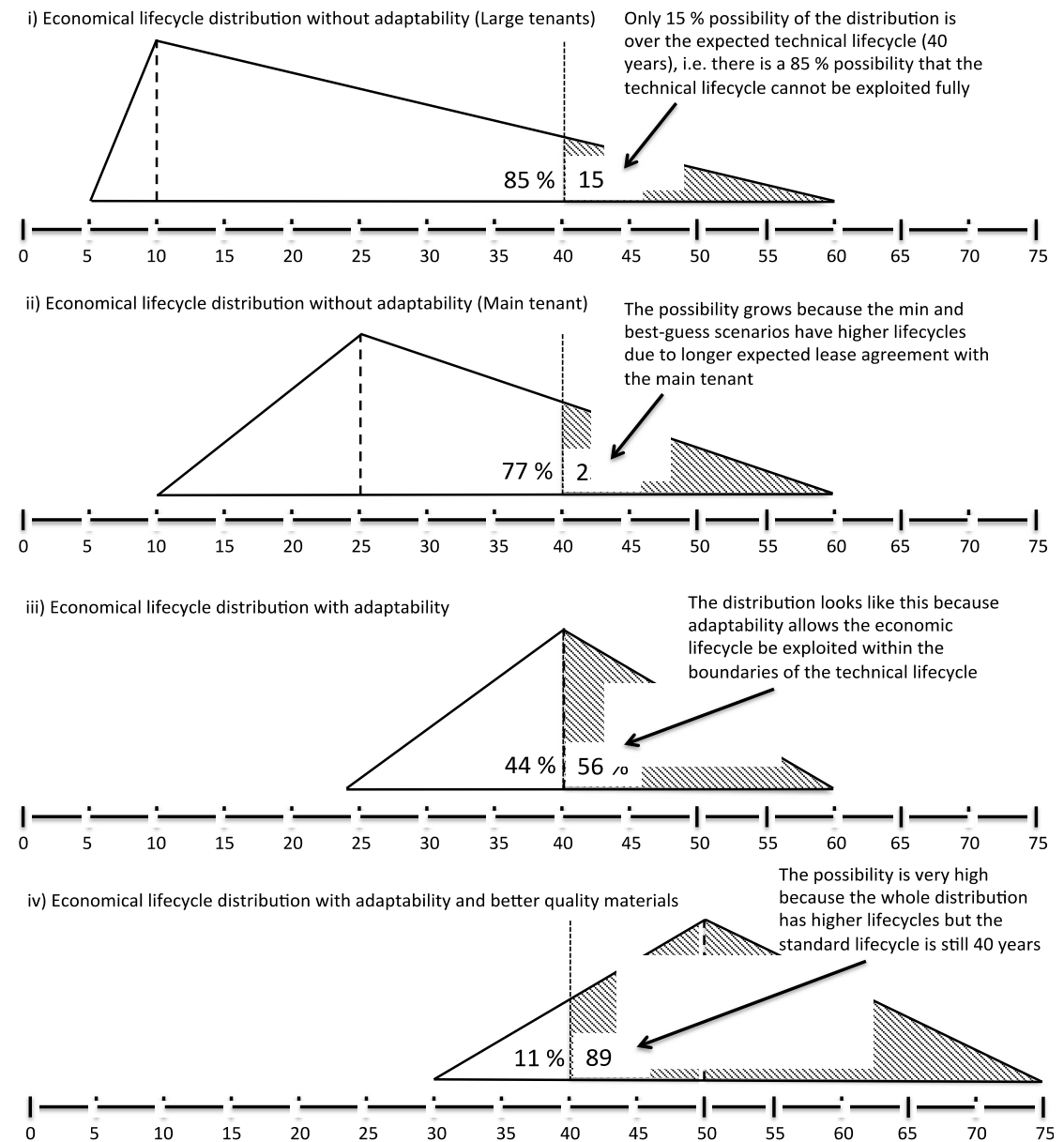


Figure 3: Economical distributions with or without adaptability

The figure presents four different economical lifecycle distributions. The first two illustrate how uncertainty affects the economic distribution and the chance of exploiting the whole technical lifecycle. The third distribution illustrates how adaptability changes the possibility of exploiting the lifecycle. The fourth adds the effect of better materials into the distribution, i.e. better materials raises the expected technical lifecycle for the PAC, which reduces the possibility that the PAC has to be replaced early.

The grey area in the distributions represents the proportion of the area that exceeds the average expected lifecycle of 40 years. This is the area where extra optional value is created when the lifecycle lasts longer than expected. The option value, is calculated from the grey area, see Vimpari and Junnila (2015) for details. The option value increases as the proportion of the positive area increases because the expected lifecycle for the technical lifecycle is higher. This means that more clever design with potential extra investments is needed to increase the adaptability. In essence, if the main tenant would leave and the space would have to be divided into much smaller areas, it would not be possible efficiently without the real options. Without the adaptabilities the areas would have to be divided inefficiently which could results into loss in rentable space, etc.

Using the formulas in the Vimpari and Junnila (2015) framework, the real option values for the distributions are as follows: i) 0,2 %, ii) 0,5 %, iii) 3,3 % and iv) 18,3 %. These numbers are the value of adaptability compared to the initial investment. For example, in distribution iv), a maximum of 18,3 % can be invested into adaptability and better materials.

To find out what kind of adaptability is needed to change the distributions, the building design solutions had to be assessed. Different designers (Electricity, Architecture/Structure and HVAC) were interviewed in order to find out what kind of adaptability has been constructed into the building. The following real options were identified. In the parenthesis is presented the best-guess technical lifecycle based on common expectations in Finland - the min and max lifecycles for the option valuation are estimated using the ISO-coefficients as the framework suggests.

- Electricity:
 - E1: Higher capacity for the main electricity connection (50 years)
 - E2: Higher capacity in the cabling (50 years)
 - E3: Higher capacity for the main electricity unit (25 years)
- Architecture/Structure:
 - A1: Openings for escalators/staircases in middle floors (100 years)
 - A2: Storey heights allow all types of use (100 years)

A3: Distance between pillars very long (100 years)

A4: Façade not load-bearing and allows for window openings (100 years)

HVAC:

H1: Higher capacity in the ventilation units (25 years)

H2: Ventilation ducts allow higher airflows (40 years)

H3: Higher capacity for district cooling can be installed easily (40 years)

These real options changes the i) and ii) distributions to iii) and iv) distributions. The extra costs and option values are presented in Table 2. In the option valuation is assumed that the standard lifecycle is 40 years. Therefore, the option value is based on the area that is over 40 years. The area weighted option value is the value of adaptability. The further over 40 years the area is, the higher the option value.

Table 2: Option values and extra investment costs

Real option	Extra investment costs	Option value	Option value (better materials)
E1	Max 5,0 %	18,1 %	46,2 %
E2	Max 5,0 %	18,1 %	46,2 %
E3	Max 5,0 %	0,0 %	0,0 %
A1	Marginal	180,1 %	221,4 %
A2	Max 5,0 %	180,1 %	221,4 %
A3	Max 5,0 %	180,1 %	221,4 %
A4	Marginal	3,3 %	13,7 %
H1	1,3 – 1,7 %	0,0 %	0,0 %
H2	1,3 – 1,7 %	3,3 %	13,7 %
H3	1,3 – 1,7 %	3,3 %	13,7 %

The results in Table 2 suggest that the option values are higher than the extra investments costs in all cases except E3 and H1. This means that the extra investments are worth the investments because the potential upside from the options is higher. Raw estimates were used for the extra investments because the designers had not systematically identified and calculated the extra investment costs. In the better materials is assumed that they increase the best-guess lifecycle by 20 %. This chosen to demonstrate how the value of adaptability increases because of better materials chosen.

The extra investments in Electricity allow using the same cabling and main electricity unit with higher loads that is if the space efficiency increases or tenants with higher electricity requirements

occupies the premises. The electricity designer had a raw estimate that these investments have a maximum extra investment cost of 5,0 %.

The extra investments in Architecture/Structure allow using the same structures if the layouts have to be converted into new use. Additionally, the structures can be used in different type of use as the storey heights are higher and facades allows for windows openings. Based on a raw estimate, the extra investments costs ranges from marginal to maximum of 5,0 %. The option values are very high because the technical lifecycles of building structures are very long.

The extra investments in HVAC allow using the same ventilation units and ducts if the space efficiency increases or a tenant with higher cooling requirements occupies the premises the same component can be used. The designer had a raw estimate that these extra investments are only 1,3 % to 1,7 %.

4. Discussion

When interpreting the results, it should be remembered that the numbers are best approximations based on the expected lifecycles. Nevertheless, the magnitudes of the results seem somewhat intuitive, as the value of adaptability should correlate with the length of the lifecycle. For example, the very high option values for the building structures seems logical if they allow using the same structures for different types of uses over a lifespan of 100 years. Naturally, when talking about lifespan lengths of this magnitude it raises questions about how relevant it is to prepare for a period that far in the future. However, if the extra investments into a very small part (e.g. pillars and ceiling height) of the total building investment ranges from a marginal to a maximum of 5,0 % of extra costs, and as a results it raises the possibility that the whole structures can be used much more efficiently, the investments is likely worth it. The option value tries to approximate the monetary value of the extra investment, even though they are merely an approximate. The option value of e.g. 180,1% would suggest that this is the maximum amount that could be invested into adaptability – intuitively it does not make any sense. On the other hand, as the extra investments point out, the real costs are very small. It should be acknowledged that some of these options could be added later but it would result into much higher investments costs as well as longer periods of vacancy during the construction activities. This is why the author thinks that the value of these options should be looked from the lifecycle perspective rather than the rental perspective.

If we look at the results of E3 and H1 where the option values are zero. The results does not make sense because it suggest that the main electricity unit and the HVAC unit does not need any adaptability because their expected lifecycles are only 25 which is shorter than 40 years that was chosen for the standard lifecycle in the valuation. The results would make sense if there would be no economical uncertainty during the 25 years but there is as the lease agreements can have a minimum length of only few years.

The challenge with the framework seems to be on how to choose correct the standard (n_{stan}) lifecycle length for different PACs and for the whole building. Actually, the results would suggest that the property owner should take an active role of choosing the expected lifecycle from the business perspective, rather than basing it on the technical quality (lifecycle) of the product. Then the value (grey area) that exceeds this expected business lifecycle would be optional and the property owner would seek for design solutions that maximize this optional value. Thus, the property owner would have to take a stand on the actual business lifecycle of product (with technical implication) rather than take them as a given from the developer, which is the case at the moment. This would result into better alignment of the economical and technical lifecycles.

5. Conclusions

This paper attempted to use the Vimpari and Junnila (2015) framework in practice by applying it into a real life investment case. The study founds that the value of real options ranges from 0,0 % to 221,4 % compared to the initial investment cost of the building component. The extra investment costs for creating these real options ranges from 0,0 % to 5,0 %. The real option values exceed the costs in most of the cases. As can be seen from the results, it is important to recognize valuable options from the ones that do not provide value in the long-term. More research and discussion regarding the practical usability of the results is needed, as the topic is quite complex. The value of the options depends on what kind of lifecycles is inputted into the framework. Defining these lifecycles is somewhat confusing because both economical and technical lifecycles have to be considered.

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Integrated Urban Water Management, the Green Economy and Institutional Eco-Innovations

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Abstract

This paper aims to pinpoint the global megatrends related to urban water management, and to make recommendations for urgently needed institutional innovations. This paper and the subsequent analyses are based on the literature study. Almost 700 million people lack access to safe drinking water, 2.4 billion lack access to improved sanitation services, and 600,000 children under five die every year as a result of lack of access to improved water services. While these estimates identify the extent of the problem, the number of people threatened by poor management of constructed systems is much greater.

The world's population is increasingly urban, and cities cannot be sustainable without ensuring reliable access to improved water services. Urban settlements are the main source of point-source pollution. In many fast-growing cities in developing countries, wastewater infrastructure is non-existent, inadequate or obsolete. Water storage, treatment and distribution systems are poorly maintained, and water losses due to leakage and theft, often exceed 40-60% of the total water distribution. Water infrastructure is rapidly aging and facing massive rehabilitation. By 2016 the capital expenditure on water infrastructure is estimated to increase 1.5 times from USD 90 billion in 2010 to USD 131 billion. It's estimated that the urban infrastructure of the world's cities over the next 20 years will require USD 41 trillion, including USD 22.6 trillion on water and sanitation.

To achieve the Sustainable Development Goal 6 “*Ensure access to water and sanitation for all*” by 2030, specific enabling conditions will be required. Therefore, the typology and concepts of the green economy, along with the principles, approaches and processes of the Integrated Urban Water Management, and the institutional innovations should be considered and applied.

Keywords: Integrated Urban Water Management, the green economy, institutional eco-innovations, efficiency improvements, strategic asset management

1. Introduction

Water is arguably more fundamental than any other resource – to life itself, supporting a huge array of ecosystem services – and to every economy and society. Water contributes directly and indirectly to virtually all other ecosystem services but the area of water supply and sanitation also comprises an economic sector in itself. Water supply and sanitation can thus be considered as a driver with its own dynamics of pricing, infrastructure and governance (UNEP 2012, 15-16, 19).

According to the United States Environmental Protection Agency (EPA), the sustainable water infrastructure (the collection and distribution systems, treatment plants and other infrastructure that collects, treats and delivers water-related services) and the sustainable water sector systems (all aspects of effective operations and maintenance practices of the utilities and systems that provide water-related services) are necessary to safeguard the sustainable environmental and economic development of all the communities (Figure 1, EPA 2012).

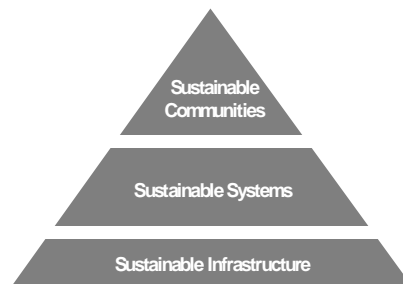


Figure 1: Sustainable communities are based on sustainable drinking water, wastewater and stormwater infrastructure and on sustainable systems' operations and maintenance (EPA 2012).

In 2015, however, 663 million people still lack improved drinking water sources and 2.4 billion people still lack improved sanitation facilities (UNICEF and World Health Organization 2015, 4-5). Deaths from water-related diseases are inadequately monitored and reported. A wide range of estimates is available in the literature, ranging from 2 million to 12 million deaths per year. The best estimates analysed by Gleick (2002, 4) appear to fall between 2 and 5 million deaths per year.

While these estimates identify the order-of-magnitude of the problem, the numbers of people threatened by poor management of constructed systems is much greater (Biswas 2013). Billions lack access to safe water that is reliably and continuously delivered in sufficient quantities (WHO 2014, iv). Of critical importance is the fact that access to an “improved” water source does not necessarily mean access to “safe” water fit for human consumption. As a result, for example, half of Africa’s hospital beds are filled with people suffering from a water-related disease (OECD 2012b cited by OECD 2013a, 38-40).

A UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS) 2014 Report provides a global update on the policy frameworks, institutional arrangements, human resource base, and international and national finance streams in support of sanitation and drinking-water. Ten key findings emerge from the GLAAS 2014 Report as follows (WHO 2014, ix-xi):

1. Governments show strong support for universal access to drinking water and sanitation.
2. Political aspirations, nonetheless, are impeded by weak capacity at country level to set targets, formulate plans, undertake implementation and conduct meaningful reviews.
3. Critical gaps in monitoring impede decision-making and progress for the poorest.
4. Neglect for WASH (water, sanitation and hygiene) in schools and in healthcare facilities undermines country's capacity to prevent and respond to disease outbreaks.
5. National financing for WASH is insufficient.
6. International aid for WASH has increased and regional targeting has improved.
7. Lack of human resources constrains the sector.
8. Sanitation in rural areas: high needs, yet low expenditures.
9. Weak monitoring of the critical 'H' factor – hygiene promotion.
10. Efforts are being made to reach the poor, but few at scale.

A UNESCO report states that a shortage of engineers in developing countries is hampering development. For example, to meet the target of the Millennium Development Goal (MDG) to safe drinking water and basic sanitation, the report gives an estimate that some 2.5 million new engineers and technicians would be needed in sub-Saharan Africa alone (Marjoram 2010, 3).

According to the United Nations Department for Economic and Social Affairs 3.9 billion people, or 54% of the global population, lived in cities in 2014, and by 2050, two-thirds of the global population will be living in cities (UNDESA 2014, 2). Major growth will take place in developing countries, particularly in urban areas that already have an aging, inadequate or even non-existent sewage infrastructure, unable to keep up with rising populations. It is estimated that the urban infrastructure of the world's cities over the next 20 years will require USD 41 trillion for investments in urban infrastructure, including USD 22.6 trillion on water and sanitation (UNEP 2011a, 44).

The increase in the number of people without access to water and sanitation in urban areas is directly related to the rapid growth of slum populations in the developing world and the inability (or unwillingness) of local and national governments to provide adequate water and sanitation facilities in these communities (UN-Water 2015, 3). Globally, more than 80% of wastewater resulting from human activities is discharged into rivers or seas without any pollution removal (UN 2015). The financial, environmental and social costs are projected to increase dramatically unless wastewater management receives urgent attention. Under-dimensioned and aging wastewater infrastructure is already overwhelmed, and with the predicted population increases and changes in the climate the situation is only going to get worse. Without better infrastructure and management, several millions of people will continue to die each year and there will be further losses in biodiversity and ecosystem resilience, undermining prosperity and efforts towards a more sustainable future (Corcoran, Nellemann, Baker, Bos, Osborn and Savelli 2010, 9-11).

Water storage, treatment and distribution systems are often poorly maintained. Moreover, in many countries of the developing world, water losses due to technical leakage and water theft often exceed 40-60% of the total water distribution (UN-Water 2012b, 4-5). Underpricing of water has contributed to the situation across Africa, where on average 35% of water supply infrastructure assets needs rehabilitation (Foster and Briceño-Garmendia 2009, 73). In the OECD countries the water services

infrastructure is also aging and decaying, and needs rehabilitation or replacement. The estimated investment gap and the state of water infrastructure in some OECD countries and in sub-Saharan Africa (SSA) are shown in Table 1.

Table 1: Estimated investment gap of water services (water and sanitation) infrastructure in some OECD countries and in sub-Saharan Africa (compiled by the authors in 2014-16).

Country/ Region	Population	State of water services infrastructure (scale)	Estimated current funding gap (EUR)	Estimated funding gap per population (EUR/hd)
Canada ¹	35,182,000 ^a	Good (Very good-very poor)	34,755,000,000 ^{**}	988
Norway ²	5,213,985 ^b	Water networks 3 (5-1) Sewers 2 (5-1)	22,329,000,000 ^{**}	4,280
Finland	5,426,000 ^c	7 (10-4) ³	4,803,000,000 ^d	890
USA	320,051,000 ^e	D (A-E) ⁵	406,426,000,000 ^{6*}	1,270
SSA	973,400,000 ^d	6 (10-4) ⁷	219,012,000,000 ^{8**}	225

Note: Currency exchange rates on 3 March 2014* and on 3 March 2016**; Population figures: <http://www.statcan.gc.ca/daily-quotidien/150617/dq150617c-eng.htm>; <https://www.ssb.no/en/befolkning/statistikker/folkemengde>; United Nations, Department of Economic and Social Affairs, Population Division (2013). World Population Prospects: The 2012 Revision, Highlights and Advance Tables. Working Paper No. ESA/P/WP.228; <http://data.worldbank.org/region/SSA>.

¹Canadian Construction Association, Canadian Public Works Association, and Canadian Society for Civil Engineering and Federation of Canadian Municipalities (2016) *Informing the Future: The Canadian Infrastructure Report Card*. 163 p.

²Rådgivende Ingeniørers Forening (2015) (Original in Norwegian) *State of the Nation 2015*. 93 p.

³ROTI (2013) *State of the Built Environment – Finland*. RIL (Finnish Association of Civil Engineers), Finland.

⁴Ministry of Agriculture and Forestry (2008) (Original in Finnish) *The Current Condition of the Drinking Water Networks and the Rehabilitation Requirements*.

⁵ASCE (2013a) *American Society of Civil Engineers 2013 Report Card for America's Infrastructure*.

⁶ASCE (2013b) *Failure to Act: The Impact of Current Investment Trend on America's Economic Future*.

⁷The estimate by the authors in 2014.

⁸Ghosh Banerjee S and Elvira Morella E (eds) (2011) *Africa's Water and Sanitation Infrastructure: Access, Affordability, and Alternatives*. The International Bank for Reconstruction and Development/The World Bank, Washington. 401 p.

The study question is ultimately, how the access to the water services can be increased and how the functioning of the built systems and facilities can be sustained through their planned lifetime. Therefore, in the following chapters we briefly introduce the typology and concepts of the green economy, along with the principles of the Integrated Urban Water Management and the institutional eco-innovations, which are – based on our findings – the keys in solving the above problems.

2. Integrated Urban Water Management

Integrated Urban Water Management (IUWM) is nested within the broader notion of Integrated Water Resources Management (IWRM). Given that cities are significant elements of their catchments, IUWM needs to be linked to IWRM plans and management processes in the broader basin context to allow the alignment of the urban water sector with others beyond the urban boundaries (Bahri 2011, 3). IUWM principles are the following (GWP 2013, 2-3): Encompass alternative water sources; Match water quality with water use; Integrate water storage, distribution, treatment, recycling, and disposal; Protect, conserve and exploit water resources at their source; Account for non-urban users; Recognise and seek to align formal and informal institutions and practices; Recognise relationships among water, land use, and energy; Pursue efficiency, equity and sustainability; and Encourage participation by all stakeholders.

It is essential that we develop a framework for green growth and water security that incorporates the integrated approach and addresses water within wider socio-economic goals (GWP 2012, 13). Figure 2 illustrates the coordinating structure that will ensure communication between departments, levels of government, local communities, and stakeholders (GWP 2013, 3, modified from Tucci 2010).

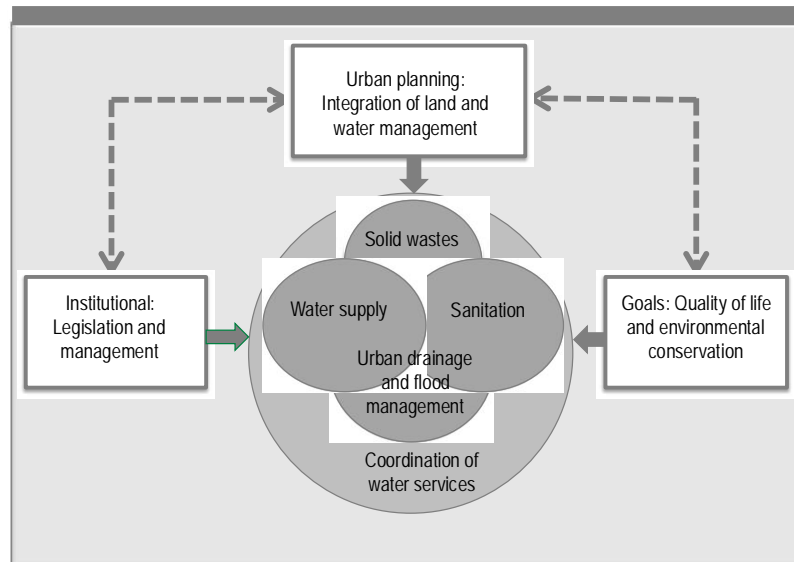


Figure 2: Integrated Urban Water Management (GWP 2013).

Urban planners can help governments overcome fragmented public policy and decision-making by linking planning with other policy sectors like infrastructure, and adopting collaborative approaches that involve all stakeholders in determining priorities, actions, and responsibilities (Figure 3, GWP 2013, 3, modified from Tucci 2010).

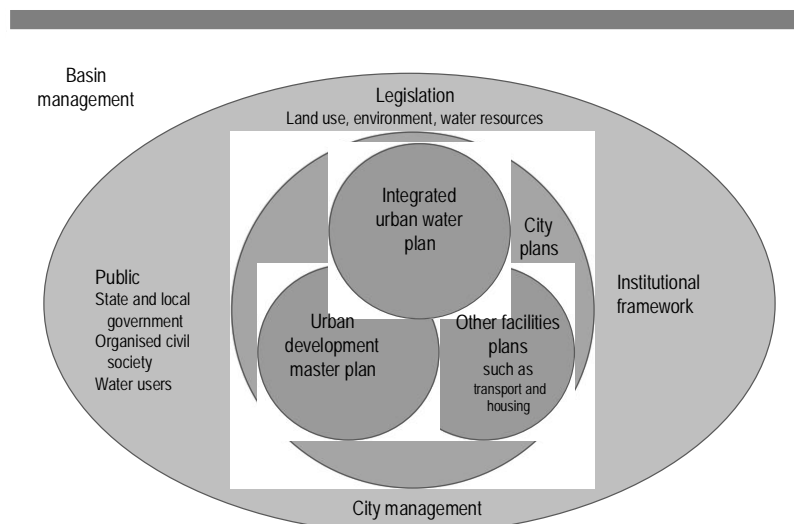


Figure 3: Institutional framework for municipal land and water planning (GWP 2013).

3. The green economy and water

The United Nations Conference on Sustainable Development (UNCSD) took place in 2012. The aim was to define pathways to a safer, more equitable, cleaner, greener and more prosperous world for all, in particular with the help of one important tool available in the context of sustainable development and poverty eradication—the *green economy*. The outcome document “*The Future We Want*” recognized that water is at the core of sustainable development as it is closely linked to a number of key global challenges. In particular, the report underlined the critical importance of water and sanitation within the three dimensions of sustainable development (United Nations 2012, 32).

According to Rotmans, the green economy is not only dealing with the new technological solutions, but it also requires sustainable ways of living, new institutions, and cultural changes (Rotmans 2012, cited by Hatakka 2013, 5). The concept of a green economy is not a replacement for that of sustainable development, but rather a way of conceiving the contribution of economic activities to sustainable development. If sustainable development is the “what,” a green economy is the “how.” (Federation of Canadian Municipalities 2011, 10).

There is, however, no internationally agreed definition or universal principles for green economy, and interrelated but different terminology and concepts have emerged over recent years. Allen and Clouth (2012, 63-64) gave several definitions developed by different organizations for the green growth and the green economy. Based on the review of emerging literature using a green economy policy typology, policies that were proposed in most of the publications included public investment in infrastructure (such as sustainable energy, water, transport and waste) as well as public investment in innovation (through measures such as funding for R&D and deployment) (Allen 2012, 40).

Water is fundamental to the green economy because it is interwoven with so many sustainable development issues, such as health, food security, and poverty. In developing countries, access to water and sanitation services is a fundamental precondition for poverty reduction and economic progress (UN-Water 2012a, 5). According to the UN-Water Decade Programme on Advocacy and Communication (2011b, 33-34):

1. Achieving a green economy is not possible without ensuring everyone has access to basic water and sanitation services.
2. Transitioning to a green economy in water requires a shift from current practice. Some key tools to promote the necessary change and support the transition: i) economic instruments; ii) green jobs; iii) cost recovery and financing; iv) investments in biodiversity; v) technology; and vi) water planning.
3. Creating incentives for improving efficiency is appropriate where basic water and sanitation services are already being provided.
4. There is an important role for social dialogue and for communities in the provision of water services. Community initiatives are vital in places where government action does not reach.
5. The transition to a green economy requires mobilising more funds, but also requires increasing efficiencies to make better use of the limited financial resources available.
6. Investing in the improvement of biodiversity is critical for sustaining or restoring the water-

related services provided by ecosystems.

7. Governments need to facilitate innovation and adoption of greener water provision and water use technologies, contributing to job creation and structural transformation towards greener economies.
8. Water planning is a powerful social tool for identifying the best way to use water resources to meet the competing needs of different users.

Direct benefits to society can be expected to flow from increased investment in the water supply and sanitation sector, including investment in the conservation of ecosystems critical for water. Research shows that by investing in green sectors, including the water sector, more jobs and greater prosperity can be created. Arguably, these opportunities are strongest in areas where people still do not have access to clean water and adequate sanitation services. Early investment in the provision of these services appears to be a precondition for progress. Once made, the rate of progress will be faster and more sustainable, thus making transition to a green economy possible. The costs of achieving a transition will be much less if the increased investment is accompanied by improvements in governance arrangements, the reform of water policies and the development of partnerships with the private sector. The opportunity to improve governance arrangements is one of the biggest opportunities to speed transition to a greener economy (UNEP 2011b, 146).

The World Water Council (2011) proposed three strategic directions, twelve priorities for action, and three conditions for success as the means to achieve progress in three strategic directions. They constitute strong enabling factors in addressing all the priorities for action (Figure 4).

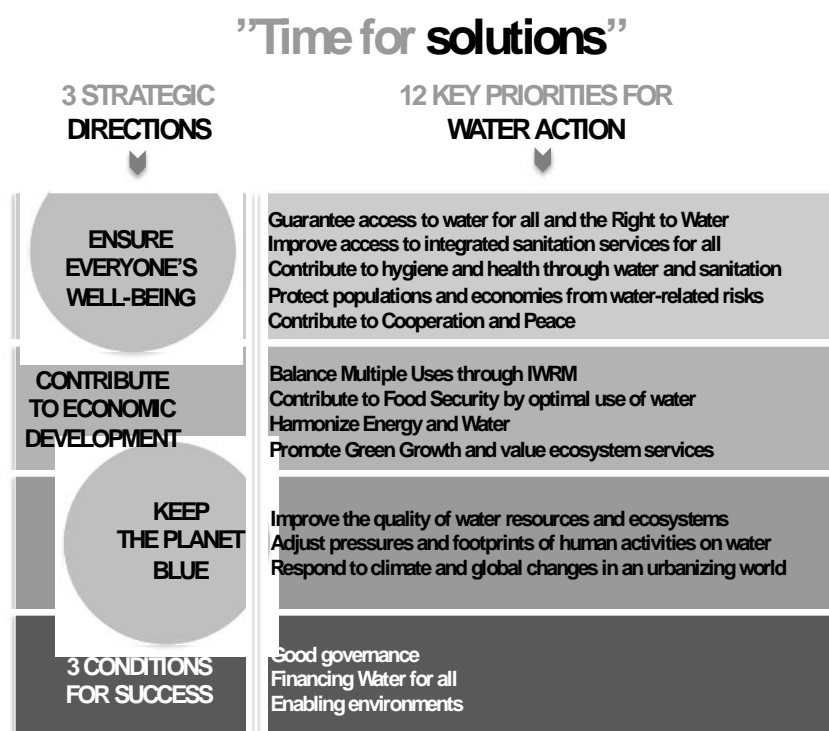


Figure 4: Three strategic directions, twelve priorities for water action and three conditions for success (World Water Council 2011).

Focusing on effectively managing assets to sustain services can be as important as focusing on new infrastructure (World Health Organization 2012, 3). The results of the abovementioned GLAAS 2014 Report show that to improve access and reduce inequalities beyond 2015, much needs to be done to effectively implement and monitor WASH policies at national level, including to (WHO 2014, ix):

- Secure, absorb and target sustained international and national financing;
- Renew focus on health facilities as a priority; to strengthen action in the crucial area of hygiene promotion;
- Support the operation and maintenance of existing infrastructure and services;
- Expand efforts in neglected rural areas where the need for improved services is greatest.

4. Institutional eco-innovations

The most popular definitions of an institution have at their core *social factors that influence, to some extent, human behaviour* (Davis 2009, 3). According to North (1991, 97) institutions are the humanly devised constraints that structure political, economic and social interaction. They consist of both informal constraints (sanctions, taboos, customs, traditions, and self-imposed codes of conduct), and formal rules (constitutions, laws, property rights). Kemper (1996) pointed out that in colloquial language the expression institution also applies to organizations. For more clarity, she used the term of *institutional arrangement*, which indicates the structural nature of institutions. According to her, institutional arrangements and actors, i.e. individuals, agencies and organizations, compose *the institutional framework*.

OECD (2011b, 1-2) notes that *innovation* will play a key role in implementing strategies for green growth. In the Oslo Manual, eco-innovation is defined as “the creation or implementation of new, or significantly improved, products (goods and services), processes, marketing methods, organizational structures and institutional arrangements which – with or without intent – lead to environmental improvements compared to relevant alternatives”. Figure 5 presents an overview of eco-innovation and its typology (OECD and Eurostat 2005, 46, cited by OECD 2009, 13):

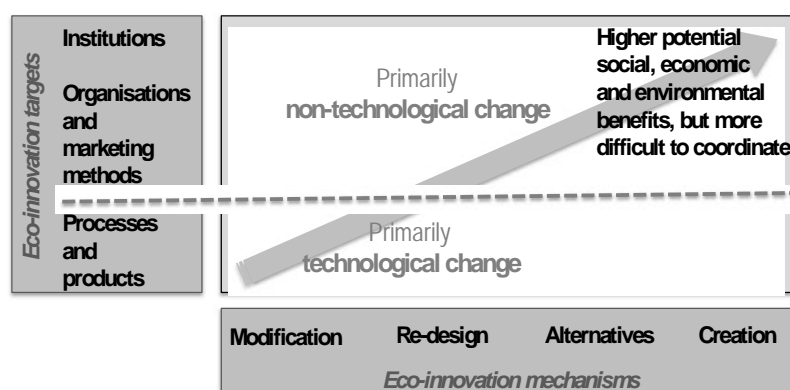


Figure 5: The typology of eco-innovation (OECD and Eurostat, 2005, modified by Hukka in 2015).

In this definition, institutional innovations such as changes in values, beliefs, knowledge, norms, and

administrative acts are included, along with changes in management, organization, laws and governance systems that reduce environmental impacts. Innovation, therefore, is not simply about technological solutions ('techno-fix' approach). Rather, innovation is a process that has three different forms with different outcomes: 1) Technological innovations providing specific techniques for managing/processing materials and energy; 2) Institutional innovations for managing on a society-wide basis – or even globally – incentives, transaction costs, rents, benefit distribution, dispersal, contractual obligations, precautions, and individual obligations; and 3) Relational innovations for managing cooperation, social cohesion, solidarity, social learning and benefit sharing (UNEP 2011a, 36).

5. Conclusions

We conclude that to make a coherent transition to the green economy and to meet emerging needs of the poorest citizens, the Sustainable Development Goal 6 “*Ensure access to water and sanitation for all*” by 2030 must be achieved. Therefore, there is an urgent need to create enabling institutional framework for urban water services provision and production – in addition to the exploitation of technological innovations. First of all, the reformed institutional framework should ensure that there are more funds available for building new urban water infrastructure to extend access to services as well as more funds for rehabilitation and replacement of existing deteriorated infrastructure.

Secondly, the framework should have a strong focus on improving resilience, performance and maintenance of built infrastructure through effective strategic asset management processes, supported by proper enforcement structures, and on upgrading pricing of services and cost recovery practices. The framework should, therefore, also include improvements in governance arrangements, reforms of water policies, and development of viable cooperation between public and private sectors. Thirdly, the critical role of engineering in addressing water-related global challenges must be recognized more widely, and human resources development should be addressed accordingly.

We also recommend that in formulation of a new institutional framework, the typology and concepts of the green economy, along with principles, approaches and processes of Integrated Urban Water Management, and institutional innovations such as changes in values, beliefs, knowledge, norms, administrative acts, changes in management, organization, laws and systems of good governance should be carefully considered and adopted to build up universal coverage and resilience of urban water and sanitation services.

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Delivering Value with BIM: A Framework for Built Environment Practitioners

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Abstract

The built environment industry worldwide is facing significant external pressures such as increased competition, higher owner expectations, rapidly changing technology and skill shortages. Building Information Modelling (BIM) has been identified as a socio-technical system that can be used to improve team communication throughout the project life-cycle, produce better outcomes, reduce rework, lower risk, provide better predictability of outcomes and improve operation and maintenance of an asset, among other benefits. Within this context, proactively establishing quality improvement cycles based on standardised work processes and corresponding measures of effectiveness will ensure better project outcomes. These outcomes can be driven by continuously improving systems and active monitoring. This paper introduces a methodology for developing a whole-of-life asset management strategy for delivering value with BIM across the life-cycle of built assets. It also presents a framework to assess progress towards value-driven goals.

Keywords: BIM, value, whole-of-life, asset management, strategy

1. Introduction

The built environment industry has been facing significant external pressures worldwide such as increased competition, higher owner expectations, rapidly changing technology and skill shortages (Hampson, et al., 2014). Building Information Modelling (BIM) is “a digital process that encompasses all aspects, disciplines and systems of built assets within a single virtual model” (Sanchez, et al., 2015). It has been identified as a socio-technical system “that can be used to improve team communication throughout the project life-cycle, produce better outcomes, reduce rework, lower risk, provide better predictability of outcomes and improve operation and maintenance of an asset” (Sanchez, et al., 2014). There is a growing body of anecdotal evidence about benefits that can be achieved by implementing BIM (Gilligan & Kunz, 2007) and some firms are measuring some benefits (McGraw Hill Construction, 2014b; McGraw Hill Construction, 2014a). However, unclear business value and return on investment (ROI) are often identified as barriers for adoption (Barlish & Sullivan, 2012).

Identifying, monitoring and managing benefits throughout the life-cycle of a project or asset have been highlighted as a way to help achieve success during implementation of new technologies (Yates, et al., 2009). “By defining how each benefit will be measured and then providing evidence for the expected level of improvement that will result from the changes, rigorous and realistic business case and financial argument for the investment can be developed” (Ward, et al., 2007). Capturing and disseminating information to ensure intelligent decision making can also help reduce risk and deal with the large number of variables characteristic of construction projects (Roper & McLin, 2005).

Within this context, proactively establishing quality improvement cycles based on standardised work processes and corresponding measures of effectiveness can help ensure better project outcomes. Metrics play a critical role in driving this process (CURT, 2005). There is a great deal of literature on BIM adoption and benefits for specific applications, stakeholders and life-cycle phases (Bryde, et al., 2013; Arayici, et al., 2011; Migilinskas, et al., 2013; Eadie, et al., 2013; Azhar & Brown, 2009; Kasprzak & Dubler, 2012; Teichholz, 2013). However, there is a lack of comprehensive studies that focus on mapping and measuring the benefits of implementing BIM across the whole-of-life of built assets (Sanchez & Hampson, 2016). This paper introduces the research done to develop a framework to assess the actual benefits of implementing BIM throughout asset planning, delivery and management applicable to both buildings and infrastructure.

2. Methodology

This research was developed in Australia in consultation with national and international organisations encompassing client, designer, surveyor, contractor and facilities management organisations as well as industry organisation that represent thousands of individual organisations across the supply chain. The research aimed to:

- (i) Define indicators to measure tangible and intangible benefits of BIM across a project's life-cycle in infrastructure and buildings; and
- (ii) Pilot test a whole-of-life BIM value realisation framework on leading infrastructure and building case studies.

The research was informed by a thematic analysis of an extensive literature review covering over 400 academic and industry references. The framework was tested through expert consultation and three exemplar case studies in Australia that featured the use of BIM during design, construction and asset management. The expert consultation included 31 industry, government and research experts from across the supply chain with 10-30 years of experience in the field and roles related to BIM implementation and uptake at the organisational level.

It was important that the framework could be easily applied to both infrastructure assets and buildings. The research team studied a number of different approaches available to develop a strategy for measuring the value of information technology in construction. It was also consistently reviewed by a group of industry and academic experts from infrastructure and buildings, and at different levels of the supply chain. An introduction to the framework was also presented at the Australasian Regional Conference organised by the International Roads Federation (IRF) and Roads Australia in May 2015. This was done to obtain feedback from a wider audience and address common concerns of BIM guidelines being often directed only to buildings and architectural design. This research builds on Love, et al. (2014) who proposed the use of Benefit Realisation Management (BRM) by asset owners. However, the present work provides a different adaptation of the BRM method and extends it to be applicable to all built environment stakeholders across infrastructure and buildings. It was also modified to include the value of unplanned and flow-on benefits as later defined, as well as used to develop a step-by-step guide and an online interactive tool.

3. BIM Value Realisation Framework

The value of BIM is realised through its benefits for different stakeholders. Benefits arise because information technology systems such as BIM enable people to carry out tasks more efficiently and effectively. They do this by allowing and shaping new ways of working through the re-design of intra- and inter-organisational processes or facilitating new work practices (Peppard, et al., 2007). The Benefits Realisation Management (BRM) approach was originally developed in the 1980s and 1990s. This method offered a way of understanding the return on investment from information technologies and systems, and overcoming the limitations of traditional investment appraisal techniques. This aspect of project management has received increasing attention in the past few years (Breese, 2012). These practices have been shown to be associated to the creation of value (Martins Serra & Kunc, 2015) and been applied to a number of sectors and stakeholder groups (Bradley, 2010; Peppard, et al., 2007). However, tailoring this framework for specific organisations and sectors is an essential step towards optimising its value (NSW Government, 2014b). Love, et al. (2014) proposed the use of BRM and resource-based view (RBV) “to provide asset owners with the capability to realize its benefits”. Although building on Love et al's idea, this research provides an alternative adaptation of the methodology to serve a larger audience and

projects at different life-cycle phases. It was also used to develop a detailed step-by-step guide and online interactive tool to provide guidance for built environment practitioners on how to operationalise the overarching framework.

The framework (Figure 1) largely follows the traditional BRM structure and principles but acknowledges that value is realised not only through specifically identified end-benefits but also through unintended benefits. This has been addressed by including “flow-on” benefits. These are benefits that can be obtained once the end-benefit is achieved. While not being specific project goals with targets and associated milestones, they are included to account for the full value delivered by implementing BIM. The monitoring processes suggests the inclusion of other considerations such as project context and unexpected situations which may hinder the achievement of specific benefits. It additionally acknowledges the role of team and organisational capabilities in attaining value from implementing BIM. This broader view may enable more complete future benchmarks and better understanding of project-to-project different levels of implementation success. Finally, it proposes that enablers have associated risk which should be taken into consideration as they may bring “disbenefits”, these are non-value-adding outcomes which are counterproductive to the implementation goals.

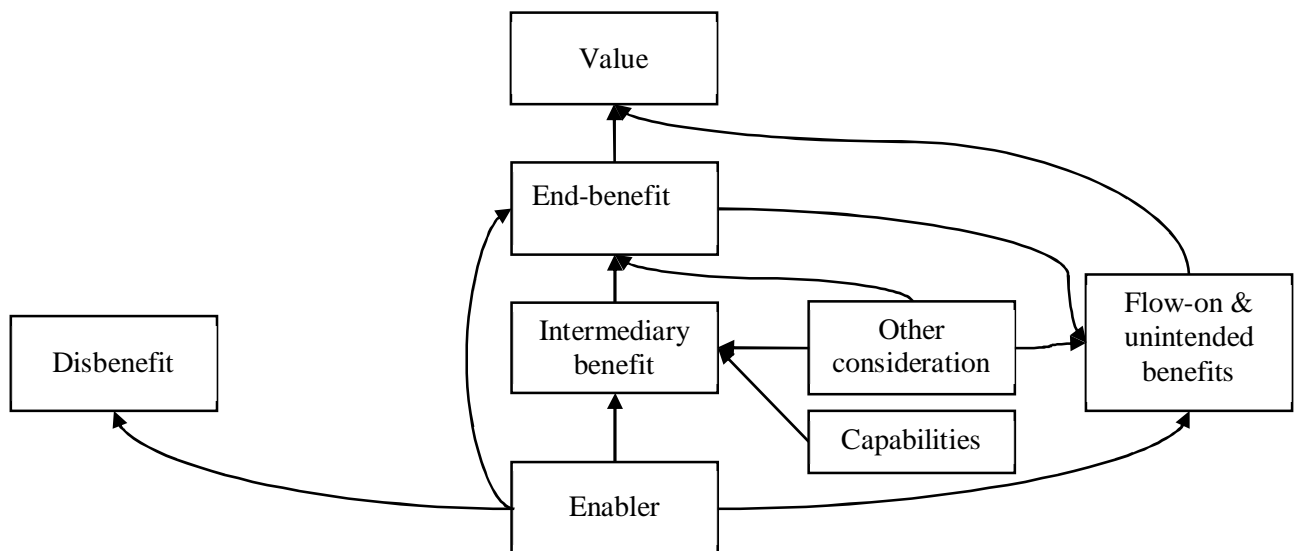


Figure 1: Framework principles

The BIM value realisation framework can be applied at any phase of the life-cycle of an asset and is meant to complement BIM implementation guidelines. The MacLeamy Curve (AIA, 2007) however applies to this process as well. This means that, as shown in Figure 2, the earlier changes and processes required to implement BIM are introduced, the larger impact they are likely to have on the outcomes of the project and realising its full value.

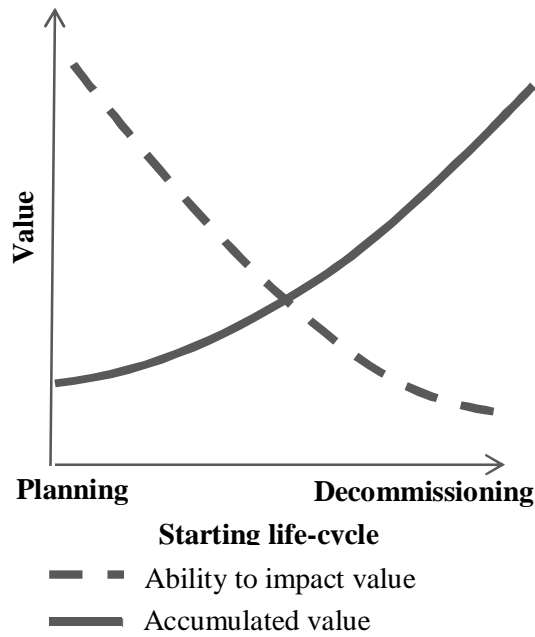


Figure 2: Value/life-cycle relationship

There is no single BIM software that covers all functionalities and processes. The value to each stakeholder is therefore delivered by identifying the specific benefits they aim to gain by implementing BIM-related tools and processes. This allows teams to have a clear understanding of the overall goals, select the path to these goals based on performance-driven objectives and establish a strategy to monitor their progress towards these goals. Thus, another key aspect of the framework is that it focuses on specific benefits driving the BIM implementation strategy and proposes specific asset and project management processes where this can be embedded.

3.1 Step-by-step Guide Summary

The detailed methodology and dictionaries were published in the book: *Delivering Value with BIM: A Whole-of-life Approach* (Sanchez, et al., 2016a). This section presents a brief summary of the main proposed steps.

Step 1 - Define end-benefits: end-benefits are the ultimate objectives. They are the value the team wants to have realised from implementing BIM – such as lower cost, improved safety and gaining competitive advantage. These are defined in a workshop environment with key stakeholders that include project manager, asset manager, designers, end-users and other relevant stakeholders. Including asset managers and end-users can help ensure a whole-of-life insight.

Step 2 - Define intermediary and flow-on benefits: these are the *story* behind each end-benefit and defined in the same workshop environment as the previous step. Intermediary benefits are those *expected* to occur between the implementation of early changes and the realisation of the end-benefits. Flow-on benefits are those that may be derived from achieving the end-benefit. There may also be unintended benefits arising from implementing specific enablers which may be identified at later stages.

Step 3 - Define enablers: enablers are processes and tools related to BIM uses and implementation. They help achieve the first intermediary benefit in the chain. A risk is associated to each enabler, and other considerations such as new skills requirements and cost need to be included in the assessment.

Step 4 - Assign metrics, targets and incentives: metrics provide the means to justifying investments made, comparing and ranking benefits, providing targets for success and

benchmarking and monitoring progress towards goals. Assigning metrics to benefits is the basic requirement to provide effective accountability. Choosing as many metrics as possible related to the identified benefits may provide better insight into the success of the implementation strategy. Targets should be assigned to each metric and, if appropriate, financial incentives for exceeding targets.

Step 5 - Embed metrics and targets into progress report documentation and processes: this ensures accountability and provides a rich source of information based on which the group can make decisions and introduce changes in a timely manner in order to correct situations that may be hindering the achievement of the goals established in previous steps. Metrics, targets and incentives should be embedded in the project documentation including the regular progress report as well as the BIM model itself as appropriate. These should also include processes to record context information that may be used to understand different levels of success across different projects.

Step 6 - Workshop follow-up / feasibility and approval: this step is a reality check to evaluate what specific software solutions can be used as enablers to achieve the selected benefits most effectively. The associated cost, for example, will largely depend on the capabilities of the project team and previous experience with specific software packages as well as licences already purchased.

Step 7 - Progress review and correction initiatives: benefits require active monitoring and advancement towards targets related to benefits should be reported on and reviewed during project progress meetings.

Step 8 - Ongoing active learning: benefits are dynamic and will change as technology develops. Therefore, benefits, enablers and metrics dictionaries should be developed and regularly reviewed and updated.

Next steps: following the value realisation strategy, there are a number of considerations that will have to be addressed such as standards, protocols, BIM management roles, risk apportioning, skill development plans and system requirements. This methodology is proposed to be complementary to technical implementation guidelines and standards.

3.2 Dictionaries

BIM is not a single software package that teams can just buy and implement in isolation. It is a new way of working that commonly includes the use of a number of tools, processes and software solutions. One of the exemplar case studies carried out for this research project was based on the design and construction of the Perth Children's Hospital in Australia. This study identified 20 different BIM-related tools and processes that were associated with 26 different benefits (Sanchez, et al., 2015). The second case study was based on the design of the New Generation Rollingstock Maintenance Centre also in Australia and identified 17 tools and processes associated with 25 benefits (Utiome, et al., 2015). This can be overwhelming, especially for new

users. To address this issue, the research team carried out an extensive literature review to develop a set of dictionaries.

The *Benefits Dictionary* includes 31 profiles of benefits that are currently achievable from implementing BIM. Benefit identification is a critical process in the BRM methodology “used to create a detailed plan of how those benefits are to be realised throughout the life-cycle of implementation and use of the new technology, process or system” (Sanchez, et al., 2016b). Benefits are defined as improvement on the status quo; as opposed to enablers which are those tools and processes used to achieve a benefit. This distinction is important because in many academic and industry publications enablers are often cited as benefits themselves. Clash detection is for example often mentioned as a benefit of using BIM. This however makes more difficult identifying appropriate metrics that can be used to monitor progress and create industry benchmarks. In this example clash detection is a tool/process; an element that cannot be measured in specific terms but just is or is not in use. The real benefit of clash detection is an improvement in the efficiency of the process of detecting clashes, brought by higher levels of automation and better communication and coordination; this in turn leads to fewer errors and lower cost. All of these are benefits that can be measured in different ways and specific levels can be targeted as success criteria.

Each profile provides a general description of each benefit and provides information about some interpretations that are specific to particular life-cycle phases. They also include a list of enablers that can help realise and maximise the value of BIM at different life-cycle phases, benefits that can flow-on from achieving the profiled benefit, main benefiting stakeholders, metrics that can be used to monitor the benefit and examples of projects where they have been achieved. The list was created based on a thematic analysis of the literature with input from the three exemplar case studies. It includes benefits at different scales that could be considered intermediary or end-benefits depending on the strategy chosen. This was done aiming to cater for progressive and incremental implementation strategies that may focus on different benefits at each step. This may be especially relevant to small and medium sized enterprises (SMEs) and cautious client organisations with limited resources.

The *Enablers Dictionary* contains information about 51 enablers grouped under two overarching categories and 28 sub-categories. The categories were developed using the Pennsylvania State University “BIM Execution Plan” (Penn State, 2011) as a starting point and further developing it based on input from industry experts. The two overarching categories are:

- (i) **Intrinsic/core:** These are enablers that were considered to form the basis of BIM and maximise benefits from its use across different life-cycle phases. These included processes that were not standard practice in many countries yet but were considered an intrinsic part of BIM implementation strategies that aim to maximise its value for all stakeholders. Examples include “design authoring and data-rich accurate models”, “early and effective stakeholder engagement” and “object libraries”.
- (ii) **In Use:** These are enablers which are either commonly used nowadays and/or that, although having had limited use in common practices, either are already growing in use

or have the potential to do so in the near future and provide significant benefits. Examples include “3D laser scanning”, “automated clash detection”, “design reviews”, “GIS-BIM” and “digital fabrication”.

The *Metrics Dictionary* aims to provide a practical way of avoiding wasted efforts often seen in recording and tracking metrics which are being tracked elsewhere. The dictionary includes a comprehensive set of 43 metrics that were found to be practical and offer a set from which each project can select those that are most appropriate to their goals and needs. These metrics are mostly based on literature but also include indicators proposed by the authors based on professional experience, experts consulted and the three exemplar case studies. Metrics were categorised in four groups:

- (i) People - serve to monitor benefits achieved through changes in behavioural patterns or that directly affect staff. Examples include “safety”, “meetings”, “stakeholder involvement” and “labour intensity”.
- (ii) Processes - monitor benefits achieved through changes to general process improvement and generally aim to measure the efficiency of these processes. Examples include “time predictability”, “schedule conformance”, “cost of change”, and “latency”.
- (iii) Procurement - monitor benefits achieved during or through procurement and asset management processes. Examples include “cost per unit”, “quality”, “program capacity” and “globalisation”.
- (iv) Sustainability and future proofing - monitor benefits achieved in terms of better environmental sustainability outcomes and improved emergency management. Examples include “resource use and management”, “carbon emissions and footprint”, “emergency latency” and “emergency plan and response effectiveness”.

It should be noted that, although case study participants highlighted sustainability as one of the drivers to implement BIM, the research team found it particularly difficult to find literature about metrics that could be included in this category. This is proposed as a potential gap in the literature for future research.

A complete list of benefits, enablers and metrics can be found online on BIM Value (see section 3.3) or in Sanchez et al. (2016a).

3.3 BIM Value

The experts consulted to test the practicality to the framework suggested that one of the main barriers to adoption is fast and easy access to information about benefits, enablers and metrics. This led to the research team translating the dictionaries into an open access online interactive tool to step through the first four levels of the framework. This tool, BIM Value (<http://bimvaluetool.natspec.org/>), provides a tailored information delivery system. It guides the user through six steps where they select the stakeholder group and life-cycle phases they are interested in and the tool provides a set of benefits that apply to those two parameters. The user can then select those benefits they are interested in and the tool provides a new list of enablers and metrics which apply to the selected stakeholder group, life-cycle phase and benefits. In the final step, it produces a report with a summary of descriptions of the different benefits, enablers and metrics selected that also includes examples and references to follow upon. The tool also

offers the possibility of accessing the dictionaries directly and provides links to other sites with BIM-related videos and guidelines. In its first week and with close to no publicity, the tool had over 240 new users trying it out, mainly from the UK and Australia. Four months later, the tool has had over 4,000 views with a return rate in March 2016 of 49.3%. This is suggested to be a reflection of the industry's interest in accessing information about tangible and measurable benefits from implementing BIM.

3.4 Research Limitations

The methodology presented here, although based on an arguably proven approach such as BRM and submitted to a thorough review process with industry and academic experts has had a limited validation process. The framework was partially validated by the Sydney Opera House which was transitioning into a BIM-based asset management system. Feedback from this effort and the previously outlined consultation was used to finalise the framework into its present form. However, although originally planned, a more comprehensive validation process was not possible due to time and resources constraints. The research team will continue to work towards the validation of the complete process in the near future.

3.5 Future Research

Future research will aim to continue to develop and improve the BIM Value tool through new modules in order to increase its value to the industry. One of such modules is for example expected to form the basis for a world-first BIM benefits benchmarking system (BIM Value Benchmark). This new effort will also seek to understand how meta-data created from using the tool can be used to most benefit the industry.

4. Conclusions

This publication has introduced a methodology to identify and monitor benefits that will serve to realise and deliver value with BIM across the life-cycle of an asset to different stakeholders. This research was based on an extensive literature review, expert consultation and three exemplar case studies. An important aspect of the research was to collaborate with industry and government organisations across the supply chain to receive feedback on the practicality and completeness of the outcomes. This collaborative effort aimed to ensure that the outcomes of the research were most relevant to different industry stakeholder groups as well as complementary to outputs of other organisations active in this space. Outcomes of this research are expected to help achieve more informed value-driven assessment and continual improvement of the implementation of BIM across assets and life-cycle phases.

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Combining BIM and Lean Construction: Towards Enhanced Collaborative Working?

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Abstract

In this paper, the influence on collaborative working by using BIM and two Lean Construction inspired tools in a real-life design process is scrutinized. Statsbygg, as the building commissioner, expected that requiring the use of BIM, as well as the two Lean Construction principles; co-location and a takt-time planning would enhance the collaborative working among the design team. The case study is based on qualitative data which stems from semi-structured interviews, observational as well as document studies. The findings indicate that the combination of BIM and co-location helped to improve the collaborative working including fostered faster communication, and contributed to a good social climate in the design team. However, the data also suggest that not all parts of Statsbygg's contractual "BIM and Lean Construction package" were equally successful in practice. The takt-time planning tool was not used at all by the design team. An explanation for this disparity in successfulness is partly due to that BIM and co-location got more attention from Statsbygg compared to the takt-time planning tool in the implementation process. Moreover, the design team had experiences with BIM and co-location from an earlier project, and thus found it easier to make use of elements that were familiar. Based on the analysis, it is concluded that the combination of BIM and co-location have a potential to impact positively on collaborative working in the design phase by linking actors together both technological and organizational. However, such an outcome requires a careful planning and implementation process.

Keywords: BIM, building process, case study, collaboration, lean construction

1. Introduction

The architectural, engineering, and construction (AEC) industry creates complex and unique buildings. Construction work is organized as projects; temporary coalitions between two or more organizations (Jones and Lichtenstein 2005). Construction projects consist of teams from different companies who work together to realize the project's goals. These industry specific characteristics are of great importance for how the industry operates. As pointed out by numerous researchers, the construction industry suffers from several unfortunate conditions that affect the industry unfavourably. Some have characterized the relationships in construction as "loose couplings" (Dubois and Gadde 2002). This notion refers to temporary coalitions of companies and individuals that come together to complete a project, and then disband. An important feature is the fragmented nature of the industry. Consequently, potent collaboration between actors from different companies throughout the constructions process is required. Still, prior experience recognizes that this is really difficult to achieve. However, in the last decade we have seen promising technology in terms of building information modelling (BIM). With the use of BIM, a network of interdependent actors can collaborate to develop and utilize a 3D object of the planned building (Taylor and Bernstein 2009). Ideally, BIM technology should create a tight technological coupling among the actors who share models (Dossic and Neff 2010). The starting point of this paper is how potentially tight technological couplings work out in an industry known for its fragmented nature.

In this paper, an explorative case study from Statsbygg is investigated. Statsbygg provides guidance in the purchase and leasing of premises and, in respect of new buildings, act as building commissioner on behalf of the Norwegian government. This case deals with the detailed design phase of a refurbishment of a university building where Statsbygg acted as building commissioner. The case study is about Statsbygg's request of using BIM, and some Lean Construction principles including co-location of the design team as well as a takt-time planning system. Statsbygg's expectation was that this combination would enhance collaborative work among the actors in the design team. By collaborative work I refer to the joint working of various actors or different organizations to effectively accomplish a project (Xue et al. 2010). However, one cannot simply assume that improved collaborative working is automatically achieved. Previous case studies have shown that implementation and use of BIM and Lean Construction are affected by the interplay between the triangle of technology, people and process. To succeed, mutual adaptations regarded to the three elements are required by the involved actors (cf. Moum 2008). Thus, the following research question will be examined: How was the collaborative work among the design team in the case studied affected by the request of using BIM and Lean Construction?

2. Conceptual framework: Lean Construction and BIM

Taiichi Ohno is the person usually credited for having launched the Toyota Production System (TPS), which can be seen as a precursor to what is here referred to as Lean Construction. Lean thinking is generally based on the following five principles: 1. the value associated with the product as specified by the customer. 2. The value stream, identifying the value stream for each

product and to avoid waste. 3. Flow, to create a value flow without interruption. 4. Pull, to let customer needs guide the production process. 5. Continuous improvement, creating a continuous improvement throughout the process (Womack and Jones 1996). Lean Construction is inspired by TPS, and emerged as a concept in the early 1990s. Lean Construction is based on an assumption that Lean manufacturing principles cannot be transferred directly to the construction industry. The construction industry is characterized by more variety and uncertainty about production compared to the manufacturing industry. Koskela (2000) proposed the use of the Transformation-Flow-Value (TVF) theory where production was conceptualized in three ways: 1. As a transformation of inputs to outputs. 2. As a flow, in addition to transformation there is waiting, inspection and moving stages 3. As value; where production is seen as means for the fulfilment of the customer needs. The conventional conceptualization of production within construction industry has been based on the transformation concept only. This implies that production management in this conceptualization is all about dividing the total transformation into tasks which is sought to be handled as efficiently as possible. Koskela (2000) claims that all three conceptualization are necessary and they should be used simultaneously. The TVF theory led to the birth of Lean Construction. The aim of Lean Construction is thus “... to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value” (Koskela et al. 2002, p. 211). It is significant to stress that the term Lean Construction may refer to the use of Lean in the entire construction process and not only the construction phase. However, in this paper Lean Construction is used to denote the use of Lean principles and tools in the design phase (cf. Emmitt et al. 2004).

The acronym BIM can be used to refer to a product building information model, a structured dataset describing a building, or an activity building information modelling - the act of creating a building information model (Moum 2008). In this paper, BIM is a term referring to three-dimensional computer-aided and product-oriented design technologies and processes in the AEC-industry. With the use of BIM, a network of interdependent actors can collaborate to develop a model of the planned construction works (Taylor and Bernstein 2009). A frequent scenario is that the designers merge their discipline-specific models to a multidisciplinary model, and by using applications for visualization and collision controls get a better cross-disciplinary understanding of each other's requirements, detecting conflicts, errors and omissions across disciplines (Moum 2008).¹ It has been argued that the construction industry may be facing a new paradigm triggered by BIM (Azhar 2011). This paradigm shift is partly expected to change the traditional discipline's practices towards more integrated processes. It is also expected that BIM can result in a seamless flow of information across different actors and disciplines in the construction process. This implies that it is not only a change in technology itself, but that the change also affects procedures, tasks, roles, etc. Consequently, the new paradigm can be seen as organizational as well as technological. One of the most striking arguments for implementing BIM is that it has the potential to improve the collaboration among the actors involved in the construction process. To

¹ In this scenario, BIM is not used to its full potential. See this link for a discussion of different BIM maturity levels: <https://www.thenbs.com/knowledge/bim-levels-explained>

accomplishing these promised improvements, the project team needs to adapt and work together in an integrated unit.

2.1 BIM, Lean Construction and collaborative working

Lean Construction and BIM are not dependent on each other. This means that Lean Construction can be adopted without BIM and BIM can be adopted without Lean Construction. However, evidence of interactions between Lean Construction and BIM has been identified. In a paper, Sacks et al. (2010) discuss interactions of Lean Construction and BIM. Based on a comprehensive analysis they find that Lean Construction and BIM have several overlaps. Consequently, the authors claim that: “... *the breadth and depth of interconnections between them [Lean and BIM] implies that any company or project on a lean journey should seriously consider using BIM for enhancing the lean outcomes. Conversely, any company or project implementing BIM should ensure that their adoption/change process is contributing to the fullest extent possible to making their processes leaner*” (Sacks et al. 2010, p. 979). Based on this conclusion, I assume that the potential for improvement of a construction process are enhanced when BIM and Lean Construction are integrated. As the discussion above shows, basic premises for both BIM and Lean Construction are about improving collaboration by different actors in the construction process. This was also present in Statsbygg’s thinking in the project. Statsbygg assumed that BIM and Lean Construction positively affect each other and that the combination of the two would strengthen the collaborative work in the design phase. The relationship between BIM, Lean Construction and their impact on collaborative working as it is perceived in this paper, is illustrated in figure 1. In the following, figure 1 will be briefly explained. The introduction of BIM and Lean Construction in a project may have impact on collaborative work in all parts of the construction process. In addition, using BIM and Lean Construction can affect and influence different processes on several levels. Following Moum (2008), three levels can be identified: 1. the micro-level which focus on individual processes. 2. The meso-level covers processes and mechanisms within a group, for instance the design team. 3. The macro-level covers mechanisms on the overall project level. There has been increasing recognition in research that collaborative working is one of the most important and critical success factors for construction projects (Xue et al. 2010). In this paper, collaborative working constitutes the “dependent variable”, while BIM and Lean Construction are the two “independent variables”. This paper studies the impact of BIM and Lean Construction on collaborative working delimited to the *design phase*. This is no coincidence; a fundamental pillar of a successful construction project is a good design process (Moum 2008). Thus, I concentrate on BIM and Lean Construction’s impact on collaborative working among the design team. This implies that processes primarily on the *meso-level* will be in the spotlight (highlighted in figure 1).

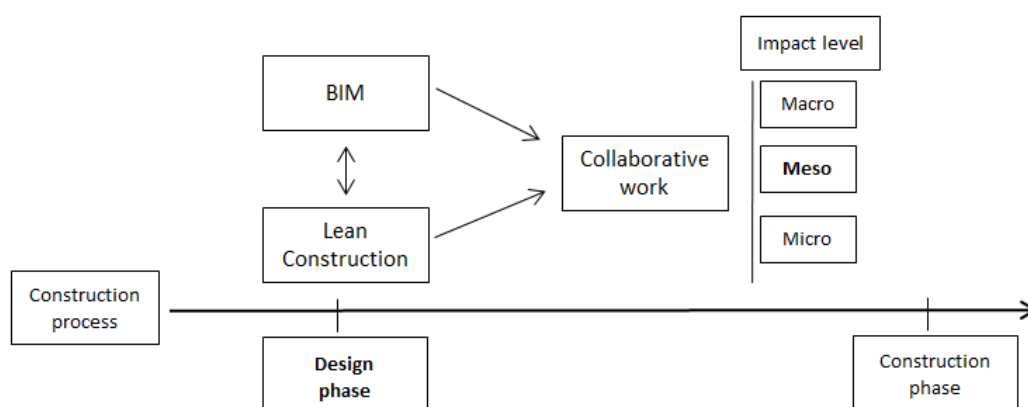


Figure 1. BIM, Lean Construction and collaborative work.

3. Methods

According to Yin (2003), a case study consists of an in-depth inquiry into a specific and complex phenomenon, set within its real-world context. Case studies are seen as appropriate to answer “how” and “why” questions and allow for the investigation of many variables consequently generating in-depth knowledge (Yin 2003). In this paper the impact of using BIM and Lean Construction on collaborative working in a real-life construction project is studied. Consequently, an in-depth case study seems necessary. The case study in this paper is based on qualitative data which are generated from semi-structured interviews with leaders and “hands on” project participants; this includes both people from Statsbygg and the design team. The purpose of the interviews was to get informants' own assessments of the project and how the use of BIM and Lean Construction affected different aspects of collaborative work. In the interviews, I asked questions about how co-location influenced collaboration across organizational boundaries, how BIM was used across disciplines as well as what takt-time planning meant for planning processes. All interviews were done in Norwegian. Consequently, the quotes used in this paper are translated from Norwegian to English by the author. All in all, it was conducted eleven semi-structured interviews. As a part of the data collection I have also observed five design meetings. About 10 persons attended each of these meetings. In this part of the study I chose a non-participant strategy (Yin 2003). Such a strategy implies that I was not a part of the activity taking place at the meetings, but simply visible observers. In addition, documents have been used as a supplement to other data types generated through interviews and observation. The documents are mainly project-specific documentation from Statsbygg. This includes contracts and tender documents, written information about the building, as well as more general information such as Statsbygg's current BIM manual.

4. The case: Urbygningen

Statsbygg is one of the industry partners in an ongoing Norwegian research project called SamBIM (Collaboration with BIM as a catalyst) financed by the Norwegian research council. This research project is based on a joint effort of Norwegian industry and research partners. In this project several actors from the construction industry wants to try out and develop BIM-driven processes and collaborative models that boost value creation in the SamBIM partners, in the building projects, and in the AEC-industry.

The case study in the paper deals with the detailed design phase of a refurbishment of a university building named *Urbygningen* at the Norwegian University of Life Sciences (NMBU) located outside Oslo. This building project is one of Statsbygg's contributions to the portfolio of case studies in the SamBIM project. The detailed design phase lasted from April 2013 to august 2014. The buildings gross floor area is 8.190 m² and the budget for refurbishments is 307.5 million NOK. The rehabilitation of Urbygningen has been a long-drawn process. The preliminary design was completed in 2009. Then, the project was abandoned for several years while waiting for the necessary government funding. In January 2013, Statsbygg received an assignment from the

Norwegian Ministry of Education and Research to start up the process for rehabilitating the building Urbygningen at NMBU. In March 2013, Statsbygg put the project out to tender. The task was about hiring a design team for carry out the detailed design phase. Because of the connection to SamBIM, the building project's ambitions were raised compared to a more “normal” Statsbygg project according to some of the informants from Statsbygg. In the contract documents it was also emphasized that the project should be executed as what is referred to as a “Lean project”. One of the tender documents had a distinct focus on collaborative working, BIM and Lean Construction. This document was titled “Collaboration memo” and describes how Statsbygg envisioned BIM and Lean Construction in this project. In the document we can read the following: “... *Lean construction should be used in this project, both during the detailed design phase and construction phase. Lean is introduced in the project together with BIM and logistics planning. Lean is about creating flow between individual actors, disciplines, phases and tasks in a construction project allowing holistic process. An important factor succeeding with Lean is that everyone in the project participates and is willing to take part of the process*” (Statsbygg 2013). Altogether, Statsbygg anticipated that the use of BIM and Lean Construction should lead to a project with more collaborative working among the actors in the design team thus leading to better design phase (Statsbygg 2013).

4.1 Implementation: How was the design phase carried out?

Based on a competitive tendering, a design team was selected. The chosen design team was a constellation of five Norwegian consultant companies. This group started their work in the spring of 2013. In the very beginning of the design phase the whole design team attended a training course where they were given a brief introduction to the main ideas of Lean Construction and takt-time planning principles. According to my informants the takt-time planning principles were neither used nor particularly mentioned throughout the design phase. This lack of use was by my informants related to the fact that the design team itself did not have any experience with such principles. In addition it was emphasized that the planning principles was not further requested by Statsbygg during the design phase. In other words, it was mainly the design team's responsibility to determine the organizing of their work, albeit based on Statsbygg's contractual specifications. It was in particular the use of BIM and co-location of the design team in a so-called big room which got most attention and became the fundamental work principles. This kind of working implied in this project that the design team should be co-located in a common office two days a week. This form of working is inspired by Lean Construction and some principles taken from so-called Virtual Design and Construction (VDC) (Chachere et al. 2009). There exists several touch and overlaps between Lean Construction and VDC. An important shared feature is the focus on activities that bring value to the project and minimize waste activities. When working co-located, all relevant actors are gathered in a big room where they work simultaneously using technology such as BIM. In this construction project, the big room was furnished with desks, one interactive whiteboard as well as an old fashioned screen and projector. In addition, adjoining offices were made ready for separate meetings, phone calls etc. They also had a fairly large room where everyone had a permanent work station. Statsbygg and the design team agreed upon a weekly schedule. The schedule meant that the main disciplines should be present two days each week together with representatives from Statsbygg. Representatives from the end-user would also

be present when needed. The intentions with this form of working were to strengthening collaborative working, including the interdisciplinary collaboration as well as reducing waiting time.

5. Findings

In my interviews, I was concerned about getting deeper insight into how the use of BIM and Lean Construction affected the relationship and collaborative working among the actors in the design phase. These are processes which primarily are located at the meso-level as discussed in the paper's conceptual framework (figure 1).

All actors interviewed were familiar with BIM from earlier projects. Most of them had worked on several BIM-enabled projects. When asked about BIM and collaboration, almost all informants told that BIM had led to a better understanding and knowledge of the other designers' work and had brought valuable opportunities for interdisciplinary control. Below is a quote that demonstrates what a number of informants told in the interviews:

"BIM is a significant improvement. It is easier to work together when we have a common model. I can see what's have been done by others. I can also see how other designers have planned and how I must relate to their work" (Designer).

In the quote above, aspects related to the interdisciplinary work are highlighted as favorable by using BIM. Nevertheless it was especially the combination of BIM and co-location in a big room my informants emphasized as particularly useful. All informants' from the design team had earlier experience from projects where co-location and BIM were used in combination. This experience was by several pointed out as something valuable because the team knew about the working methods and what that entailed. In addition, the design team was familiar with each other from a Statsbygg project some months in advance, were the combination of BIM and co-location was tested. Some informants claimed that this familiarity gave the project a flying start because the team did not have to "go up a completely new path". Below follows a quote from an informant who underlined the significance of being familiar the "new" way of working form prior projects:

"This [the co-location of the design team] was not completely new to me. I have been working on another project with Statsbygg where we were co-located two days each week biweekly. Several persons from the design team [in this project] were also involved in that project" (Designer).

5.1 More and better inter-organizational collaboration

Several of my informants upheld that the combination of BIM and the co-located type of working had facilitated the group working together as a unitary team. This was partly explained by pointing out that it was much easier to approach designers from other disciplines and companies when the team was co-located and the intention was that they should work together. Some informants pointed out that this kind of working contributed to erase the organizational boundaries between

the different companies. The two following quotes illustrate some of what is discussed in this section; in addition they show that the informant's claim that they behave differently towards people they get to know better:

"... it is about that we get a different relationship, a better relationship, with the other persons in the project when are co-located and working together compared to the 'usual projects'. This is my experience at least" (Designer).

"I think maybe I behave a little differently towards the other people in the project [when co-located]. I mean, differently towards the people I do not usually work together with in my company" (Designer).

The next quote illustrates the dynamics that may occur when the design team is co-located. The informant points out that designers who initially was not a part of a discussion easily can join in and contribute to the interdisciplinary development of the project:

"I think it is very positive to be co-located... If I have a problem I need to discuss with another discipline. Traditionally, I would make a phone call. However, when we are co-located and talk together often also other consultants are drawn into the discussion make important contributions. This would not happen if just the two of us talked about this on the phone" (Designer).

Some of my informants also claimed that working co-located with BIM had a positive impact on what they referred to as the team spirit. Because of the co-location the actors spent quite some time together socializing; working, held meetings and had lunch breaks twice a week. In my interviews, the social aspects were a recurring theme. Two informants put it like this:

"We have spent much time together, it's nice and I think that it has helped us to create a good social atmosphere in the group" (Designer).

"Co-location has a positive effect on faster communication. In addition it can also prevent conflicts, and create a better atmosphere [in the design team]" (Designer).

5.2 Faster communication and shorter waiting periods

Several informants were particularly concerned about being co-located, which they perceived as leading to short lines of communication and better opportunities to make decisions quickly; *"decisions can be made right away on the spot"*, as one designer said. Especially the combination BIM and co-location opened for faster ways of communication. Using BIM co-located made it feasible to go quickly into the model together, to watch and discuss different scenarios. Some informants argued that such a combination meant that they could make clarifications and quick decisions, as compared with traditional projects that could take several days if the communication took place on telephone or email. This may imply that the design phase in full can be completed faster with this way of working. In the interviews, the informants told a great deal about faster

communication and reduced waiting time. Below is a quote that summarizes an essential part of what I was told in the interviews:

“The greatest profit in my view is that we have access to everyone who know something about the project in less than a minute - often it takes only 10 seconds [to contact other members of the design team]. This makes things very efficient. In that sense, other projects can learn a lot” (Designer).

5.3 A challenging aspect: “professional loneliness”

Even though a number of positive sides of working co-located with BIM for the collaborative working were mentioned, some more difficult aspects came up in the interviews. Several informants told that being away from the workplace and then from their own professional environment could be challenging. This is due to the lack of co-workers or others with more or less the same educational background for discussing professional issues. Such an aspect can be denoted to as a kind of professional loneliness. One informant told about the professional loneliness in this way:

“You lose some of the contact with others in your profession. In my previous project, the whole group was co-located, it was better. It was an advantage. In this project I feel a bit ‘lonely’. At my workplace I have a lot of colleagues to discuss with” (Designer).

Most of the processes discussed in this paper are group processes at the meso-level. However, professional loneliness primary concerns individual design team members at the micro-level (cf. figure 1).

6. Discussion

Prior research has pointed out that collaboration problems in construction processes are partly caused by industry characteristics. The industry is project based, meaning that construction projects most often consist of participants from several different companies working together for a limited time span (Jones and Lichtenstein 2005). The central question in this paper is then if the combination of BIM and Lean Construction can help to remedy this problem and thus lead to enhanced collaborative working among the design team?

My data suggest that this to some extent occurred. In particular, it turned out that the combination of BIM and co-location of the design team generated quite good results on the collaborative working. This is in accordance with the framework presented in section 2.1. Hence, the findings point to that BIM and Lean Construction influence each other positively in enhancing collaborative working. First and foremost, virtually all my informants were very satisfied with the use of BIM. Several informants told that BIM makes it easier to collaborate across disciplines and companies. The informants highlighted the opportunity to work on a common model, carry out clash controls, and the visualization possibilities as especially useful and important for strengthening the collaborative working. In addition, almost all informants stressed that the use

of BIM in combination with co-location of the design team fostered fruitful climate of collaboration. Several informants also stated that communication is going faster under such conditions; the co-located team can quickly find good solutions while using BIM technology to visualize complex problems and potential solutions. These kind of situations opened up for making decisions “on the spot”, which was particularly advantageous. In addition, quite a few told some more about social aspects; when working closely together each week the member of the design team becomes more familiar with each other and that could result in a greater level of understanding for others professional perspectives. In other words, my findings point toward that such an approach helped to improve the inter-organizational and interdisciplinary collaboration, fostered faster communication and made improvements in waiting time, as well as it contributed to build understanding among the involved actors. As a whole, this contributed to enhance the collaborative working among the actors in the design team. Despite many positive experiences, some informants also expressed that co-location could lead to a form of professional loneliness. This happened as a result of missing colleagues with more or less the same competence to discuss professional issues when co-located.

However, the data also reveals that not all parts of Statsbygg’s contractual “BIM and Lean Construction-package” were successful in practice. This relates especially to the intended use of a Lean Construction inspired takt-time planning concept. In the findings I described that the building commissioner Statsbygg specified some specifications. However it was largely the responsibility of the design team itself to take care of the implementation. The empirical presentation and discussion in previous sections has shown that the informants consider that they succeed quite well with implementing BIM and working co-located, but not with takt-time planning. According to the informants from the design team, the lack of using the takt-time planning system could partly to be explained by fact that it was not further requested by Statsbygg during the design phase. In addition, the design team did not have any experience with such a system. The lack of demand combined with limited experience made it easy for the design team to take the presumably easiest path; they chose what they had done some months ago, namely BIM and co-location. This is not necessarily a bad choice. It implies that the design team applied a model they knew worked quite well and that they could further improve in this project. A drawback is that such a decision easily can lead to a kind of lock-in situation where old certainties are exploited rather than searching and exploring for new and perhaps more superior ways of working (March 1994). Because of the design team’s lack of experience, it would probably be favorable if Statsbygg as an actor with a lot of resources to a larger extent had been helping to facilitate the implementation process in this case. This can be seen in connection with another SamBIM case project where Statsbygg played a much more active role in the implementation process. In that project Statsbygg was a driving force in the implementation of BIM and various Lean Construction tools in the design phase. At the same time Statsbygg emphasized to involve the design team in decisions about BIM and Lean Construction (Bråthen and Moum 2015). Bråthen and Moum (2015) claim that Statsbygg’s active role combined with the involvement probably was essential for the successful implementation. As the analysis points out, BIM and co-location had a quite good effect on the collaborative work in the case studied. However, this positive effect could possibly be even better if the takt-time planning system had been adopted together with BIM and co-location as initially planned by Statsbygg. Earlier research such as

Sacks et al. (2010) emphasize that great advantages can be realized when several processes and tools are combined.

7. Conclusion

The various processes and tools that Statsbygg planned to test out in this construction project turned out quite differently in practice. The disparity in successfulness is probably partly due to that different elements being emphasized in varying degrees by Statsbygg in the implementation process. Put differently, elements which are given little or no attention in the implementation process are less likely to lead to good results. Due to no knowledge within the design team combined with little attention from Statsbygg in terms of takt-time planning, there was not created a necessary ownership and a common vision for the use of this planning system in the project. These shortcomings were probably significant for the less successful result of the takt-time planning system compared to the combination of BIM and co-location. This argument may also have a more practical implication for actors like Statsbygg who wants to take an active role in the development of the construction industry. To succeed with new working methods, the actual implementation and development process “on the ground” is just as important as formulating well considered and innovative contract specifications.

Despite this, it is important to be aware of the limitations of this case study. There are certainly some factors in this pilot case which distinguishes it from “the usual construction project”. One factor is related to the fact that the design team knew each other quite well and had worked co-located with BIM in another Statsbygg project some months earlier. This “earlier experience factor” may have led to better results than usual since the constellation already knew each other and had partly adapted work principles. In addition, the findings in this paper are limited to a single case study. Further research from other contexts is thus needed to draw firm conclusions which could be applied to the construction industry at large. Despite the abovementioned limitations, it appears that BIM and co-location have a potential to impact positively on the collaborative work in the design phase of construction projects by linking actors closer together both technological and organizational. For that reason, the previously proposed conceptual framework finds support in the empirical evidence. Indeed, such a successful outcome requires a careful planning and implementation process.

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The Information Modeling and the Progression of Data-Driven Projects

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Abstract

The aim of this paper is to investigate different approaches adopted to define the content of a Building Information Model (BIM). In order to improve the effectiveness of the Built Asset during the whole life-cycle, the Construction Industry is moving towards a digital eco-system. Thus, the implementation of Data-Driven Projects based on Building Information Modeling is wide-spread and becomes more and more a mandatory requirement. The Building Information Modeling methodology is based on an Information Model that contains the updated and amended information related to the project, starting from Briefing and Conceptual Design. So to achieve a performing process, it is essential to provide any needed information at the right time. For this reason, several concepts related to the definition of data sets belonging to BIM, such as 'Level of Development' and 'Level of Detail', have been established. The main focus of this study is to provide an overview on this topic and to investigate possible different approaches. The study is based on both literature review and interviews. The findings indicate that there is not a univocal approach suitable to manage this issue, and numerous definitions and acronyms have been defined in different Countries, especially in US and in UK. However, it is possible to compare them and to find similarities. The findings can be used to gain an in-depth understanding on this topic, especially for experts who work with BIM in various Countries.

Keywords: Building Information Model, Level of Development, Level of Detail, Level of Definition, Level of Information.

1. Introduction

In order to achieve whole life-cycle effectiveness, the Construction Industry is moving towards a digital eco-system. The implementation of Data-Driven Projects based on Building Information Modeling is spreading and becoming more and more a mandatory requirement. Indeed, several Countries such as the UK, Germany, Spain and France are actively mandating governmental strategies, seeking to promote a Smart Construction Industry. The Building Information Modeling methodology is based on a Building Information Model (BIM) that virtually represents the design and project, and contains updated information (Eastman et al., 2011). In order to attain any expected outcomes, it is essential to provide needed information at the right time to the right person. For this reason, several concepts related to the definition of data within the BIM have been developed. Different data are needed for different purposes; thus, from the early beginnings it is important to clearly define the authorized uses and responsibilities. Authors themselves realized that nowadays there is not a clear understanding of these concepts and the literature does not provide enough findings. Thus, the focus of this paper is to provide an overview on this topic and to investigate possible approaches as well as similarities. Finally, a possible future scenario concerning the data management is discussed.

2. Methodology

First, in order to obtain information on the data management within Information Modeling, a literature review has been performed. The concept and application of this topic is still relatively new, thus, there are limited scientific existing studies. The literature review therefore does not include only academic publications, such as journal papers and books, but it incorporates also guidelines, specifications, protocols, standards and reports published by governments and other regulatory bodies, blogs and articles published in respected online newspapers. Different types of databases have been analysed: both scientific (e.g. *ScienceDirect*[®]) and non-scientific (e.g. *BuildingSMART*[®]) available online. The same keywords ('Building Information Modeling' and 'Building Information Model' associated to 'Level of Detail', 'Level of Development', 'LOD') have been used to find references. Sixty-two documents have been analysed, but only part of them were useful for the research work and are included in the reference list. Later, semi-structured interviews were carried out with five public agencies that delivered publish standards (in UK and US) as well as with their consultants. The interviewees were selected based on their role (e.g. BIM Managers) and experience in this topic to better understand how documents and tools, related the management of data within a BIM, are implemented as well as possible benefits and challenges. The interviews were conducted in person and they were recorded. Afterwards, in order to analyse data, responses were transcribed into statements where evidence was convergent.

3. An Overview on the Progression of Data-Driven Projects

This paragraph is based on literature review and it presents the principal initiatives to support information production and exchange within a BIM. At the end of the paragraph, Table 1 summarizes such initiatives and compares different definitions, acronyms and classifications.

3.1 The origin of ‘LOD’: from Information Levels to Level of Detail

Denmark has been one of the first Countries to define a classification for information within BIM (van Berlo et al., 2014). The *3D Working Method 2006* introduces seven (0-6) *Information Levels* to set the content of discipline models at a given time in the design process. The Information Level is a ‘*stage of information content and/or quantity*’ and it is related to ‘*individual discipline models and building elements and/or geometrically limited building sections*’ (BIPS, 2007). The seven levels describe a rising degree of detailing and correspond to the traditional construction phases, but they can be customized to allocate roles based on the nature of tasks (BIPS, 2007). The document suggests to use a table in order to clarify Information Levels for each phase and working practices (BIPS, 2007). Moreover, for each Information Level the document shows *Graphical representation, Alphanumeric representation, Objective, Parties/responsibilities, Content, Use, Degree of detailing* and *Classification* to be used (BIPS, 2007). It is possible to affirm that the Information Level is related to geometrical as well as non-geometrical data that different parties can rely on. This concept has been incorporated in the Australian CRC document in 2009, but Information Levels are associated with *Model Development phases* (0-6) and *Object data levels* linked to Level of Detail (A-E). The Level of Detail refers to ‘*detailed geometry and with additional or different information attached to the objects*’ (CRC, 2009).

In 2004 the software company Vico Software started to work on a standard apt to facilitate the management of information within a BIM (Bedrick, 2008; Vico Software, 2015). Indeed, Vico developed the Model Progression Specification (MPS) defined as ‘*a language that owners, designers, and builders can use to define every element and task in the building construction process. It serves as a coordination point for information about the building, what is being modeled, and to what level of detail it is being modeled, estimated, and scheduled. It provides the efficient framework for the project stakeholders – a written checklist that matures from a very schematic level of detail to a high level of detail in terms of 3D geometry, cost, and time*’ (Vico Software, 2015). Vico created a standard to manage BIM in an effective way, introducing the MPS concept as well as the ‘Level of Detail’. The Level of Detail plays an important role within the MPS and is defined as ‘*the specificity required for a particular element at a particular stage of the project*’ (Vico Software, 2015). Moreover, the ‘*level of detail for a BIM model must correspond to the needs of the modeler, the project engineer, and the estimators and schedulers. LOD identifies how much information is known about a model element at a given time. This "information richness" grows as the project comes closer to breaking ground*’ (Vico Software, 2015). Thus, for Vico the ‘Level of Detail’ concept is associated to the reliability of information in a particular period of time and it also refers to a quantitative aspect that progressively increases. The acronym ‘LOD’ for the first time is used for ‘Level of Detail’.

The company Webcor Builders teamed with Vico to further develop this concept, and later they brought it to the technology subcommittee of the American Institute of Architects (AIA) California Council’s Integrated Project Delivery (IPD) Task Force (Bedrick, 2008; Vico Software, 2015). In 2008 Bedrick defined the Level of Detail as ‘*descriptions of the steps through which a BIM element can logically progress from the lowest level of conceptual approximation to the highest level of representational precision. It was determined that five levels, from*

conceptual through as-built, were sufficient to define the progression. However, to allow for future intermediate levels we named the levels 100 through 500. In essence, the levels are as follows: 100. Conceptual; 200. Approximate geometry; 300. Precise geometry; 400. Fabrication; 500. As-built. The definition is linked to a ‘BIM element’ and not to the entire model. Bedrick (2008) also provided a definition of each level in a table and he reported some ‘Authorized uses’ of the BIM. The Level of Detail can be used in two different ways: (1) to define phase outcomes and (2) to assign modeling tasks (Bedrick, 2008). In the first case, the Level of Detail of various elements must be defined because even if elements progress from one level to the next one, they can have different rates at the design develops (Bedrick, 2008). This concept is very important because it moves from the concept of scale in traditional design process where all elements are represented in a homogeneous way. Thus, it is clear that the requirement of a BIM at e.g. LOD 200 no longer makes sense. The second use, instead, deals with the ownership of the geometrical representation of elements (Bedrick, 2008). Indeed, the *Model Component Author (MCA)* is introduced as ‘*responsible for creating the 3-dimensional representation of the component, but not necessarily for other discipline-specific information linked to it*’ (Bedrick, 2008). In this case, a separation between the geometrical representation of a component (3D geometry) and any data associated with it is clear. Thus, the MPS can track only who is in charge of the geometry creation and not who is responsible for the information, which usually is the most important part of a BIM.

3.2 The introduction of Level of Development

Later, the work performed by the AIA California Council’s IPD Task Force was adopted by the AIA National Documents Committee to be developed (Bedrick, 2008). In 2008 the concept was incorporated in the *E202™–2008. Building Information Modeling Protocol Exhibit*¹ (AIA, 2008). The AIA evolved the notion into ‘Level of Development’ (Bedrick, 2013a). The AIA (2008) document does not contain any references to the Level of Detail and the acronym ‘LOD’ stands for Level of Development. The *E202™–2008* defines the protocols, expected LOD and Authorized Uses of the BIM for a specific project. Moreover, thanks to a Model Element Table, specific responsibility (Model Element Author/MEA) is assigned for the development of each Model Element to a defined LOD at each project phase (AIA, 2008). The Level of Development is defined as ‘*the level of completeness to which a Model Element is developed*’ (AIA, 2008). The *E202™–2008* defines five progressively detailed levels (100, 200, 300, 400 and 500). Each subsequent LOD builds on the previous one and includes all previous characteristics (AIA, 2008). Moreover, for each level it gives a definition of the *Model Content Requirements* and it explains the *Authorized Uses* that can be customized (AIA, 2008). The LOD refers to the reliance on Model Elements; so, even if they could include more data than required, any user may rely only on the accuracy and completeness of the stated LOD (AIA, 2008). In the AIA (2008) document the MEA is responsible for both geometrical and non-graphical aspects of the Model Element and from LOD 200 to 500 also non-geometric data can be attached.

¹Definitions from AIA Documents have been reproduced with permission of The American Institute of Architects, 1735 New York Avenue, NW Washington, DC 20006.

After the publication of *E202™–2008*, Vico continued to develop the MPS releasing version 2.0 in 2010 included ‘Aspects’ and ‘Classes’ concepts (Vico Software, 2015; Trimble Navigation, 2013). For each ‘Classes’ a *Target Level of Detail* can be defined (000, 050, 100, 200, 300, 400, 450, 500, 550, 600) (Vico Software, 2015). However, a clear definition of each Target Level of Detail is not available. In 2011 the latest version MPS 3.0 introduced different types of generic building elements called ‘Primitives’ (Vico Software, 2015; Trimble Navigation, 2013). Trimble Navigation (2013) developed a guide for each ‘Primitives’ showing Model ‘Classes’ with written requirements (mostly geometrical) and images. The guide (Trimble Navigation, 2013) does not provide any reference to suggested Level of Detail for each Model ‘Classes’. The main focus of Vico is on 5D; for this reason the structure of MPS mainly supports effective cost and schedule evaluations rather than the overall process.

3.3 The use of LOD in several Guidelines and the introduction of ‘Model Granularity’ and ‘Grade’ definitions

In 2010, the Department of Veterans Affairs (2010) published ‘The VA BIM Guide’ that includes a spreadsheet, ‘Object Element Matrix’, to define BIM objects, properties, and attributes for each Level of Development (LoD). Both acronyms ‘LoD’ and ‘LOD’ are used and definitions of Level of Development are based on the *E202™–2008* (Department of VA, 2010). Later, the NATSPEC published the National BIM Guide (2011) including the *NATSPEC BIM Object/Element Matrix* based on the Department of Veterans Affairs matrix. In addition, the NYC DDC (2012) introduces the *Model Level of Development (LOD)* concept as ‘*level of detail to which a Model is developed and its minimum requirements. The Level of Development is accumulative and should progress from LOD 100 at Conceptual Design through LOD 400 at completion of Construction*’. However, it also ‘*describes through five categories, the completeness of elements in a Building Information Model. Completeness will range from geometric detail to element information*’ (NYC DDC, 2012). There are some inconsistent aspects between the two definitions because the first refers to the ‘*Model*’, while the second to ‘*elements*’ of the BIM. In the appendix, there are Object requirements tables to set LOD from 100 to 400, however, the guideline presents also LOD 500; for this reason, Table 1 contains a (?). The DDC Level of Development has been developed in alignment with the *E202™–2008* and it introduces the *Model Granularity* concept as the ‘*representation of geometry needed to support specific BIM use*’ (NYC DDC, 2012). It is associated to the ‘*level of detail needed*’ that can ‘*vary by object and by model, and the BIM itself may not represent the exact design intent of real live elements*’ (NYC DDC, 2012). Another US institution, the Pennsylvania State University (2012), has adopted the *E202™–2008* Level of Development standard for their projects, but it expanded the LOD 500 category (510, 520, 530, 540, 550) to more adequately meet their needs for operation and maintenance phases. Table 1 contains a start (*) under LOD 500 to remind that this level has been further developed.

In 2012, the US Army Corps of Engineers (USACE) released the BIM Minimum Modeling Matrix (M3), a spreadsheet for modeling requirements. It contains three levels of Development (LOD) from 100 to 300 (USACE, 2012) based on *E202™–2008*. Moreover, the *Element Grade (GRADE)* is added to the LOD concept because ‘*within each Level of Development, there is the potential to represent information in various formats. In practice, it has been proven that there*

are certain elements for which there is a greater benefit in providing 3-dimensional representation, while in others drafting or representation in the form of narratives is sufficient for a particular deliverable' (USACE, 2012). The M3 contains two columns to specify the Grade (A, B, C, '+'); there is not a column for the MEA, but a *Primary Discipline* can be set.

In the UK, the AEC (UK) Initiative released for the first time a BIM Protocol in 2009 and in 2012, published version 2.1. It introduces the *Model Development Methodology* concept that is related to the Level of Detail, also called *Grade* (AEC (UK), 2012). Even if the protocol recognizes that the '*graphical appearance is completely independent to the metadata included in the object*', there is only a classification for geometrical aspects (G0-G3) (AEC (UK), 2012). This concept has been included in the first version of the AEC (CAN) BIM Protocol (2012) together with new acronyms ('LOD^{ev}' for Level of Development and 'LOD^{et}' for Level of Detail). However, the last version (2014) includes only the Level of Development (LOD) concept that is related to both Model Elements and Model.

In Netherland, even if the concept of Level of Development has been used, there has been a lot of confusion on the real meaning (van Berlo et al., 2014). Thus, seven *Information Levels* (0-6) have been created following the Danish standard (BIPS, 2007) together with a matrix, a practical guide and a project template (van Berlo et al., 2014). The practical guide contains the purposed use of *Information Levels* supported by pictures and use case examples (van Berlo et al., 2014). The project template is used as a spreadsheet that holds a demarcation of the project and for each section; responsibilities, status of that model, classification system and minimal Information Level can be defined (van Berlo et al., 2014). In this case, the Information Level could be assigned to the model or part of it, and not only to Model Elements.

3.4 The new version of AIA documents and the BIMForum LOD Specification

In 2013, the AIA published three new documents related to the management of a BIM that should be incorporated into an agreement between parties and used in conjunction: *E203™-2013*, *G201™-2013* and *G202™-2013*. In addition, the AIA published the *Guide, Instructions and Commentary to the 2013 AIA Digital Practice Documents*. According to the *E203™-2013*, the Level of Development (LOD) describes '*the minimum dimensional, spatial, quantitative, qualitative and, other data included in a Model Element to support Authorized Uses associated with such LOD*'. Indeed, the Level of Development of a given Model Element informs project participants about '*how developed the information is expected to be, and the extent to which that information can be relied upon, at a particular point in time in the development of the Model*' (AIA, 2013d). Thus, the main focus of the LOD concept is still related to the reliability of data within the BIM. The new document (AIA, 2013c) defines content of model elements as '*minimum*' and not '*specific*' requirements, as reported in the previous version (AIA, 2008). There are still five levels, however, instead of '*Model Content Requirements*' (AIA, 2008) the new version (AIA, 2013c) uses '*Model Element Content Requirements*'. Starting from LOD 200, each definition (AIA, 2013a) is divided in two parts: graphical and non-graphic representation. The definition is discussed for each LOD; instead, a general statement is used to define non-graphical

information (AIA, 2013c). The structure of the Model Element Table (AIA, 2013c) is similar to the one already included in the previous document (AIA, 2008) with the exception of note sections that are added for each project milestone (AIA, 2013c). Moreover, the MEA is no longer seen as a modeler (AIA, 2008), but as a responsible party for the management and coordination of the development of elements (AIA, 2013a). For the first time, the *AIA Guide* (2013d) clearly explains the difference between Level of Detail and Level of Development making a comparison between the traditional approach and the BIM-based one, where there could be elements with high Level of Detail but very low Level of Development. The definitions of LOD in the AIA document (2013c) are a point of reference for other Countries such as France (Le Moniteur, 2014).

In 2011 a new group in the US, called BIMForum, started to work on a LOD Specification (BIMForum, 2013). In 2013, the *Level of Development Specification* was published including AIA's basic LOD definitions (2013c) for each building system and graphical examples of most of them (BIMForum, 2013). Definitions included in the *LOD Specification* (2013) were developed to address 'model element geometry', taking into account three of the most common uses: quantity take-off, 3D coordination and 3D control and planning. The working group believed that by taking this approach, the interpretations would be complete enough to support other uses (BIMForum, 2013). Also in this case, the acronym LOD means Level of Development. The Specification should be used in conjunction with a project BIM Execution Plan, providing a 'means of defining models for specific information exchanges, milestones in a design work plan, and deliverables for specific functions' (BIMForum, 2013). Also this document (BIMForum, 2013) provides a clear explanation on the difference between Level of Detail and Level of Development; the first can be considered as 'input to the element', while the latter as 'reliable output' (BIMForum, 2013). There are two main differences related to the LOD definitions between the Specification (BIMForum, 2013) and the *G202™-2013*. The first deals with the introduction of LOD 350 to enable coordination between disciplines (BIMForum, 2013). Only the *Guide* (AIA, 2013d) contains a reference to this new LOD (AIA, 20013, p. 60), even if it is not included in the *AIA Document G202™-2013*. The second difference is related to LOD 500 that has not been further defined and illustrated by the BIMForum working group (BIMForum, 2013). In 2014, a new version of the Specification was published adding new graphic illustrations in compliance with common building codes and at the end of October 2015 a new version was released with relevant updates (BIMForum, 2015). Indeed, for the first time non-graphical attributes were added and the Specification was divided in two parts: (1) Part A and (2) Part B (BIMForum, 2015). Part A, *Element Geometry*, basically defines required geometry and it is an extension of the previous version with a new appendix (BIMForum, 2015). Moreover, an interpretation of LOD definitions has been added for LOD 100, 200, 300, 350 and 400 (BIMForum, 2015). Part B, *Associated Attribute Information*, instead, is a Model Development Specification (MDS) spreadsheet that defines required attributes (numeric and/or textual) (BIMForum, 2015). Part B contains a Model Element Table where LOD, MEA and Notes can be defined for milestones (BIMForum, 2015). Moreover, there are Attributes Tables divided in three parts: attribute description, LOD profile and project-specific milestone (BIMForum, 2015). More attention should be paid while using this spreadsheet in order to create univocal information, because there is not an automatic correlation between the Model Element Table and Attributes Tables (e.g. to create consistent project-specific milestone). BIMForum Specifications have been

a point of reference for contractual documents (e.g. ConsensusDocs[®]301 (2015)) as well as several guidelines and protocols (e.g. Massport (2015) and Canada (AEC (CAN), 2014)). The NATSPEC (2013) published a BIM Paper on the use of BIM and LOD to promote the adoption of the BIM Object Element Matrix for non-geometrical data and LOD Specification (BIMForum, 2013) for appropriated geometry. This document should be updated to include parametric requirements of the latest BIMForum Specification (2015). In addition, the document (NATSPEC, 2013) refers to the use of ‘Grade’ developed by USACE (2012).

3.5 The UK introduces new definitions and acronyms

In the UK new definitions and acronyms have been set. Indeed, the *PAS 1192-2:2013* does not include the Level of Development but it defines the Level of Definition as ‘*collective term used for and including “level of model detail” and the “level of information detail”*’. The Level of Model Detail (LOD) is ‘*the description of graphical content of models at each of the stages*’ and the Level of Model Information (LOI) is ‘*the description of non-graphical content of models at each of the stages*’ (BSI, 2013). *PAS 1192-2:2013* defines seven levels of model detail and information (1-7). Moreover, Figure 20 contains example pictures for each level and other information such as permitted uses, output and parametric information (BSI, 2013). The CIC BIM protocol (2013) introduces the Model Production and Delivery Table (MPDT), a key document that ‘*both allocates responsibility for preparation of the Models and identifies the Level of Detail (“LOD”) that Models need to meet at the project stages or data drops stated in the table*’. However, there is no any reference to the LOI. In February 2014, the Technology Strategy Board decided to develop a free-to use digital BIM tool and since October 2015, the final version of the ‘NBS BIM Toolkit’ has been available. Its aim is to integrate the classification system with the Digital Plan of Work to control the presence of required data at each phase. Indeed, for each stage (0-7) of the RIBA Plan of Work, the Employer’s Information Requirements (EIRs) can be defined including the Level of Definition of each element. Thanks to this tool, at each stage of each project, it is possible to define details, roles, tasks and deliverables. In addition, for each deliverable a LOD, a LOI and a responsible entity should be set. The tool changed the definitions from ‘Level of Model Detail’ to ‘Level of Detail’ and from ‘Level of Model Information’ to ‘Level of Information’ but the same acronyms are used. Finally, the tool can verify a BIM against defined requirements. This tool is the first example of a digital platform for the definition of data within a BIM, taking into account the entire life-cycle of built assets. Recently, the new version of the AEC (UK) was released (2015) including definitions from the *PAS 1192-2:2013*. The protocol contains a new classification of *Component Grade* to be conformed to the Level of Detail (1-6) (AEC (UK), 2015). The acronym LOD has been added and ‘Grade’ is used as synonym for Level of Detail. Finally, the CPIC (2013) document requires a *Responsibility matrix for information production* to define ‘who models what (the BIM Author) and to what Level of Detail (LOD)’ for specific *Model Authoring* and *Model Analysis*; together with a *Task Information Delivery Plan* (TIDP) and a *Master Information Delivery Plan* (MIDP).

Table 1: Comparison of different classifications related to the management of data in the BIM

Source	Name	Authorship	Definition	Level						
Denmark: BIPS	3D Working method	Parties/ Responsibility	Information Level	0	1	2	3	4	5	6
Australia: CRC	Object data levels	Responsibility	Level of Detail	-	A	B	C	-	D	E
Vico Software	Model Progression Specification	-	Target Level of Detail/ Level of Detail	-	100	200	300	-	400	500
US: Department of VA	BIM Object/Element Matrix	Model Element Author	Level of Development (LoD/LOD)	-	100	200	300	-	400	500
Australia: NATSPEC	NATSPEC BIM Object/Element Matrix (BOEM)	Model Element Author (MEA)	Level of Development (LOD)	-	100	200	300	-	400	500
US: NYC DDC	Object Requirements	-	-Model Level of Development/ Level of Development (LOD) -Model Granularity	-	100	200	300	-	400	500 (?)
US: Pennsylvania State University	BIM Information Exchange – Level of Detail Matrix	Model Element Author (MEA)	Level of Development (LOD)	-	100	200	300	-	400	500 *
US: US Army Corps of Engineers	USACE BIM Minimum Modeling Matrix (M3)	-	-Level of Development (LOD) -(Element Grade/Grade (A, B, C, +))	-	100	200	300	-	-	-
Netherlands	Matrix and Project Template	Aspect-model	Information Level	0	1	2	3	4	5	6
US: AIA E203™-2013	Model Element Table	Model Element Author (MEA)	Level of Development (LOD)	-	100	200	300	-	400	500
France: Le Monieur	-	-	Level of Development (LOD)	-	100	200	300	-	400	500
US: BIMForum 2015	LOD 2015 Element Attributes Tables	Model Element Author (MEA)	-Level of Development (LOD) -Level of Detail -Element Geometry -Associated Attribute Information	-	100	200	300	350	400	500
Canada: AEC (CAN) 2014	Information exchange worksheet or modelling matrix	Responsibility	Level of Development (LOD)	-	100	200	300	350	400	500
UK: PAS 1192-2:2013	-	-	-Level of model Definition -Level of model Detail (LOD) -Level of model Information (LOI)	1	2	3	4	5	6	7
UK: CIC	Model Production and Delivery Table (MPDT)	Model Originator	Level of Detail (LOD)	1	2	3	4	5	6	7
UK: NBS BIM Toolkit	NBS BIM Toolkit	Responsibility	-Level of Detail (LOD) -Level of Information (LOI)	1	2	3	4	5	6	7
UK: AEC (UK) 2015	-	-	-(Level of Definition) -(Level of Information (LOI)) -Grade/Level of Detail (LOD)	1	2	3	4	5	6	-

Finally, it is important to take into account that CityGML (2015) has developed five Levels of Detail (LOD 0-4) to define geometrical details and semantic precision (Tolmer et al., 2014) to link BIM with Geographic Information System (GIS) data (Kang and Hong, 2015).

4. Discussion and Future scenarios: from static assembly to dynamic entities

Nowadays, there is still confusion on how to manage the content of a BIM and definitions are differently interpreted. This lack of consistent understanding could be due to the presence of different definitions and acronyms in the industry that have changed during the years, vary from different Countries and, sometime, are inconsistent. For example, the ‘Level of Detail’ was originally associated to the reliability of both geometrical and non-geometrical data (BIPS, 2007), but recently it deals more with the level of geometrical attributes (e.g. BIM Forum, 2015; AIA, 2013c; BSI, 2013). The same acronym ‘LOD’ is used for both Level of Detail (e.g. BSI, 2013) and Level of Development (e.g. BIM Forum, 2015); similar concepts are differently called (such as ‘Level of Information’ (AEC (UK), 2015) and ‘Associate Attribute Information’ (BIM Forum,

2015)); and the Level of Development is associated both to elements (e.g. BIM Forum, 2015; AIA, 2013c) and the entire model (e.g. NYC DDC, 2012; Massport, 2015).

Usually, space programming and BIM authoring follow an elemental approach mirrored in the EIRs and BIM Execution Plans. However, thanks to the BIM Toolkit, the progressive maturity of the assemblies might be decoupled. The LOD Specification allows managing the different speed on the elemental basis, whilst the NBS BIM Toolkit makes it affordable on a sub-elemental degree, because LOD and LOI could be split and data might be misaligned. Such an assumption has to be felt as disruptive, because it implies that different players could concurrently manage shareable and accountable data upon the same element or assembly according to different progressions. Thus, in spite of pursuing the traditional BIM uses, the linear progression of the design stages is clearly hampered, because the original space programs could be troubled by the architectural digital sketches as far as general construction is concerned. For this reason, Drobnik and Riegas (2015) suggest to introduce a Level of Development (LOD) 0 as well as a negative one (e.g. LOD -100) due to the complexity of the iterative design process. Meanwhile, heterogeneous elements have to be handled within a Common Data Environment (BSI, 2013) or rather, within a digital eco-system merging hardware and software on the internet of buildings, infrastructures, grids and things. Unfortunately, such a stressing elemental perspective, where the design teams are asked for anticipating the progressions and are stimulated for optioneering the solutions, is additionally burdened by the behavioral and interactive design. The simulated users' and passengers' behaviors, as well as the simulated flows and motions, engender some spatial syntaxes and options which could be, on a real time basis, interactively checked and validated by means of immersive environments (CAVEs or portable devices). Indeed, dealing with game engines, more and more, the BIM will have to take into account not only *discrete* Level of Detail, but also *continuous* LOD (CLOD) (DigitalRune, 2013). Moreover, the validation plays a key rule for the success of Data-Driven Projects and Model Checking should be used to control the content of the BIM as discussed also by Hopper (2015). Today, the control of different Levels (e.g. of Detail, Information and Development) is still difficult and the NBS BIM Toolkit tries to fill this gap. However, more effort is needed to validate the information flow related not only to EIRs, but also to the Facility Management data. In addition, the pre-occupancy management requires the involvement of potential users within the early design stages, because more and more an intelligent clientship deals with a 'to be' servitized and sensed built asset. Therefore, a question is arising, stemming from the aforementioned remarks: could such a design process be consistent with the traditional elemental approach centered more on static (objectual) assembly rather than on dynamic (motional) entities?

5. Conclusions

This study indicates that there is not a univocal approach to define and manage the content of a BIM and several definitions and acronyms have been defined in different Countries, especially in US and UK. However, it is possible to compare them and find similarities. Results can be used to get an in-depth understanding on this topic, especially for experts who work with BIM in several Countries. Finally, the authors believe that in the future Model Checking should be included in the process and more flexibility is needed moving from static assembly to dynamic entities.

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The Perceived Business Value of BIM: Results from an International Survey

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Abstract

Building Information Modelling (BIM) has emerged as an IT-based solution towards the construction industry's challenges. The expectations on BIM are high in both research and industry and there has been an increasing interest in evaluating the benefits and business values of BIM. Many of the reported benefits and business values in research have been the same or very similar. This suggests that there might exist certain categories of benefits of BIM and that the benefits also might interrelate with each other. However, whether this is the case has not been explored in previous research. The purpose of this study is to explore how the business value of BIM is perceived by exploring what categories of benefits of BIM there are and how these benefits interrelate with each other. Results from a large international survey on the perceived business value of BIM are analyzed. The findings show that there are two categories of benefits of BIM. The first is project progress related and relates to managing and minimizing project managerial issues. The second is project outcome related and relates to increasing efficiency and optimization. The interrelation of the benefits is also shown by which category of benefits they contribute to and by their relative importance in these categories. The findings have both theoretical and practical implications.

Keywords: Business value, BIM, project management, survey, factor analysis

1. Introduction

The construction industry is an important player in economies and societies throughout the world and significantly contributes to GDP and employment (e.g. Ortiz et al 2009). Is also an industry characterized by challenges in terms of low productivity (e.g. Teicholz et al 2001), slow adoption of new information technologies (e.g. Brandon et al 2005), low innovation (e.g. Styhre 2011) and negative impact on the environment (e.g. Ortiz et al 2009). Building Information Modelling (BIM) has by many proponents been suggested as an IT-based solution towards the industry's challenges (e.g. Succar 2009, Rezgui et al 2009, Crotty 2013). BIM has been described as "a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the buildings life cycle" (Succar 2009). The high expectations on BIM can also be reflected in that there are currently many governmental BIM initiatives promoting the use and implementation of BIM (e.g. UK Cabinet Office 2011, Trafikanalys 2015).

In order to understand if the implementation of BIM meets the high expectations, the effects of the BIM implementation must be evaluated. Firms implementing BIM have also stated that a major challenge towards their adoption of BIM has been that that they themselves have not had sufficient time to evaluate the business value of BIM and experience a lack knowledge about the business value of BIM ((McGraw-Hill 2009, 2010) FMI and CMAA 2007). There has been much research aimed at evaluating and measuring the benefits and business values of BIM (Table 1). Many of the studies have come to similar conclusions about the effects of BIM and have tended to repeat the same benefits and business values of BIM (Table 1). Many of the benefits and business values are also similar to each other (Table 1) and are likely to interrelate in ways that previous research have not yet investigated. For example, a commonly reported benefit of BIM is cost reductions, which is likely to be impacted by and interrelate with other commonly reported benefits of BIM, such as earlier completion times or fewer errors. The similarity and repetitiveness of the many benefits and business values of BIM reported in previous research suggest that there might be certain categories of benefits of BIM and certain interrelations between the benefits. This issue that has however not been investigated in previous research. The purpose of this study is to explore how the business value of BIM is perceived by exploring what categories of benefits of BIM there are and how these benefits interrelate with each other. This is accomplished by analysing the results from a large international survey on the perceived business value of BIM through factor analysis.

2. Rationale for investing in BIM

An underlying assumption behind a firm's choice to make an investment, such as investing in new IT, can be described by the theory of the firm and transaction cost theory (Coase 1937). Firms decide to make an investment when the investment provides a return that that is greater than its initial investment costs (Coase 1937). The theory of the firm and transaction cost theory are based on the assumption of rationality in organizational decision making. Firms are assumed to make rational choices based on complete and perfect information and to make investments that maximize the profit of the investment. However, firms actually make decisions in uncertain and changing environments where the firms are left with an uncertainty and unpredictability about the future, where they do not

have complete access to all the available information and where the information is often incomplete and imperfect (Coase 1937, Simon 1959, Simon 1991). These conditions limit the extent to which firms can make rational decisions and inhibit the seeking of maximization (Simon 1959, Simon 1991). The individuals of the firm also suffer from bounded rationality meaning that they are bounded and limited in their cognitive ability to analyse and process all the available information, to discern which of the incomplete and imperfect information that is of relevance for the decision making process and to make rational decision in complex and uncertain situations. These conditions results in that firms often decide to make an investment given that the investment yields a satisfying return rather than a maximizing one (Simon 1959, Simon 1991). Firms are described as being content with making decision that satisfy rather than maximize a target return. Thus, the decision-maker is a satisfier and one seeking a satisfactory solution rather than the optimal one (Simon 1959, Simon 1991).

The argument and rationale for making decisions to invest can be applied to construction firm's decisions to invest in BIM. Drawing on the theories in Coase (1937) and Simon (1959, 1991), firms make decisions to invest in BIM given that the investment in BIM yields a return that is satisfying enough. In order to evaluate weather the investment in BIM yields a satisfying return, the investment in BIM has to be evaluated and measured and the benefits and business values of BIM assessed. Research also shows that particularly in the constriction industry, managers often need to prove that the investment in new IT, and in particular BIM, will yield a certain return or satisfy a certain target before they receive the funds to invest in new systems and processes (e.g. Becerik-Gerber and Rice 2010, Marsh and Flanagan 2000). Therefore, the benefits and business values of BIM need to be evaluated.

3. Benefits and business values of BIM

There have been numerous studies that have attempted to evaluate and measure the benefits and business values of BIM (Table 1). The benefits of BIM have been studied from both qualitative and quantitative research approaches and by both researchers and industry actors (Table 2). A total of 23 peer-reviewed journal papers and 9 industry reports were analyzed in order to map the benefits and business values of BIM.

There were a total of 38 different benefits and business values of BIM identified in the literature review. The most common benefits of BIM in research include reduced errors, rework and changes (e.g. Becerik-Gerber and Rice 2010, Barlish and Sullivan 2012), faster completion times (e.g. Dawood and Sickka 2008, Hartmann and Fischer 2008), cost savings (e.g. Kam et al 2013, Suermann and Issa 2009, Haymaker and Fischer 2001), improved information management (e.g. Grilo and Jardim-Gonclaves 2010, Mäki and Kerosuo 2015), more accurate design (e.g. Demian and Walters 2014, Gilligan and Kunz 2007) and improved collaboration and collaboration among different disciplines and actors (e.g. Demain and Walters 2014, Zuppa et al 2009).

Table 1: Benefits and business values of BIM in research and industry reports

<i>Benefits of BIM</i>	<i>Frequency</i>	<i>Benefits of BIM</i>	<i>Frequency</i>
<i>Less errors, rework & changes</i>	<i>21</i>	<i>Fewer RFI</i>	<i>8</i>
<i>More accurate design</i>	<i>20</i>	<i>Less conflicts and disputes</i>	<i>8</i>
<i>Improved information management</i>	<i>18</i>	<i>Risk management</i>	<i>7</i>
<i>Faster completion times</i>	<i>17</i>	<i>Marketing new clients</i>	<i>6</i>
<i>Reduced costs</i>	<i>17</i>	<i>Improved simulations</i>	<i>6</i>
<i>Higher quality</i>	<i>16</i>	<i>Better decision</i>	<i>5</i>
<i>Improved collaboration</i>	<i>15</i>	<i>Client satisfaction</i>	<i>5</i>
<i>Improved coordination</i>	<i>13</i>	<i>Stakeholder engagement</i>	<i>5</i>
<i>Improved communication</i>	<i>13</i>	<i>Increased ROI</i>	<i>4</i>
<i>More design alternatives</i>	<i>11</i>	<i>More engaged staff</i>	<i>4</i>
<i>Better estimations</i>	<i>11</i>	<i>Improved team work</i>	<i>3</i>
<i>Clash detections</i>	<i>11</i>	<i>Reduces waste</i>	<i>3</i>
<i>Improved life cycle management</i>	<i>10</i>	<i>Code compliance</i>	<i>3</i>
<i>Increased productivity</i>	<i>10</i>	<i>Increased profitability</i>	<i>2</i>
<i>Improved scheduling</i>	<i>10</i>	<i>Creativity</i>	<i>2</i>
<i>Increased safety</i>	<i>9</i>	<i>Employment satisfaction</i>	<i>2</i>
<i>On-site efficiencies</i>	<i>9</i>	<i>Less administration costs</i>	<i>1</i>
<i>Competitive advantage</i>	<i>9</i>	<i>Faster bid preparation</i>	<i>1</i>
<i>Higher efficiency</i>	<i>8</i>	<i>Innovation</i>	<i>1</i>

Table 2: Sources in literature review on the benefits and business values of BIM

<i>Authors in peer-reviewed journals</i>		<i>Industry reports</i>
<i>Aranda-Mena et al 2009</i>	<i>Hartmann et al 2012</i>	<i>Autodesk 2007</i>
<i>Azhar 2011</i>	<i>Hartmann & Fischer 2008</i>	<i>BSI 2010</i>
<i>Barlish & Sullivan 2012</i>	<i>Kam et al 2003</i>	<i>FMI and CMAA 2007</i>
<i>Becerik-Gerber & Rice 2010</i>	<i>Kaner et al 2008</i>	<i>Gilligan & Kunz 2007</i>
<i>Bryde et al 2013</i>	<i>Khanzode et al 2008</i>	<i>Haymaker & Fischer 2001</i>
<i>Chien et al 2014</i>	<i>Manning & Messner 2008</i>	<i>McGraw-Hill 2009</i>
<i>Davies & Harty 2013</i>	<i>Mäki & Kerosuo 2015</i>	<i>McGraw-Hill 2010</i>
<i>Dawood & Sikka 2008</i>	<i>Suermann & Issa 2009</i>	<i>Open BIM network 2012</i>
<i>Demian & Walters 2014</i>	<i>Zuppa et al 2009</i>	<i>buildingSMART UK 2010</i>
<i>Dossick & Neff 2010</i>	<i>Coates et al 2010¹</i>	
<i>Eadie et al 2013</i>	<i>Yan & Damian 2008¹⁾</i>	
<i>Grilo & Jardim-Gonclaves 2010</i>		

4. Method

In order to explore what different categories of benefits of BIM there are and how these benefits interrelate with each other, the results from a large international web-based survey on the perceived benefits of BIM is analyzed through factor analysis. The survey was created based on a literature

¹ In Conference Proceedings

review of the benefits and business values of BIM in previous research (Table 1) and on in-depth semi structured interviews with nine experienced BIM representatives in the Swedish AEC industry from clients/owners, contractors and consultants about the perceived business values of BIM. The BIM representatives were selected by purposive sampling based on their experience of BIM, their current position, and their engagement in BIM communities.

The survey consisted of three parts. This paper addresses the second part of the survey where the respondents were asked questions about what benefits they had perceived from implementing BIM in a specific ongoing BIM project of their choice. Based on the literature review and interview study, 15 benefits of BIM were included in the survey (Table 3). The respondents were to assess to what extent they had perceived each of these 15 benefits of BIM as beneficial to their specific BIM project on a seven point Likert scale, where 1 equaled no perceived benefit and where 7 equaled a large perceived benefit (see Table 3). The survey was addressed to and administrated to a group of BIM users in the AEC industry that were perceived to be knowledgeable and experienced in working with BIM - the members of the worldwide buildingSMART network (<http://www.buildingsmart.org>). The survey was administrated to the target respondents in three steps. In a first step, the target respondents were contacted via each buildingSMART regions contact person listed on the buildingSMART website. The contact person was asked to distribute the link to the web-based survey to their members in their respective chapters. One potential bias of contacting representatives of an organization to distribute the survey to their members is that the response rates are typically lower of this procedure when compared to distributing the survey directly the population of individuals of that organization (Baruch 1999). Therefore, in a second step, the individual members of the selected 12 buildingSMART chapters were contacted directly via email. In a third step, the members of the selected 12 chapters were also contacted via groups on LinkedIn.

The purpose of factor analysis is to reduce larger sets of data and variables into a smaller set of variables in order to identify if there are certain types or categories in which these variables tend to group in (Kim and Mueller 1978, Stevens 2012, Thompson 2004). Factor analysis is suitable when there are many variables in a dataset and when these variables are suspected to group in certain types or categories (Kim and Mueller, 1978) (such as there are in the respondent's answers to the 15 benefits showed in Table 3). In factor analysis, the aim is to find the linear combination of the variables that achieves the maximum amount of variance. A first factor (category) is given by the linear combination of the original variables that accounts for the maximum possible variance. A second factor (category) then captures the information that was not captured by the first factor and is also uncorrelated with the first factor (Kim and Mueller 1978, Stevens 2012, Thompson 2004). Only those factors (categories) are retained that fulfill the Kaiser criterion. The Kaiser criterion stipulates that only those factors (categories) that have an eigenvalue > 1 can explain the variance and are thus retained as factors (Stevens 2012). Those components with eigenvalue less than 1 contribute little to explaining the variance and are thus not retained. The factors retained then represent different types or categories of the variables analyzed. The factor loading of each variable indicates which variables that belong to which factor (category). The variables that are retained in one factor are uncorrelated with the variables retained in another factor (Stevens 2012). In the next section, the results of the factor analysis and the interpretation of the results are presented.

5. Results

Of a total of 988 respondents contacted to answer the survey 234 responded, corresponding to a response rate of 23,7%. For web and email based surveys, response rates usually range around 20%-30% (Kaplowitz et al 2004, Baruch and Holtom 2008). In Table 3, the respondent's answers to the question about what benefits they had perceived from working with BIM on a seven point Likert scale are presented.

Table 3: The responses in the survey regarding the perceived benefits BIM

<i>The perceived business value of BIM</i>							
<i>What benefits do you/did you expect from using BIM in the specific project?</i>	<i>(1= no benefit, 7= very large benefit)</i>						
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>
<i>Increased worksite safety</i>	22	21	23	37	41	22	20
<i>Improved coordination</i>	1	0	2	7	29	45	102
<i>Increased client satisfaction</i>	2	2	10	24	38	56	54
<i>Higher profits</i>	9	11	16	42	47	33	28
<i>Lower overall costs</i>	6	7	15	37	42	42	37
<i>Earlier completion times</i>	2	10	15	32	55	43	29
<i>Improved energy performance</i>	15	14	21	42	35	31	28
<i>Less modifications (e.g, errors, rework, changes)</i>	1	4	5	11	36	54	75
<i>Improved communication (e.g, fewer RFI)</i>	2	1	8	17	33	51	74
<i>Improved understanding of project purpose</i>	7	2	9	12	37	54	65
<i>Increased productivity</i>	2	2	10	25	51	47	49
<i>Higher quality of final product/service</i>	3	3	2	12	45	55	66
<i>New business (e.g, new clients/services)</i>	14	13	19	31	41	33	35
<i>Reduced conflicts</i>	2	4	3	18	44	55	60
<i>More accurate estimations (e.g, quantity take-offs)</i>	3	6	4	27	38	52	56
<i>Total number of responses</i>	92	102	165	378	617	679	785

Factor analysis was performed on the 15 benefits in order to examine whether there were existed certain types or categories of benefits of BIM and to examine how the benefits interrelate with each other. The results from the factor analysis are shown in Table 4. Two factors, i.e. two categories of benefits of BIM, emerged (with eigenvalues >1). The first factor (first category of benefit of BIM) seemed to be more significant as it had an eigenvalue of 6.86 (compared to the eigenvalue of 1.14 of the second factor). The factor loadings in Table 4 show which variables (which of the 15 perceived benefits of BIM) that belong to each of the two factors (two categories). The larger the factor loading, the more relevant the variable is in explaining the factor (category). The benefits of the first category are uncorrelated with the benefits of the second category, and vice versa.

Table 4: Results from the factor analysis on the 15 perceived benefits of BIM

<i>Factor analysis on the perceived benefits of working with BIM</i>	<i>Eigenvalue Factor 1 6.86</i>	<i>Eigenvalue Factor 2 1.14</i>
	<i>Factor loadings for Factor 1</i>	<i>Factor loadings for Factor2</i>
<i>Increased worksite safety</i>	<i>0.31</i>	<i>0.49</i>
<i>Improved coordination</i>	<i>0.74</i>	<i>0.17</i>
<i>Increased client satisfaction</i>	<i>0.55</i>	<i>0.43</i>
<i>Higher profits</i>	<i>0.20</i>	<i>0.83</i>
<i>Lower overall costs</i>	<i>0.19</i>	<i>0.78</i>
<i>Earlier completion times</i>	<i>0.36</i>	<i>0.69</i>
<i>Improved energy performance</i>	<i>0.31</i>	<i>0.58</i>
<i>Less modifications (e.g. errors, rework, changes)</i>	<i>0.77</i>	<i>0.21</i>
<i>Improved communication (e.g. fewer RFI)</i>	<i>0.73</i>	<i>0.31</i>
<i>Improved understanding of project purpose</i>	<i>0.53</i>	<i>0.33</i>
<i>Increased productivity</i>	<i>0.50</i>	<i>0.62</i>
<i>Higher quality of final product/service</i>	<i>0.67</i>	<i>0.33</i>
<i>New business (e.g. new clients/services)</i>	<i>0.28</i>	<i>0.52</i>
<i>Reduced conflicts</i>	<i>0.73</i>	<i>0.25</i>
<i>More accurate estimations (e.g. quantity take-offs)</i>	<i>0.54</i>	<i>0.34</i>

From Table 4, the first factor (the first category of benefits of BIM) consists of the following benefits of BIM (in relative order):

1. Less modifications - fewer errors, rework, changes (largest factor loading 0.77)
2. Improved coordination (largest factor loading: 0.74)
3. Reduced conflicts (largest factor loading: 0.73)
4. Improved communication (largest factor loading: 0.73)
5. Higher quality of final product (largest factor loading: 0.67)
6. Increased client satisfaction (largest factor loading: 0.55)
7. More accurate estimations (largest factor loading: 0.54)
8. Improved understanding of project purpose (largest factor loading: 0.53)

From Table 4, the second factor (the second category of benefits of BIM) consists of the following benefits of BIM (in relative order):

1. Higher profits (largest factor loading: 0.83)
2. Lower overall costs (largest factor loading: 0.78)
3. Earlier completion times (largest factor loading: 0.69)
4. Increased productivity (largest factor loading: 0.62)
5. Improved energy performance (largest factor loading: 0.58)
6. New business - eg new clients (largest factor loading: 0.52)
7. Increased worksite safety (largest factor loading: 0.49)

The benefits in the first category of benefits of BIM seem to be related to managing and minimizing project managerial issues (i.e. project progress related). The benefits in the second category of benefits of BIM seem to be related to efficiency and optimization (i.e. project outcome related).

The factor analysis shows the relative importance of the benefits. In the first category of benefits of BIM that were project progress related (i.e. related to managing and minimizing project managerial issues), the benefit of less modifications (such as fewer errors, rework and changes) had the highest factor loading and was the most significant benefit in explaining the category. Then followed, in relative order, improved coordination, reduced conflicts, improve communication, higher quality of final product, increased client satisfaction, improved understanding of project purpose and more accurate estimations. In the second category of benefits of BIM that were project outcome related (i.e. related to efficiency and optimization), the benefit of higher profits had the highest factor loading and was the most significant benefit in explaining the category. Then followed, in relative order, lower overall costs, earlier completion times, increased productivity, improve energy performance, new business, and increased worksite safety.

6. Discussion

In the outset of this paper, it was argued that previous research has come to repeat the same benefits of BIM and/or very similar benefits of BIM. Many of these benefits were also claimed to likely interrelate with each other in ways that the previous have not explained. This study aimed to contribute to this gap. The theoretical contribution of the findings is an increased understanding of the different categories and types of benefits BIM and increased knowledge about the dimensions, variations and nuances of these benefits. Although the 15 benefits of BIM examined in this paper are not entirely new by themselves (see literature review of the benefits of BIM), the novelty of the findings lie in showing the perceptions among BIM users worldwide of the different types of benefits of BIM and the relative importance of these benefits. The novelty also lies in showing to what type of

project management activities that these benefits contribute to. For example, BIM was found to contribute to both project progress related activities and project outcome related activities. The findings also contribute with increased understanding about where the impact of BIM seems to be largest. The impact of BIM was larger on the project progress related benefits (related to managing and minimizing project managerial issues), such as improved coordination and fewer conflicts, as indicated by the larger factor loading of 6.86. The findings thus have practical implications as well and contribute with increased knowledge about how BIM can be applied in the daily management of projects in order to create business value.

The main impact of BIM on project progress related activities (and not on project outcome related activities) contribute with a contrast to previous research on the benefits and business value of BIM. In reports, project outcome related effects, such as increased return on investment and other economic effects, were identified as the main contributors to the business value of BIM (e.g. McGraw-Hill 2009, 2010 and FMI and CMAA 2007). In research, the efficiency and optimization related benefits of BIM are often promoted (e.g Kam et al 2013, Barlish and Sullivan 2012, Suermann and Issa 2009, Manning and Messner 2008). However, the findings in this study showed that the project outcome related effects of BIM (e.g. higher profits, lower costs, earlier completion times and other economic effects), almost did not qualify as a category of benefits of BIM in the factor analysis. With an eigenvalue of only 1.14, it almost did not qualify according to the Kaiser criterion that implied an eigenvalue > 1. Thus, for practitioners and policy makers investing or planning to invest in BIM, this study suggest that the major business value of BIM lies in the daily project managerial activities in improving project management such as improving coordination and communication among all project actors, reducing conflicts and disputes and minimizing the errors make by the partied involved in projects.

There are also limitations to this study. For example, targeting the members of the buildingSMART network in the survey implies that their responses are more likely to be biased and reflect a more optimistic view of BIM as opposed to a more neutral view of BIM. In analyzing the results, the author was aware of this sampling bias, yet there is a need for future studies that explore how the business value of BIM is perceived among different kinds of users of BIM who have both positive and neutral views of BIM and who are both experienced and less experienced in BIM. Suggestions for future research also include examining how to implement BIM in order to achieve the two categories of benefits of BIM. Future research could also examine how various project and profession specific factors positively or negatively contribute to how the benefits of BIM are perceived.

7. Conclusions

The expectations on BIM are high. There has been many studies examining the benefits and business values of BIM and many of the benefits and business values found have been the same or very similar. From a large international survey on the perceived business value of BIM, two types of categories of benefits of BIM were discovered. The most important category of benefits of BIM was project progress related and evolved around managing and minimizing project managerial issues. The findings had both theoretical and practical implications. They made a contrast to previous studies on

the benefits and business values of BIM and showed where the impact of BIM on the day to day management of project was largest.

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Clients' and Users' Perceptions of BIM: A Study in Phenomenology

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Abstract

Although Building Information Models (BIM) are declared as singular and correct expressions of buildings, these still are merely representations of designs and complete buildings. The digital model is not the building and is not the design. The digital model does allow visualisations of the buildings allowing stakeholders a new perception of the building through its 3D representation with the ability to choose viewpoints and to travel dynamically, but virtually, through the represented building. This paper explores what is perceived by clients and users in building information models using phenomenology. It emphasises the differences in perception and explores the meaning of this for design and construction. The work has involved interviews and experimental studies with users using models in different forms including static 3D, walk-throughs, 2D and room data sheets. The results show that different people view models with a difference in focus, intent and expectation. This makes models not have a singular and correct expression which means that the engagement with stakeholders still needs to be worked on and actively managed during design and construction. Digital tools then are not finished expressions but examples to be worked with dynamically and used to demonstrate differences proactively to help work on these different perceptions so that a higher performing building can be produced. The future of BIM to deliver value for both the client and users then lies in its ability to provide soft informed representations.

Keywords: Building-use, users, performance, perceptions, representations

1. Introduction

The application of digital technologies is developing rapidly and is now being adopted by the Architecture, Engineering and Construction (AEC) industry. In AEC, Building Information Modelling (BIM) is considered to be the new improvement solution for the construction industry as it allows the transition to better communication of information so that it can be shared and exchanged between different stakeholders (Drettakis *et al.*, 2007). Bullinger *et al.*, (2010) have pointed out that although the existence of such technology has supported the integration of multi-stakeholders, the involvement of the end-user has so far been limited; this is considered to be a major issue in current approaches. This is due to the promotion of BIM, more as a vehicle to drive productivity and efficiency for the construction industry, rather than to increase value in its outputs (Miettinen and Paavola, 2014). This is hiding the client and user perspectives on BIM and not utilising its potential for radical improvement.

The paper is part of a larger research study on enhancing building performance in buildings during design using BIM. The focus of this paper is on the way clients and users perceive their buildings in design and how BIM might be used to allow user input. The key point is the way that BIM represents the building to help this process. The issue of representations in building design is not new but the development of digital representations is explored. This presents theory of how BIM is perceived in a more phenomenological manner where it is the subjective experience that is crucial. This paper uses data from interviews with client teams and interviews and experimental studies with users. The latter, used BIM models in different forms including static 3D, walk-throughs, 2D plans and room data sheets. The results are explored both comparing the positions of client team and users and emphasising the user perceptions of BIM and their particular needs. The conclusion identifies how BIM needs to be modified to handle soft information to enable a more user involved design as well as greater understanding of user needs by the client team.

2. Literature Review

2.1 Design and Users

There has been a growing movement to make design more performance orientated (Kolarevic and Malkawi, 2005). This concept is embedded in Vitruvius's 1st century BC requirements for buildings of commodity, firmness and delight as well as the more detailed and quantitative design quality indicator (CIC 2003). The ratio 1:5:200 (1 = construction cost; 5 = maintenance and building operating costs; 200 = business operating costs) (Evans *et al.*, 1998) focuses attention on the fact that the business operation of a building, costs several orders of magnitude more than its design and construction costs. Even though this ratio is challenged (Hughes *et al.*, 2004), the idea that buildings should be designed to assist the work of the business is crucial. However, there is a gap between the expectations of design and how a building actually performs (Bordass *et al.*, 2001). Jensen *et al.* (2011) and Sanoff, (2000), argue that involving users in the design and operation of the built environment taps into their knowledge and preferences and so creates spaces that work more effectively. Vischer's (2008) built

environment theory identifies building use and user as critical design determinants of buildings. Sanoff (2000) has pointed out the difficulty of delivering this experience, due to, for example, the gap between the demands from the users and the design provided by the architects. Forty (2000) claims that building space appears to be a homogeneous concept, partly because architects consider space via representations (abstract space) rather than experiencing space by living it (lived space). However, Hensel et al. (2009) argue that bridging the gap between lived and abstract space requires another level of complexity, which is stopping any change from current practice. The solution to greater building performance requires user involvement and the handling of the complexity of technically undertaking this and including it in the process (Barratt and Stanley 1999). The sophistication and integration provided by BIM offers the opportunity to address this problem explicitly but this has only currently been researched in a limited manner.

2.2 BIM, Design and Users

Building Information Modelling provides a repository in a centralised data location for a full design model integrating structural, architectural, mechanical, electrical and plumbing (Kensek 2014). Its use in design has developed rapidly as a tool for composition, testing and construction delivery with full national government support. There is a complexity associated with the technical side of BIM within its software and hardware that limits the size of the model and their ability to represent all the information explicitly, and this remains a problem within the AEC industry (Johansson *et al.*, 2015). This creates a challenge for the development of BIM for it to be useful for design rather than just as a repository for the end design (Whyte 2013). There has been little consideration of challenges associated with user involvement during the design stage (Kunz and Fischer, 2009). Kim *et al.* (2015) have reviewed user involvement during both pre and post construction showing how simulation tools can be employed by architects to understand the relationships between users and spaces. They concluded, however, that one of the current challenges is ‘formalising’ this involvement process, and there was a need for further inquiry into virtual design and construction tools. Khemlani (2008) reported that 3D and 4D simulation (e.g. Navisworks) have enhanced users’ understanding of the design allowing a third person view to support users’ in obtaining a sense of scale, but this navigation is relatively simplistic. There are some recent attempts to involve end-users and facility management; e.g, Lee and Ha (2013) have proposed a BIM-based tool for residential buildings to meet different customer needs which would allow them to be involved in decision-making. It was found that collaboration using the tool helped to meet customer needs for the optimum use of space. Shen et al. (2012) proposed a user activity simulation and evaluation method (UASEM) that aimed to enhance the user’s visual experience of the built environment, but did not explore whether such simulations have an impact on improving design solutions. Oerter *et al.* (2014) pointed out that the use of avatars within the BIM environment can support by providing feedback to the users’ and clients. None of these studies acknowledged the problems of perception of BIM environments.

2.3 Digital Representations and Users

The shift to a digital world in construction involves the creation and use of digital representations. According to Allen (2009), 'representations' are an entire intellectual and social construct that allows the imagination to construct new fragments of reality. Representations are the interface between the data and individuals as the representation conveys meaningfulness in a form to enable the data to become information. Thus, the design process requires a study of representations suitable for users to be integrated into the design process. Many theories of knowledge-use see mental activity working on representations thus it is possible to see representations as reality (Zhang and Norman, 1994) and for computing to work as this representation as reality. This has been opposed most vociferously by philosophers such as Dreyfus and Dreyfus (1986) who argue that thinking can occur without mental representations and Lorino *et al.*, (2011) suggest that external representations have a communicative role in the activity itself. According to Hatfield (2003), the visual experience aims to represent a visual space in relation to the physical space. In the study of visual space, it is often assumed that the observer has an internal representation of surrounding physical space where he/she attempts to measure properties of the visual space to establish how well various properties of physical space are preserved in the mapping to visual space (Loomis *et al.*, 1992). Ishii (2006) argues that people have an active interface with digital information with two components: control and representation. These can also be described as input and output where controls refer to what input users provide to manipulate information, while representations refer to what is perceived with the human senses.

There is a growing body of work on the phenomenology of digital environments. Turk (2001) explored how the product models in BIM are not as conceptually robust and material as they are presented and discussed. Meaningful work requires engagement with people with virtual worlds which has been reviewed by Farr *et al* (2012) who call for the greater use of the concept of embodiment to support user interaction.

3. Research Methodology

This research reported here sought to gain a richer understanding of users' and client's perceptions of BIM with a view to using it to improve user involvement in design. Given this problem of alternative perspectives, the research question was set to determine how BIM might help this situation during the design phase. This study adopted a critical realist position (Mingers 2000) and used qualitative methods. The study investigated three case study building projects at different times of their design, construction and operation phases all of which had used digital design. Two of the buildings were university teaching blocks and the third was a local authority office. Data were collected using semi-structured interviews with the client design teams and users and an experiment where 2D and 3D representations of the buildings were shown to users who at the same time answered questions in a questionnaire. Overall, the study involved four participants representing the client side, and nine participants representing the building users side.

It was recognised that the building users' perspective is best conceived phenomenologically. A phenomenological position focuses on the subjective experience of individuals thus is concerned with being, consciousness, and awareness (Seamon 2007). As such individuals experience a context, i.e. the building or work on a building, modified by their own beliefs about themselves and their well-being. Users' perceptions are created from the interaction of this 'being' with the physical and social environment provided by the building. In Christopher Alexander's terms this requires a wholeness of conception of a building (Seamon 2007). The study was phenomenological in that it asked questions into the thinking and feelings of the respondents. In particular, it asked questions about their lived experience which composed their perceptions. The phenomena in this research were firstly the way the design team and users saw buildings and secondly the way they interacted with the representations of the buildings as generated by BIM models. In the first phase, the study asked open ended questions about the nature of building performance in the buildings they engaged with for their work. It did this without defining performance in order to stimulate a subjective response. These responses were analysed in a form of discourse analysis to draw out the phenomenological perceptions. In the second phase, the study aimed to gain insights into the respondent's engagement with BIM. The case study was delivered using BIM, and thus the client was already familiar with the outputs of BIM whereas the users had to be briefed on what BIM was in order to gather meaningful data. A questionnaire was used to collect data from a group of users as they were shown 2D representations and 3D walkthroughs. However, the questions were again open-ended to allow the subjective impression to be captured. Different types of spaces within the building were shown and the participants had to write down what their perceptions were of the represented spaces. The data were analysed to explore how users could assist client teams during design.

4. Results and Findings

Different Perspectives of Performance

The first set of data was gathered during interviews with both the client team members and users about the buildings they were engaged with for their work. The data showed a number of characteristics that separated the building client team and the building users. Firstly the users' requirement for performance is concerned with how they could act in a space.

'I want an environment that allows me to perform a certain task or daily job comfortably' (PS u1, 2013)

"Building performance is gauged by how comfortable an environment is, so it provides the right temperature, access to fresh air and the right level of lighting" (WS u1, 2014)

"In terms of community space, it is any space that can take you completely out of work, so you can sit, relax, allow to do work, but most important that it makes you feel like offline" (WS u2, 2014)

The users' expressions do contain functional aspects like temperature, fresh air and lighting but these are actually subjective characteristics. However, they do refer to a way of being in the building environment that involves performance supported by an environment that is beyond their aware attention. The notion of 'right' is here self-defining giving it a very subjective character. This is emphasised more when users express problems of the space.

“Some problems we have now, some facilities don’t fit within their spaces, and we don’t necessarily have the right furniture” (PS u3, 2013)

“the furniture within the open spaces is too big, and some of the sockets do not sit down properly” (PS u3, 2013)

“It is important to consider the positioning of some facilities such as projectors, one of the major concerns I have now, is whether our current spaces provide the right environment to work or lecture within” (PS u3, 2013)

“I think as a team we don’t really have enough space to perhaps store some of the things that we need, so when you work, you want things, you want the things around that you would normally need, so you want them to be accessible and to hand, but it becomes hard when things are pile up because you haven’t got enough space” (WS u2, 2104)

This draws out how users see things particularly which get in their way and so come to their attention. This is both as an individual experience but also a social experience e.g. the need for a team to have things at hand to perform their task.

The building client team performs a role as well as using experience, both of which centre on the delivery of buildings.

“For XXXX building, we tend to drive specification to a need, so what we are really controlling over, not necessarily the legislative side, but more a specification side, so when you walk into room, you still feel like a university building” (PS c2, 2013)

‘the space is defined by four sides with single or multiple accesses and designed to perform a particular function’ (PS c3, 2013)

“For such a modern educational building, we had to ensure the balance between aesthetics, robustness and durability, thermal comfort, appropriate levels of natural and artificial light, energy usage, flexibility to suit changing uses, acoustic performance, capital budget and on-going maintenance costs, brand identity for the university,” (PS c4, 2013)

“From my perspective, building performance is related to maintenance, energy and operation, and also all the systems within the building, so it’s about maintaining all the level of understanding” (PS c1, 2013)

“I think that performance is about saving money, so what we are looking for is a cost effective building, value for money, deliver what we want for the occupants, and try and reduce as many issues as possible” (WS c1, 2014)

Clearly, this is much more technical view than the users’ where problems exist in relation to what is deliverable and controllable against a functional brief and view of building operations.

BIM and Design

The second set of data gathered from the client team and users considered how BIM could help them see performance in design. The users’ results are responses to 2D and 3D images. Although users are not proficient with building representations, these representations did provide the users with information. Firstly, in response to the static 2D images which were building plans:

Hard to get a real feel of size/ Doesn't show the scale (CS, u1, 2D, 2014)

Good for seeing layout of furniture/ Can't tell how many people will fit in room (CS u2, 2D 2014)

Certainly, the users did not feel that they could appreciate any spatial quality from the 2D representations. However, the 3D and dynamic images were also challenging:

Doesn't show colour/it might change feel if [colour] shown/ 3D gives better visualisation, but you can't visualise how much space your computer will take up (CS u4, 3D, 2014)

I hate revolving doors /Spaces don't look comfortable/ Desks look small – need to see what it looks like with the PC on it./ Cannot tell the space, ventilation, light (CS u2, 3D, 2014)

Probably stuffy, Small, Shared space / Unsure have ability to open windows /Room access is difficult to tell whether it is scan or lock or other (CS u1, 3D, 2014)

Users need details that are not important for the delivery model. The users were inclined to be upset by what they could not see. These details are needed as an experiential scaffolding to understand how the spaces can be used and how easily this is. The users did not trust the 3D representations; they thought they might be used to make it look attractive by using reduced size furniture or hide problems. This goes back to the organisational context within which the new building was being designed.

Turning to the client team, they saw 3D helping them with their role:

"The representations provided information on the areas within the building, and allowed me to gauge it against the brief" (CS, c1, 2014)

"The visualisation has provided accurate briefing on predicted space use by occupants" (CS, c2, 2014)

However, as these were experienced members of the client team, they did understand the inadequacies of BIM for delivering subjective performance information and how the users (or even non expert clients) were disappointed with the BIM representations; e.g.

"Spatially, it's quite restricted what you can do beyond an appreciation for the space itself, so one thing is that BIM in its current iteration lacks is that visual connectivity to the building itself so it gives you an understanding of the form and shape but not necessarily how it actually physically looks. So when people look at the model, they actually look quite disappointed expecting much more of a 3D representation of what's physically out there not just the shape and form." (CS, c2, 2014)

This was interesting as the client team promoted BIM strongly but from experience they also saw its current limitations for other than technical delivery.

5. Discussion

5.1 Users and Clients

The case study data explicitly shows that users and client teams perceive the buildings in different ways. The client team's perceptions are driven by their experience and need for building delivery producing a requirement to control and be explicit through measurement about aspects that they have specified. The users' perceptions are driven by their experience of working in buildings producing a need for comfort and ease of action. In a sense the two

perspectives are connected but the users' perspective is describing a function in relation to their task. The client team has a more abstract view, not concerned with user tasks, but around measurable functions; but this abstraction can hide many problems of user tasks. This was shown by the client (*PS c2, 2013*) when demanding that certain specifications were delivered but these were not there for the occupants' needs. It is argued that the differences between the views of the client and users are not currently explored during design. Indeed, the client teams seemed somewhat reluctant to engage users, other than departmental managers, as they provided too complex or unspecifiable requirements, plus users gave often contradictory and unrealistic requirements which could be contrary to the client team's delivery objectives. The case studies also showed that clients have a corporate perspective on buildings as being expensive and their strategy is to cut this cost and make building-use more efficient; often referred to as space rationalisation. This was conducted purely at a space cost vs space area per activity level. Most often space per activity was set as a standard for that activity throughout the building even making savings by explicitly reducing this standard globally by say 10%. Client design teams do not investigate the business performance of space and how this might enhance work or how their designs might impede work. The idea that such decision-making might cost money from ineffective business operations was not in any way acknowledged. The users' perspective (e.g. (*PS u1 2013*) and (*WB u2 2014*)), had a focus upon the use of spaces in terms of how they operated as facilities and whether they provided comfort; thus, performance for users is much more from their individual perspective and not from some general or standardised basis.

5.2 Perceptions on digital representations

Not surprisingly given their drivers for buildings, the client team and users also perceived the digital representations (2D and 3D) presented to them differently. Looking at the client's side (e.g. *CS c1, 2014*) their perception of the representations is directly associated with the brief they had formed at the design stage. Some of the representations supported the quantitative aspects, such as area and occupancy level. Others were used as a reference to aid them in visualising aspects within the 3D representations such as furniture type, access to services (e.g. electricity sockets) and lighting (e.g. *CS c2, 2014*); which do support predicting how the space is can be utilised by the occupants. However, the client team use the visualisations and the completeness of the model to satisfy them about the successful delivery of the building.

The case was different from the users' perspective, as each representation triggered a number of concerns. They struggled to use the representations to experience the spaces. According to Oliva *et al.* (2010: 108) "we often acquire information about our surroundings by moving our head and eyes, getting at each instant a different snapshot or view of the world". The users try to use both their past experience as well as the representations to make sense of what they saw. Their concerns related to both operational and usability aspects but also the inadequacy of getting a feeling for the space. For instance, the user (*CS u1, 3D, 2014*) had concerns about space accessibility and whether windows could be opened. We argue that the gap between client and users is phenomenological where the client's concern focuses on the tangible aspects of the built environment whilst the users engage with intangibles that directly influence their experience.

5.3 New Interactions with BIM

The inquiry then into whether BIM can support the use of user experience in design is problematic. In this study a pragmatic approach was adopted to see what could be seen from the BIM models. Whilst acknowledging that virtual environments have been used as a collaborative design tools (e.g. Iorio *et al.*, 2011), which allow information exchanging and sharing; these do not acknowledge the differing information requirements from the client's and users' perspectives. The current immersive virtual environments, which allow a sense of presence (e.g. Heydarian et al 2015), do not recognise how such environments can support the users' input into the design. The visualisation tends to focus on objects (e.g. Heydarian et al 2015) as this is easily provided by a virtual world that people experience in games. The difficulty of distinguishing a gaming virtual world and an understanding of the experience of a real physical world then becomes critical. The IT world is obsessed by creating an apparent simulated reality even when this is not possible. The evolution of virtual reality applications has focused on the interface provided to visualise objects rather than what information is needed to design user productive space.

Current visualisation does not allow people to feel a space merely showing a connection of detail. This detail is all that is necessary for computer games where the gaming aspect, e.g. the action hero killing elves, is set within a context. In the building design world, it is the context and our engagement with it that is the critical aspect not the detailed representation of the objects. In fact, it may be that, because perception is phenomenological, simple representations that are engaged with interactively and dynamically, may be more successful. Such a change in outlook for digital representations requires a change in aspect and intent. The intent has to be about inducing feeling and experience and the aspect has to be more holistic. The idea that the interaction is metaphorical rather than simulated reality (Dade-Robertson 2012) and the phenomenological aspects (Murray 2000) needs to be explored in greater detail. Future interaction with BIM would require further constructive approaches where lived experience is informing the digital experience, which potentially can support producing more informative representations. This needs to be undertaken within a metaphorical informing environment involving a social situation, an interactive process and a dynamic enquiry.

6. Conclusions

Given that there is much evidence that buildings do not meet user needs (Bordass et al, 2001) methods are required to address this. The advent of BIM provides the opportunity to engage users more in design and so to deliver buildings that perform better. This paper has adopted a phenomenological position on the use of BIM. Using a study of client team and user views of BIM, it established that they have different needs and different perceptions of building performance and BIM. For the client the performance is described by functional and quantitative aspects that can be controlled for building delivery. However, for the user, the performance is experiential and so is not containable by functional terms or aesthetic considerations. This phenomenological aspect has not been acknowledged and certainly does not feature in the current BIM debate. There is an assumption in BIM promotion that visual

representations are all that is required to accommodate experience where this paper demonstrated that this is not the case. Although gaming worlds are experiential they have not been created for this application and engage people at a superficial level.

The evidence suggests that it is not virtual realism that is needed as regards experiential engagement; it is a user interactive process with a range of information that can elicit experiential understanding. Some of this may be quantitative or visualisations but other representations and interactive enquiry are needed. The paper suggests that BIM needs to support much softer information and this will be more metaphorical, interactive and developmental placed within a social situation of design. This also means that it is not possible to automate such activities and work is needed on the processes of design not just the product. The future of BIM then to deliver value for both the client and users lies in its ability to provide soft informed representations.

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Implementing Building Information Modelling in Building Services Engineering: Benefits and Barriers

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Abstract

Building information modelling (BIM), which involves the use of computer-generated n-dimensional (n-D) models to manage and integrate information in different phases of a building's life cycle, has rapidly evolved over the past decade. Yet there is still limited use of BIM in the Hong Kong construction industry, especially in building services engineering (BSE) which covers various disciplines such as electrical, air-conditioning, fire services, and plumbing and drainage. In order to explore how to achieve wider adoption of BIM in BSE, a study was commenced. Through an extensive search and review of relevant literature in the initial stage of the study, benefits of and barriers to implementation of BIM in building projects were identified. With reference to the characteristics of design, construction, operation and maintenance works, analyses were made to ascertain the applicability of the benefits and barriers in different building lifecycle phases. The findings will be used for designing a questionnaire for a focus group meeting that will be conducted in the next stage. Reported in this article include the outcomes of the above works and the tasks ahead.

Keywords: Barriers, benefits, building information modelling, building services engineering, construction industry

1. Introduction

In the 21st century, advanced information technology (IT) has rapidly changed the work processes of almost every industry. In the construction industry, one of the most significant IT developments has been the proliferation of the Building Information Modelling (BIM) technology. BIM is an IT-enabled approach that involves development and use of computer-generated n-dimensional (n-D) models to manage and integrate the essential building design with project data in different phases of a building's life cycle.

Recently, the global construction industry has entered a new era where adoption of state-of-the-art BIM has begun. More and more governments and public authorities have even set up a scheduled roadmap for full adoption of BIM. Though the Hong Kong government, for example, has decided to promote BIM implementation, there are only a few BIM-enabled construction projects. Whilst the Hong Kong Housing Authority has intended to implement BIM in all public housing projects from tendering stage in 2015, whether and when the best potential of BIM could be realized are yet to be seen.

Although the topic of BIM has been widely studied, very few studies are focused on the use of BIM in building services engineering (BSE), which covers various disciplines such as electrical, air-conditioning, fire services, and plumbing and drainage. As such, a study was commenced to explore how to achieve wider adoption of BIM in BSE.

2. Literature Review

2.1 BIM and Buildings

The concept of BIM has been in existence for a long time (Xiao and Noble, 2014). The first notion of virtual buildings came about in the 1970's (Eastman et al., 2011) and it did not come to the forefront of thinking until the term 'Building Information Modelling' was used as the title of a white paper by Autodesk in 2003, where the acronym "BIM" was also introduced. However, to define BIM is problematic as no single definition of BIM seems to exist. According to NIBS (2007), BIM is considered as *"a digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its life cycle, from its earliest conception to demolition"*. Gu and London (2010) had the same idea. They considered that BIM is an IT approach that enables the management of digital building information in different project phases in the Architecture, Engineering, Construction and Operation (AECO) industry.

BIM can be defined with more inclusive definition. Eastman et al., (2011) defines BIM as *"a verb or adjective phrase to describe tools, processes, and technologies that are facilitated by digital machine-readable documentation about a building, its performance, its planning, its construction, and later its operation"*. It is important to note that BIM is far more than a simple transition of 2D objects to n-D modelling offered by software vendors but manages graphical components and attributes of building information, allowing computer-aided generation of

drawings and reports, design evaluation, project scheduling clash detection and resource organization from project design till building operation (Chan, 2014; Smith and Tardiff, 2009). BIM applications connect all parties such as architects, contractors, surveyors and owners to work together on a common information system (Eastman et al., 2011). This allows all parties to share information with each other and increase the confidence and consistency among them.

Today, BIM has been used in different stages of construction projects - from conceptual design phase to operation and maintenance phase. Many BIM studies have been conducted by academics, professional groups and software vendors (Autodesk, 2010; Bryde et al., 2013; Lu et al., 2014; McGraw Hill, 2014; Popov et al., 2010; Zhang et al., 2013). One group of these studies documents the use of BIM on specific successful project cases so as to demonstrate where BIM should be applied in building projects (Bryde et al., 2013; Hanna et al., 2014). A number of other studies, focussing on the software development of visualization and coordination at design stage, simulate improvements in future construction work for avoiding redundant work or demolitions caused by design changes or errors (Popov et al., 2010; Lu et al., 2014).

2.2 BIM and Building Services Engineering

Building services engineers are mainly responsible for design, installation, operation and maintenance of mechanical, electrical and plumbing systems required for the safe, comfortable and environmentally friendly use of buildings. Nevertheless, the BSE sector is considered to be one of the riskiest sector in the construction industry because it is a follow-up trade - its involvement in a project's construction sequence hinges on other critical trades, such as architecture and structural engineering (Hanna et al., 2013).

The rising interest of BIM in the BSE sector can be seen by referring to the potential benefits it can bring to the consultants and contractors for controlling change, increase in productivity and better coordination during the design and construction of buildings. Studies found that 10-30% conflicts can be resolved by using BIM prior to the construction stage (Eastman et al., 2011). Additionally, an approximate 2% cost saving and 3% time saving were attributed to the use of BIM (Korman et al., 2008).

The existing research on the use of BIM in the BSE sector is limited. Previous studies concentrated on the coordination practices and they tried to find out, for instance, which software was popular (Hanna et al., 2014; Korman et al., 2008; Yung et al., 2014). On the other side, some studies provided insight into the use and value of BIM. Simonian et al. (2009) found that the electrical contractors are able to expand their services with BIM implementation. The adoption of BIM could also enhance the delivery and value of the contractor's expertise; streamline workflow; improve communication with clients, consultants and contractors; broaden the services they offer to clients; and increase the revenue per employee.

A number of reports and papers have also been published to provide insight into the use of BIM and recommend improvements to BIM practices in the mechanical and electrical construction

industries (Azhar and Cochran, 2009; Azhar et al., 2008). Whilst such research found that the advent of BIM in the industries can contribute to significant cost and time savings and quality improvements, several barriers to BIM adoption were also identified, including the lack of BIM knowledge and technological experience, software compatibility issues and high initial investment costs.

Hanna and his colleagues highlighted the state of BIM practice in the US and Canadian mechanical and electrical industries (Boktor et al., 2014; Hanna et al., 2013; 2014). The study results indicated that there was a significant increase in the use of BIM in electrical contracting when compared to the previous results obtained in 2008 and 2009. It was found that the use of BIM in the electrical construction industry has helped productivity and profitability; however, electrical contractors are still struggling to overcome the challenges of BIM implementation (Hanna et al., 2014).

The above parts show that the existing literature of BIM focused mainly on the benefits, barriers and implementation framework of BIM in the construction industry in general. Potential benefits and barriers which are specific to BIM implementation in the BSE sector are not entirely clear. Therefore, as reported in the following, a review of the relevant literature was made to identify the applicable benefits and barriers in relation to the use of BIM for BSE.

3. Benefits of Implementation of BIM for BSE

After an extensive literature review, it was found that a significant volume of studies agree that BIM adoption can bring along multiple benefits to the AECO industry. These benefits, as listed in Table 1, are applicable to the BSE sector.

Table 1: Benefits of Implementation of BIM for BSE

<i>Benefits</i>	<i>Justification</i>
(a) <i>Better cost management</i>	• <i>BIM can be used to check for structural, architectural and building services clashes so as to reduce the cost spent on rework and requirement changes (Bryde et al., 2013; Construction Industry Council, 2014).</i>
(b) <i>Better time management</i>	• <i>By using the integrated BIM model to visualize, explore and analyze the impact of changes, the project stakeholders can have better monitoring to the change in scope and progress of the whole project (Construction Industry Council, 2014; Guo et al., 2014; Hanna et al., 2013; Hanna et al., 2014; McGraw Hill Construction, 2014)</i>
(c) <i>Better quality control</i>	• <i>As a project moves into the construction phase, the depth of information contained within the n-D BIM model improves the contractor's ability to understand the design details and resolve problems (Bryde et al., 2013).</i>
(d) <i>Better risk management</i>	• <i>BIM increases the surety of investment and decision-making by improving visualization with respect to clarity, confidence and risk management (Bryde et al., 2013; Construction Industry Council, 2014).</i>
(e) <i>Better safety management</i>	• <i>BIM assists with the development of a method statement and enhances the understanding of construction safety issues that may arise (Construction Industry Council, 2014; McGraw Hill Construction, 2014).</i>
(f) <i>Better security</i>	• <i>BIM can assist the owners to better plan for security control during construction through early identification of the adequacy of relevant</i>

<i>Benefits</i>	<i>Justification</i>
	<i>equipment provided in the construction site (Construction Industry Council, 2014).</i>
<i>(g) Better project management</i>	<ul style="list-style-type: none"> <i>BIM systems having model production enables the construction sequence to be simulated prior to construction, which also facilitates activity programming for project management (Bryde et al., 2013; Construction Industry Council, 2014; Hanna et al., 2013; Hanna et al., 2014).</i>
<i>(h) Better decision making</i>	<ul style="list-style-type: none"> <i>Visual representations of BIM can help to enhance project stakeholders to understand the design details, resolve problems and aid decision-making (Construction Industry Council, 2014).</i>
<i>(i) Better visualization of design and construction process</i>	<ul style="list-style-type: none"> <i>BIM shows what different options look like, not only upon completion but before and during the works. Its visualization capacity can help project participants to better understand the design and construction process (Boktor et al., 2014; Chan, 2014; Guo et al., 2014; Hanna et al., 2013; Hanna et al., 2014).</i>
<i>(j) Better design and drawing</i>	<ul style="list-style-type: none"> <i>Using BIM in the design phase can help to ensure consistency among a project's many plans and drawings and monitor changes easily throughout the design process (Chan, 2014; Construction Industry Council, 2014; Hanna et al., 2013; Hanna et al., 2014).</i>
<i>(k) Better assembly of data and information</i>	<ul style="list-style-type: none"> <i>With consistent and standardized exchange of information, BIM can reduce the information lost during handover from designer to contractor (British Standards Institution, 2010; Construction Industry Council, 2014).</i>
<i>(l) Improved quantity take off and tendering</i>	<ul style="list-style-type: none"> <i>When BIM is correctly aligned with the method of measurements, the programme can generate the necessary quantity of materials for measurement purpose (Boktor et al., 2014; British Standards Institution, 2010).</i>
<i>(m) Improved construction workflow and method</i>	<ul style="list-style-type: none"> <i>BIM provides previews of the site planning and construction works, which facilitates the enhancement of construction sequence and method (Construction Industry Council, 2014; McGraw Hill Construction, 2014).</i>
<i>(n) Improved interdisciplinary communication, coordination and engagement</i>	<ul style="list-style-type: none"> <i>BIM enables significant improvements in inter-disciplinary coordination and communication through the use of consistent and standardized information (Construction Industry Council, 2014; McGraw Hill Construction, 2014).</i>
<i>(o) Enhanced the value of different discipline</i>	<ul style="list-style-type: none"> <i>BIM help the professionals to execute labour intensive work (e.g. CAD drafting, quantity measurement), thereby freeing professionals to focus on value-added work and activities (Construction Industry Council, 2014).</i>
<i>(p) Better lifecycle asset management and performance</i>	<ul style="list-style-type: none"> <i>An accurate BIM model captures the requirements, design, construction and operational information etc. facilities management of the building. Through more detailed asset and life cycle planning, lifecycle costs are better understood and performance is more predictable (BIM Task Group, 2013; Boktor et al., 2014; Construction Industry Council, 2014).</i>
<i>(q) Earlier occupancy</i>	<ul style="list-style-type: none"> <i>By utilizing BIM, the efficiency of construction can be improved and hence earlier use of the building can be achieved (ASHARE, 2009; Construction Industry Council, 2014).</i>
<i>(r) Improved environmental performance and promote sustainability</i>	<ul style="list-style-type: none"> <i>The full 3D energy consumption analysis can be performed by the BIM model and simulation programme with a short lead time (ASHARE, 2009; BIM Task Group, 2013; British Standards Institution, 2010; Construction Industry Council, 2014).</i>
<i>(s) Improved productivity and</i>	<ul style="list-style-type: none"> <i>As a clearer link between design decisions and cost implications are developed through BIM adoption, clients are able to attain better</i>

<i>Benefits</i>	<i>Justification</i>
<i>business outcomes</i>	<i>productivity and business outcomes for the company (Construction Industry Council, 2014; McGraw Hill Construction, 2014).</i>
(t) <i>Better customer service</i>	<ul style="list-style-type: none"> • <i>By improving communication and understanding of the clients' needs for the project at the at the planning and design stage, BIM can help the construction professionals and contractors to provide better service to the client (Construction Industry Council, 2014).</i>
(u) <i>Improved stakeholder and public engagement</i>	<ul style="list-style-type: none"> • <i>BIM improves a project team's ability to present the specifics of a design and their intentions to stakeholders and the public. Proposals can be better understood by the public through accurate visualizations (Chan, 2014; Construction Industry Council, 2014).</i>
(v) <i>Provision of a forward thinking platform</i>	<ul style="list-style-type: none"> • <i>BIM "pre-builds" a project, allowing problems to be addressed as and when found throughout the design process (Construction Industry Council, 2014).</i>

With the above-identified potential benefits, it is considered that BIM implementation can provide a number of major benefits to the BS engineers in managing the time, cost and quality of a construction project from the design till the operation and maintenance stage (Table 2). With BIM, BSE data and information are more easily shared, value-added and integrated into the architect design model at any point in time. BS engineers do not have to wait until the completion of architectural design concept to proceed with their work. Digital BSE product data can assist BS engineers in providing more accurate cost estimation and management in the design and construction stage, with lifecycle costs more predictable in the subsequent operation and maintenance stage. Quick and versatile simulation functions of BIM software also help to achieve better production quality of BSE.

In addition, BIM can provide benefits in the design stage - facilitating aesthetic considerations, design decision, system function and performance and quality control by the BS engineers. With BIM, BS engineers are able to detect any clash between building services and building structure, which means mistakes are identified before work commences on site. The BIM visualization can also help the BS engineers to quickly analyse and compare several design alternatives, conducive to quality control in later stages.

Other than its benefits to the design stage, BIM application is also beneficial to the construction, and operation and maintenance stages for it can enhance sequencing and installation consideration, accessibility, sustainability, occupancy, safety requirements, data assembly, interdisciplinary cooperation and engagement for the BSE sector. Using BIM enables clash detection and hence early resolution of conflicts in the design stage. Thus, the schedule of BSE activities can be accurately prepared. When BSE coordination work starts, different professionals in the BSE team can rely on BIM models when they need specific information, instead of searching information from different engineers in the traditional manner. Safety analysis can also be conducted by using simulation tools to check for safety and health issues in the planning of BSE works.

Table 2: Benefits of Implementation of BIM for BSE in different building lifecycle phases

<i>Benefits</i>	<i>Design</i>	<i>Construction</i>	<i>Operation and Maintenance</i>
(a) <i>Better cost management</i>	X	X	X
(b) <i>Better time management</i>	X	X	X
(c) <i>Better quality control</i>	X	X	X
(d) <i>Better risk management</i>	X	X	X
(e) <i>Better safety management</i>		X	X
(f) <i>Better security*</i>	X	X	X
(g) <i>Better project management</i>	X	X	X
(h) <i>Better decision making</i>	X	X	
(i) <i>Better visualization of design and construction process</i>	X	X	
(j) <i>Better design and drawing</i>	X		
(k) <i>Better assembly of data and information</i>	X	X	
(l) <i>Improve quantity take-off and tendering**</i>	X	X	
(m) <i>Improve construction workflow and method</i>		X	
(n) <i>Improvements in interdisciplinary communication, coordination and engagement</i>	X	X	X
(o) <i>Enhanced the value of different disciplines</i>	X	X	X
(p) <i>Better lifecycle asset management and performance</i>			X
(q) <i>Earlier occupancy</i>		X	X
(r) <i>Improved environmental performance and promote sustainability</i>		X	X
(s) <i>Improved productivity and business outcomes</i>	X	X	X
(t) <i>Better customer service</i>	X	X	X
(u) <i>Improve stakeholder and public engagement</i>	X	X	X
(v) <i>Creation of a forward thinking platform</i>	X	X	

*The benefit of better security is controversial (CIBSE, 2015). ** Whether quantity take-off is involved in the design or construction stage depends on the procurement method.

4. Barriers to Implementation of BIM for BSE

Although many benefits can be gained by the implementation of BIM, the pace of its adoption for BSE is much slower than anticipated. This may be because BSE companies and practitioners are struggling to overcome the barriers to BIM implementation. Such challenges are summarized in Table 3.

Table 3: Barriers to Implementation of BIM for BSE

Barriers	Justification
(a) <i>IT infrastructure and software related problem</i>	<ul style="list-style-type: none"> There is lack of a common standard and protocol for data interoperability and data management of which BIM models cannot be efficiently shared between different disciplines (BIM Task Group, 2013; Construction Industry Council, 2014; RICS, 2011).
(b) <i>Project participants related issues</i>	<ul style="list-style-type: none"> Project participants may not appreciate the value of collaboration among different parties working on the same project throughout its duration (Boktor et al., 2014; Construction Industry Council, 2014; RICS, 2011).
(c) <i>Lack of client demand</i>	<ul style="list-style-type: none"> Adopting BIM incurs the client to pay more professional fees to the design professionals. Private clients will demand BIM in their project design and construction when they realized the benefits of BIM (Chan, 2014; RICS, 2011).
(d) <i>Lack of training or education</i>	<ul style="list-style-type: none"> Although there is a wide range of BIM short courses offering in the market, the quality of these BIM courses varies considerably as no clear BIM guidelines are available for institutions to follow (RICS, 2011).
(e) <i>Lack of studies to quantify the value of BIM</i>	<ul style="list-style-type: none"> There is a lack of local studies to quantify the exact local benefits and value of BIM, which also affects the industry to adopt BIM (Burcin and Kensek, 2010).
(f) <i>Lack of government support</i>	<ul style="list-style-type: none"> Government support is strongly related to the ambitious of BIM implementation in the construction industry (Chan, 2011; RICS, 2011).
(g) <i>Lack of legal standards or specification to cope with BIM adoption</i>	<ul style="list-style-type: none"> There is a lack of relevant contract terms and legal standards that reflect the changes in data ownership, confidential information, risk allocation, and procurement practices that will be affected by the adoption of BIM (BIM Task Group, 2013; Chan, 2014; Construction Industry Council, 2014; RICS, 2011).
(h) <i>Lack of new or amended form of contract</i>	<ul style="list-style-type: none"> Prior to BIM adoption, there is a need to review existing contract provisions as to ensure the responsibilities and risks among contracting parties can be properly reflected (Chan, 2014; Construction Industry Council, 2014; RICS, 2011).
(i) <i>Widespread of mistakes and errors produced</i>	<ul style="list-style-type: none"> BIM's integrated concept blurs the accuracy and control of data entered into the model of which an error will be propagated among stakeholders if a mistake is produced (Chan, 2014).
(j) <i>Timing issues</i>	<ul style="list-style-type: none"> Most construction projects have a tight design schedule and intensive construction period in terms of return on investment philosophy. However, design consultants cannot avoid the uncertainty of design changes according to clients' requests. This not only increases the difficulties for design consultants to reduce time on project documentation, but may also contribute to delay in construction phase. The delay in construction may also impede the BIM utilities (BIM Task Group, 2013).
(k) <i>Investment and costing issues</i>	<ul style="list-style-type: none"> Investment of BIM is strongly related to high level management commitments as adopting BIM incurs initial investment costs related to management and administrative processes, including staff time, hardware, software and training (Azhar and Cochran, 2009; Construction Industry Council, 2014; Hanna et al., 2013; Hanna et al., 2014).
(l) <i>Too new and complicated for use</i>	<ul style="list-style-type: none"> Adopting BIM is difficult for certain amount of design professionals as they are educated and trained in the conventional 2D CAD environment and do not know much about BIM (Azhar and Cochran, 2009; Chan, 2014).
(m) <i>No opportunity to use</i>	<ul style="list-style-type: none"> In the construction industry, due to the tight design schedule and intensive construction period, design and construction companies normally will not consider the adoption of BIM in the project until it is required by the clients or owners. Thus, without the requirement of the client, there is no opportunity for BIM to be used by the construction professionals (Azhar and Cochran, 2009).

The barriers to implementation of BIM for BSE can be categorized into different categories (Lai and Yik, 2006): knowledge, finance, motivation, information and timing (Table 4). The knowledge category refers to the limiting factors related to lack of familiarity and understanding of the relevant software and contractual requirements for BIM adoption. When moving to adopt BIM, new requirements are needed to ensure effective interoperability and information exchange. However, the traditional training for BS engineers may not facilitate them to readily pick up new BIM technology and requirements. The absence of standard BIM contract documents in protecting the BSE information also prevents BS engineers from adopting BIM in the construction project. The financial category is about money-related limiting factors and the motivation category is about lack of support from different parties. The BSE sector consists of many small companies which have trouble to afford high initial investment to purchase the needed BIM software. With insufficient number of case studies showing the potential financial benefit of BIM, the BSE sector does not show much interest in investing towards the change in technology. The information category refers to the supporting cases and technology limiting factors. Timing issues affect the opportunity of using BIM in the BSE sector.

Table 4: Categories of Barriers to Implementation of BIM for BSE

<i>Barriers</i>	<i>Knowledge</i>	<i>Financial</i>	<i>Motivation</i>	<i>Information</i>	<i>Time</i>
<i>(a) IT infrastructure and software related problem</i>	X	X		X	
<i>(b) Project participants related issues</i>	X		X	X	X
<i>(c) Lack of client demand</i>			X		
<i>(d) Lack of training or education</i>	X				
<i>(e) Lack of studies to quantify the value of BIM</i>				X	
<i>(f) Lack of government support</i>			X		
<i>(g) Lack of legal standards or specification to cope with BIM adoption</i>	X				
<i>(h) Lack of new or amended form of contract</i>	X				
<i>(i) Widespread of mistakes and errors produced</i>	X				
<i>(j) Timing issues</i>					X
<i>(k) Investment and costing issues</i>		X			
<i>(l) Too new and complicated for use</i>	X				
<i>(m) No opportunity to use</i>		X		X	X

5. Conclusion and Future Work

Although it has been widely believed that BIM is an advanced technology that improves the performance and productivity of building projects, there has been a relatively slow uptake of BIM in the Hong Kong construction industry, especially in the BSE sector. This paper has

identified the possible benefits and barriers for implementing BIM in BSE. It is clear from the above findings that BIM can help to enhance productivity, profitability and project performance in terms of time, cost and quality in various building lifecycle phases. On the other hand, BIM is still in an evolving process and there are many barriers to its implementation.

The findings provide a solid basis for designing a questionnaire for use in a focus group meeting to be held in the next stage. In order to obtain as many useful findings as possible from a focus group discussion, careful selection of the group members who are experienced and representative in the field is necessary (Berg, 2009; Fern, 2001; Hesse-Biber and Leavy, 2004). The meeting, during which opinions of BSE related experts will be solicited, will validate the applicability of the above benefits and barriers to BSE.

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Understanding the Current Context and Challenges of BIM Adoption on Construction Sites

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Abstract

The deployment of Building Information Modelling (BIM) on construction sites has been slower than many anticipated and has lagged behind BIM adoption by design teams. The greater social and organisational complexities surrounding the on-site construction process suggest that BIM implementation faces multiple challenges. However, today's information technologies also offer opportunities for improvements in overcoming some of the barriers to construction process integration and efficiency.

The socio-technical environment has changed considerably over the past five years - smartphone use has become ubiquitous, tablet computers have become familiar and widespread as have wireless technologies, cloud computing, social media, and mobile data. Thus the current context for BIM implementation is quite different in terms of hardware, software, users and their expertise and expectations to what it was in 2010. In contrast, the research publication cycle is relatively slower and much of our accumulated knowledge and understanding of the construction site context vis-a-vis BIM as represented in the academic literature dates back to an earlier time.

This paper reports a survey of Estonian construction managers' opinions regarding BIM use on site obtained through semi-structured interviews. The survey found that BIM use on Estonian construction sites has been largely experimental to date and that most construction managers have little or no experience of it. Clear steps towards BIM implementation are not generally apparent and individual needs and priorities for BIM differ markedly. It is recommended that specific, problem-based interventions would contribute to BIM adoption.

Keywords: BIM, construction innovation, construction sites, Estonia, site managers

1. Introduction

The adoption of IT on construction sites has historically been slower than expected and the implementation of Building Information Modelling or Building Information Management (BIM) on sites remains limited with information exchange on most sites still in 2D and often paper-based (Davies and Harty, 2013; Dib *et al.* 2013; Cao *et al.* 2015). While initial efforts to develop BIM tools concentrated more on design and pre-construction planning (Sacks *et al.* 2010), an increasingly wide range of applications to support the construction phase has since become available (Ding *et al.* 2015; Karan and Irizarry, 2015; Matthews *et al.* 2015). Although BIM use is reported to be widespread in the design phase (McGraw Hill Construction, 2010), it is yet to become standard practice even in countries which are relatively advanced in BIM adoption terms (NBS, 2013). Merschbrock and Figueres-Munoz (2015) noted that current BIM practice in design still relies on local 'work-arounds' to overcome obstacles in implementation. Given the greater diversity of firms and personnel engaged in the construction phase, it is unsurprising that the application of BIM tools in support of construction management has been problematic (Hartmann *et al.* 2012).

In terms of enabling the adoption of BIM on sites, recent research has questioned the effectiveness of top-down impositions of BIM technology and new ways of working to accommodate the new technology (Hartmann *et al.* 2012). In addition, Davies and Harty (2013) draw attention to the dichotomy between firm- and project-level innovations in the adoption of BIM on sites. Miettinen and Paavola (2014) note the importance of the social and human conditions for the implementation of new technology.

Despite Estonia's relatively well-developed IT sector (in terms of e-government, cyber security, widespread use of digital signatures, etc.) and the considerable movement and interaction of construction personnel (particularly subcontractors) between Estonia and Scandinavia in what is increasingly a regional construction market, BIM adoption on Estonian construction sites appears to be lagging well behind that in the Scandinavian countries. In the World Economic Forum's Global Information Technology Report 2014, Estonia ranked overall 21st in the world but this hides a far more complicated picture. It ranked relatively higher in terms of government usage (12th) than individual usage (17th) with business usage being ranked lower (28th). The lowest ranking it received was in terms of the affordability of IT (61st) (WEF, 2014). Although government has actively and successfully promoted IT development in some areas this has not been the case with regard to construction and, to date, there has not been a coordinated effort by government to impose or promote the use of BIM in public construction projects.

This paper describes an initial investigation to gain a clearer understanding of the current state of BIM adoption on Estonian construction sites and an appreciation of the current attitudes and opinions of construction managers in relation to BIM. It is intended to provide a basis for further research efforts aimed at enabling BIM adoption in the construction process. Section 2 of this paper describes the research methodology adopted for this initial study. The results of the investigation are presented in Section 3, and these are further analysed and discussed in Section 4. Conclusions including recommendations for further research follow in Section 5.

2. Research methodology

The lack of progress to date with BIM adoption on Estonian construction sites and the intention to design future research studies aimed at enabling BIM use on sites suggested the need for an initial study to gain a better understanding of the current situation regarding BIM adoption on sites. To ensure as rich an understanding of the context as possible while attempting to limit the imposition of the researchers' own notions of the situation but still allowing for comparison between responses, a qualitative approach of semi-structured interviews was adopted for the study. The construction managers responsible for construction site operations were considered the most appropriate and convenient stakeholders to interview since they were directly affected by the adoption of BIM, were central to any BIM implementation initiative and had an overview of all the issues involved.

The interview questions were divided into three main groups:

1. IT use on construction sites currently and in the future – the current situation, what and who determines IT use, expectations, needs, barriers/challenges;
2. Modes of communication and collaboration between the on-site management and the various other parties to enable the construction process;
3. BIM – what the term means to each interviewee, their experience with BIM to date and the steps being taken towards adopting it on sites.

Particular attention was paid to ensuring that different personal definitions of BIM would not limit the scope of the information obtained from respondents yet, at the same time, it was intended to discover what these personal definitions of BIM were. For this reason, the term BIM was avoided until the end of the interview and the earlier questions referred to all 'IT solutions' and all forms of 'communication and collaboration'.

From the research of Davies and Harty (2013), it was acknowledged that the firm versus project dichotomy may have an important bearing on BIM adoption on sites and, therefore, both Site Managers and Project Managers (who are less site-focused) were included as interviewees. The sample of interviewees selected comprised one Project Manager and one Site Manager from each of six firms – three of the largest general contractors in Estonia (with annual turnovers approaching or exceeding 1 billion euros) and three medium-sized construction firms. This arrangement allowed for the possibility of drawing comparisons of both Project Managers versus Site Managers as well as large versus medium firms. Small construction firms were considered to be outside the scope of this study as their working arrangements and the issues they faced with regard to BIM would not be typical to general contractors.

The interviews were carried out individually by 3 different researchers according to a common set of open-ended questions which corresponded to the 3 main question groups in the list above. All the interviews were conducted in Estonian language. The interviews were audio recorded and the audio recording was later transcribed. The content of each of the transcripts was then analysed.

3. Results

Eleven interviews were conducted during July and August 2015. The interviewees comprised one Site Manager and one Project Manager from each of five construction firms but only one Site Manager from a sixth construction firm.

Table 1: Summary of prevalent responses from the interviewees

<i>Higher Level Categories</i>	<i>Nodes most referenced by interviewees</i>	<i>Number of Interviewees</i>
<i>Current IT use on construction sites</i>	<i>E-mail</i>	<i>11</i>
	<i>Project server</i>	<i>6</i>
	<i>AutoCAD (in 2D)</i>	<i>6</i>
	<i>Dropbox</i>	<i>6</i>
<i>Project specificity of IT use</i>	<i>IT use depends on project complexity</i>	<i>5</i>
	<i>IT use doesn't depend on the project</i>	<i>5</i>
<i>Current needs for additional IT</i>	<i>Clash detection</i>	<i>4</i>
	<i>Avoiding mistakes</i>	<i>3</i>
<i>Which party determines IT use?</i>	<i>Client</i>	<i>9</i>
	<i>Main contractor</i>	<i>6</i>
<i>Current barriers / problems / challenges</i>	<i>Knowledge of subcontractors' personnel</i>	<i>7</i>
	<i>Hardware constraints</i>	<i>3</i>
<i>Positive trends / reducing barriers</i>	<i>None - problems will remain the same</i>	<i>3</i>
<i>Expected current and future benefits from IT use</i>	<i>More accurate information</i>	<i>5</i>
	<i>Improved time planning</i>	<i>5</i>
	<i>Better visualization</i>	<i>5</i>
<i>Modes of communication / collaboration</i>	<i>[Responses are shown separately in Table 2]</i>	
<i>What does the term 'BIM' mean to interviewees (in the construction context)</i>	<i>3D model</i>	<i>6</i>
	<i>Coordination through the building lifecycle</i>	<i>4</i>
<i>Interviewee's experience with BIM</i>	<i>Little or no experience</i>	<i>7</i>
	<i>Some, limited experience</i>	<i>3</i>
<i>Expectations for BIM in the future</i>	<i>More complete information</i>	<i>3</i>
<i>Steps currently being taken by firms towards BIM adoption</i>	<i>Training of personnel</i>	<i>2</i>
	<i>Setting up new systems and standards</i>	<i>2</i>
	<i>Hiring new (BIM) personnel/experts</i>	<i>2</i>
	<i>Non-specific (small) steps</i>	<i>2</i>

An initial system of classification for analysing the contents of the interview transcripts was set up on the basis of the interview questions. This classification system comprised 12 higher level

categories (refer to Table 1 above). Under each of these higher level categories, an initial set of 'nodes' was generated based on the anticipated responses to the questions. The transcripts were then analysed and evidence in support of each node was identified and referenced to the appropriate node. Additional nodes were added as necessary to accommodate the full range of responses given by the interviewees. In this way a refined list of nodes was generated and all interview responses within the complete set of transcripts were represented in terms of their references mapped to this list of nodes. Table 1 (above) summarises the nodes which were referenced by the highest numbers of interviewees under each higher level category with the exception of the higher level category: 'Modes of communication and collaboration' which is separately summarised in Table 2 (below).

Table 2: Current modes of communication and collaboration on construction sites

<i>Communication / collaboration modes</i>	<i>Proportion of interviewees referencing these responses</i>				
	<i>Between: On-site and off-site managers (contractor)</i>	<i>Within the on-site team (contractor)</i>	<i>Contractor and designers</i>	<i>Contractor and sub-contractors</i>	<i>Contractor and client</i>
<i>Face-to face (informal)</i>	91%	82%	18%	73%	9%
<i>Regular meetings</i>	36%	36%	18%	55%	82%
<i>Telephone</i>	64%	45%	73%	64%	36%
<i>E-mail</i>	73%	73%	100%	73%	55%
<i>Online collaboration</i>	0%	0%	9%	0%	0%
<i>Shared file server</i>	9%	18%	0%	0%	0%

4. Further analysis and discussion of results

In addition to the compilation of the total number of interviewees referencing each identified response node and the total number of references from the transcripts associated with each node, the results were further analysed in terms of whether the responses from Project Managers differed substantially from those of Site Managers and also whether the responses from interviewees from the larger construction firms were substantially different to those from medium-sized firms. The findings from these analyses are reported below according to each of the 12 higher level categories listed in Table 1 above.

4.1 Current use of IT on Estonian construction sites

As shown in Table 1, the use of e-mail was, unsurprisingly, reported by all respondents. The importance of e-mail to Site Managers and Project Managers is difficult to overstate as, in their words: "*e-mails are automatically archived and are equivalent to signed documents in law*" and because "*e-mails leave a mark of the conversation*".

Just over half of the interviewees reported use of 2D AutoCAD, and file sharing systems (either a project server or Dropbox) while 4 out of 11 referred to the use of 3D models and only 2

interviewees mentioned the use of software for viewing these (both referring to Tekla BIMsight).

The use of project servers was reported by 6 of the interviewees. All 6 of these were from large construction firms and this was the main reported difference in IT use between large and medium-sized firms. A second difference between large and medium-sized firms appeared to be greater use of 3D (virtual building) models by the larger firms (reported by 50% of large firm interviewees) compared to their use being reported by only 1 of the 5 interviewees from medium-sized firms.

A slight difference between the Site Managers' and Project Managers' reported IT use seemed to reflect a more technical, hands-on role of the Site Managers in that more Site Managers reported the use of AutoCAD, 3D models and Tekla BIMsight than did Project Managers.

4.2 Project specificity of IT

Interviewees' opinions differed markedly on whether project characteristics affected IT use (Table 1). The view that IT use is not dependent on the project was held by similar proportions of Project Managers (40%) as Site Managers (50%) as well as large firm representatives (50%) and medium-sized firm representatives (40%). For those interviewees who suggested that IT use was indeed project specific, project *complexity* was the most commonly cited project characteristic determining IT use but project *budget*, project *size* and project *manager* were also mentioned as determinants. In the words of one Project Manager: "*the budget determines everything*".

4.3 Current needs for additional IT solutions

As shown in Table 1, the most popular suggestions for current needs which could be satisfied through IT solutions were clash detection and avoiding mistakes. Both of these suggestions were supported more by the medium-sized firm representatives (60% and 60% respectively) than by their large firm counterparts (17% and 0%). Two interviewees from large firms who reported that 3D models were in use did not indicate clash detection as a current need. However, it is unclear from the data whether this was because clash detection was already being used or that they didn't consider it a current priority or neither of these and it simply wasn't mentioned during the interview.

Both clash detection and avoiding mistakes as well as other suggestions appeared to reflect the Project Manager / Site Manager role differentiation to some extent in that Site Managers tended to offer more specific and technical suggestions (clash detection, combined 3D model and time schedule, documentation of changes, easier and faster quantity take-offs, visualization tool, construction model) whereas Project Managers offered more general suggestions (project bank, single system for communication and file sharing).

4.4 Which party (client, designers, contractor) determines IT use

The majority of interviewees (82%) considered that the client determines what IT solutions are used on construction sites. This was a view held equally by Project Managers and Site Managers and by large and medium-sized firm representatives. From the interview context, it is clear that the interviewees were referring here to the use of new and innovative IT solutions such as those associated with BIM rather than to standard, ubiquitous IT applications such as e-mail. The notion that the client should require BIM in order for it to be used suggests an assumption that BIM use would be a burden on the contractor rather than an opportunity for efficiency gains. These sentiments were variously echoed in the interviews: *"I haven't heard of someone asking for BIM to be used [on site]"; "the client doesn't know what BIM is and therefore doesn't ask for it"; "there are projects, where the private client is quite sophisticated and price isn't the only important thing anymore"; "the [BIM] software, to be honest, slowed down the work"*.

However, this was not the only perspective nor a necessarily exclusive one, as 55% of interviewees also indicated that the contractors themselves determined IT use on sites.

Only two interviewees suggested a role for the designers in determining IT use on sites. But the role of designers appears complex - whereas one interviewee noted that the designers have helped to encourage BIM use on site: *"the 3D constructive model was probably made out of the good will of the designer"* another implied that their actions might be impeding progress in this area: *"as a rule, many designers use BIM but then they convert their models to AutoCAD and changes can't be made. The 3D model isn't sent to us."*

4.5 Current barriers / problems / challenges for IT use

Although the actual question avoided using the term 'BIM' and so referred to the adoption of any new IT solutions, it appears to have been generally understood by the interviewees that it referred to barriers to the adoption of BIM-related innovations.

The problem most widely cited by interviewees (64%) was the knowledge and capabilities of subcontractors' personnel: *"The men themselves must be able to use it."; "On site, it largely depends on the subcontractors who actually do the work... I would waste a lot of my time making it clear to them."; "A lot of subcontractors have not yet reached to the level of [proficiently using] AutoCAD"; "The biggest barrier are the project managers of subcontractors, who do not see the big picture"*.

This challenge was referred to by similarly high proportions of Project Managers and Site Managers, and by representatives of both large and medium-sized firms. It was the single most highly referenced response node in the entire analysis with interviewees making a total of 23 references to this issue.

'Hardware constraints' was the second most cited challenge (by 3 interviewees) with knowledge / capabilities of main contractors' personnel (*"but also we ourselves are unable to*

use these models, so it is difficult to order things which we don't know nor can we check"), software constraints, financial constraints and a perceived older generation resistance to new technology each being referenced by two interviewees. In addition, the following further barriers were identified (by only 1 interviewee in each case): creates additional work, clients' (un)willingness to pay for them, the current education system, time constraints, no single standard / protocol for IT/BIM use, insufficient support from IT personnel, details in BIM model differ from the real world, insufficient information in the BIM models, not cost effective on small projects.

4.6 Positive trends that are serving to reduce barriers to IT use

The most cited response was pessimistic – that there are none and problems will remain (3 interviewees) - as one put it: *"There will always be problems, as people are involved"*. Less cited but more positive suggestions included increased interest in BIM and improved computer literacy (both cited by 2 interviewees) and experience (cited by 1). *"When people get experienced and use gets more effective and quicker, then [BIM] certainly will get used"*.

No direct mention was made of improved and more available software or of new and improved hardware being positive trends.

4.7 Expectations of current and future benefits from IT use

A considerable list of potential benefits was suggested by the interviewees, these can be summarised as being the expected consequences of more accurate and complete information being available quicker and in a format which makes it easier to understand and, particularly, to visualize. As shown in Table 1, the three most highly cited of these benefits were more accurate information, improved time planning and visualization (each cited by 5 interviewees). A difference in the number of Project Managers (1 in each case) and Site Managers (4 in each case) citing these can be observed and this is likely to once again reflect the greater engagement that the site managers appear to have with the technical details of the projects. In most cases of expectations put forward, Site Managers make up the majority of or are the only interviewees who referenced them. The notable exception to this was the response: 'more efficient communication' which was cited by 2 Project Managers and no Site Managers.

4.8 Current modes of communication / collaboration between the different parties on- and off-site

In analysing the reported modes of communication and collaboration, it is convenient to consider three groups (refer to Table 2 above): those engaged in the works (the contractor's team and the subcontractors/suppliers), the designers, and the client. From the results obtained, it appears that communications between Project Managers / Site Managers and each of these groups are distinct.

Between Project Managers / Site Managers and those engaged in the works, the primary mode of interaction is informal, face-to-face meetings (presumably on the site) – *"People tend to meet face-to-face very regularly"*. This form of communication was particularly dominant among Site Managers – all of whom reported such informal meetings with the contractor's off-site personnel, with the on-site team and with the subcontractors and suppliers. The next most important modes of communication among this group were e-mail and then telephone.

Between the interviewees and designers, the primary mode of communication is e-mail (100% of interviewees) and then telephone (73% of interviewees). The automatic archiving and the accountability associated with e-mail noted in subsection 4.1 above are undoubtedly important here and one interviewee gave insight into why telephone communication remains a popular alternative: *"a phone call ensures a response"*.

Communications between Project Managers / Site Managers and the client are mainly within regular scheduled meetings (82% of interviewees) with e-mail (55%) and telephone (36%) also having some significance.

The modes of communication differ somewhat between Project Managers and Site Managers and this appears to relate to their separate roles. Project Managers (100%) reporting higher telephone use than Site Managers (50%) in communicating with designers. Conversely, Site Managers (83%) reported higher telephone use than Project Managers (40%) in communicating with subcontractors and suppliers.

Notably, there was only one reference to collaboration with designers. This took the form of online, asynchronous collaboration. There were no reports of online collaboration in real time or any formal collaboration through colocation (Big Room, knot-working, or similar).

4.9 What the term 'BIM' means to the interviewees

As anticipated, the term BIM carried different meanings for the interviewees and some of them acknowledged this: *"Everyone thinks that they understand BIM the same way, but in reality it is not the case"*. A slight majority (6 interviewees) noted the 3D model component and 4 interviewees' responses reflected the notion of 'coordination through the building lifecycle'. Beyond these were a further 12 suggestions offered by only one or two interviewees as follows: collaborative design, joint management of the construction process, communication platform/tool, 4D model (3D model with integrated time schedule), information for operation and maintenance, information model for construction, overview of work done and work to do, notifies what needs ordering and when, visualization tool, all information in a single model of the building, platform to manage time and cost.

4.10 The degree of experience that interviewees have had with BIM

Of the 11 interviewees, 3 described themselves as having some limited experience with BIM while 7 professed to have little or no BIM experience. One interviewee did not provide an

answer to this question. The experience with BIM was slightly greater amongst Site Managers than Project Managers and representatives of large firms rather than medium-sized firms.

4.11 Expectations for BIM in the future

The responses elicited from the interviewees in terms of expectations from BIM in the future was somewhat similar to those given for their expectations of current and future benefits from IT use described in subsection 4.7 above. Once again, the responses related to expectations of more complete, more accurate information being available earlier and Site Managers provided the majority of these responses.

4.12 Steps that the interviewees' firms were reported to be taking to implement BIM

Very little common ground is evident in terms of the reported steps being taken by the interviewees' firms towards BIM implementation. Although 4 reported types of actions being taken (training of personnel, setting up new systems and standards, hiring new (BIM) personnel/experts and non-specific (small) steps) were each referenced by 2 interviewees, it is only in the case of the last of these (non-specific (small) steps) that the 2 interviewees were representatives of the same firm and, since this action is 'non-specific' it is more likely a function of a coding decision than precise agreement between the two interviewees.

Among the responses provided by single interviewees (research and development activities, keeping aware of BIM developments, creating 3D models, self-development activities by individuals, no steps are currently being taken) the two last ones equate to nothing being done at the firm level. The overall impression, therefore, is of a few, minor initiatives and, generally, that the interviewees are aware of very little being done towards the implementation of BIM within their firms.

5. Conclusions

The depiction of IT use and communications on Estonian construction sites gained from the interviews indicates that BIM use appears to have been primarily experimental to date. The Project Managers and Site Managers interviewed had some awareness and knowledge of BIM but little actual experience of it and clear, common steps towards BIM adoption by their firms were not apparent. There seemed to be a widely held view that BIM adoption on sites should be imposed and paid for by the client rather than evolving from internal needs and innovation.

Thus, it appears that BIM adoption has yet to convince the majority of Estonian project and site managers that it is cost and time effective – as one put it: *"It seems that paper on the wall is still the best solution at the moment."* However, benefits are expected from BIM in the future and there are undeniable changes including improved computer literacy, hardware and software that are enabling BIM adoption. The interviews also revealed the intense pressure felt by contractors' middle management to get on with the present job and this may be dissuading them from

investing their time and effort for potential but uncertain efficiency gains in the future. *"If money and time weren't issues, I would of course make a model."*

It therefore suggests that interventions to promote BIM adoption on sites should focus on demonstrating clear efficiency gains and value for money without requiring major time and money investment. This initial research indicated numerous challenges including subcontractors' knowledge and capabilities, the considerable diversity between individual needs, views and expectations from BIM and relative satisfaction with existing, non-BIM methods. However, there was also some common ground in the form of the specific needs and current expectations for the future of BIM that were identified in the interviews. This provides an initial list of possibly fruitful areas for intervention including: clash detection, mistake avoidance, better planning, the improved accuracy and timeliness, more appropriate formatting and easier visualization of information.

The complexities implied by the revealed role, knowledge and capability differences among construction site stakeholders, as well as the current ways of working and the reasons why these are found to be advantageous suggest that a thorough examination of a specific construction site process would have to precede any BIM intervention design if it were to have any possibility for success. It is therefore recommended that further research would take the findings of this initial study into account in order to identify specific 'candidate' processes for BIM improvement interventions. These processes should then be studied in detail and on a specific site from the perspectives and with the collaboration of all the stakeholders involved in them. Experimental BIM interventions could then be collaboratively designed together with performance measurement indicators relevant to all the stakeholders prior to their deployment and subsequent evaluation. This suggests an action research approach would be appropriate in the first case to identify specific, problem-based interventions before more general BIM adoption recommendations could be made.

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Organising the Implementation of BIM: A Study of a Large Swedish Client Organisation

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Abstract

Building information modelling (BIM) is currently much discussed in the construction industry. It has been brought forward as a way to address the problems with slow increase in productivity perceived in the industry. To support and drive the industrywide implementation of BIM, many large public client organisations are currently in the process of implementing BIM. The purpose of this paper is to explore how a large client organization organises their BIM implementation. In order to reach this objective a case study of the BIM implementation process at the largest public infrastructure client in Sweden has been conducted. This case study is supplemented with interviews with the management of the implementation project together with interviews with project managers in pilot projects implementing BIM. Based on the results of this study, it has been found that the BIM implementation is mainly focused on the technical requirements to support the shift from traditional drawings, to object oriented information. How this shift towards object oriented information will influence changes to work practices is however not defined within this implementation project.

Keywords: BIM, building information modelling, implementation, causal structure

1. Introduction

Today, Building Information Modelling (BIM) is frequently brought forward as a way to address many problems in the construction industry. For many years the industry has been described as fragmented with problems of low increase in productivity (Egan, 1998 and NIST, 2004). In research, BIM is described as being able to provide several potential benefits as shown in studied pilot projects (e.g. Eastman et al., 2011). At the same time, the implementation of BIM within the industry has been very tentative and there is a view that BIM has not yet shown its promised benefits (Gustavsson et al., 2012; Jung & Joo, 2011, Fox, 2014).

The role of government and public actors in this implementation process has been discussed in BIM related research. This role has been described as a driving force towards BIM in many countries and as being critical for successful implementation (Wong et al., 2010, Wong et al., 2011). There is also a view that the industry has to be convinced of the importance of BIM adoption in order to drive implementation. Khosrowshahi and Arayici (2012) argue that there is a need for researchers in the field to intervene in order to reach higher levels of BIM maturity. Furthermore they present a roadmap for BIM implementation in the UK construction industry to address the disinterest currently found in parts of the industry (Khosrowshahi & Arayici, 2012). In many countries there are and have been BIM initiatives by the government. Several large public client organisations are starting to demand the use of BIM in order to drive development. In the UK for example, there is currently a demanding that all public contracts awarded from 2014 and onwards contain requirements that all project participants will work collaborative through the use of BIM (CabinetOffice, 2011:14). In Sweden several BIM related initiatives are being conducted, many public client organisations are defining their requests for BIM use in projects (BIM i Staten, 2014). In parallel with this process the Swedish Transport Administration, the largest Swedish client for infrastructure projects, is initiating their implementation of BIM. With the expressed goal of increasing productivity both in their organisation and the industry as a whole, they are aiming to implement BIM in all of their projects.

This argued importance of BIM connected with public actor's central role as driver for change highlights the relevance of studying this implementation process. The purpose of this study is to explore how the Swedish Transport Administration organises their implementation of BIM. With the objective of analysing how BIM is expected to influence organisational change, both internally as a client organisation and how other actors are expected to be influenced, this article studies the BIM initiative and the implementation process by this client actor.

2. Method

In order to explore how the BIM implementation process is organised within this public client organisation a case study of the 'BIM initiation project' at the Swedish Transport Administration has been made. This qualitative case study has focused on analysis of documents produced as a result of this project. Furthermore it has been supplemented with 4 semi-structured interviews with the management of the project together with 4 semi structured

interviews with BIM responsible persons in the pilot projects most influential to the 'BIM initiation project'. The results from this case study has been analysed based on a literature review studying BIM implementation initiatives in other countries. This literature review has gone beyond the BIM field and studied research on the implementation of other IS/IT and how such implementation generates increase in productivity.

2.1 Delimitations

This study is limited to the analysis of the first stages of the BIM implementation process by a large Swedish infrastructure client. The studied process contains the initial implementation project by this actor which was later continued with two more simultaneous projects in different branches of the organisation. How the implementation process actually influences change is not part of this study. Rather this study focuses on how the BIM implementation is organised, the successfulness of this process will be analysed in later studies. That is to say, this paper does not analyse any actual increase in productivity, but rather focus on what steps this organisation took in order to implement BIM.

3. Literature review

BIM is described by many as a paradigm shift in the construction industry (Azhar, 2011). Several substantial benefits have been shown. In order to take advantage of the numerous potential benefits there are many barriers to BIM adoption that has to be bridged (e.g. Eastman et al. 2011), and implementation of BIM is described as a major managerial task (Khosrowshahi & Arayici, 2012). Not only technical solutions are required, rather, there is a need for corresponding changes in work practices and skill sets of the project participants to be made (Froese, 2010). In addition to these changes, substantial changes in business practices and rearrangements of contractual agreements are needed (Mihindu & Arayici, 2008; Succar, 2010; Tylor, 2007). The BIM concept is also unprecise; it can be implemented and used in many different ways, on many different levels. Each of these levels of BIM-use presents different possibilities combined with various challenges in order to achieve successful implementation (Succar, 2009). To achieve BIM implementation at higher maturity levels there is a need for proper implementation at the organisational level together with its integration at the industry level (Khosrowshahi & Arayici, 2012). It is also suggested that the greatest gains can be found at these higher levels of BIM maturity (Khosrowshahi & Arayici, 2012).

3.1 The role of public actors

Client organisation has been argued to be the actor who benefits the most from BIM implementation (Eadie et al., 2013). It is also the actor, together with the main contractor, who is in power to demand compulsory BIM use (Linderoth, 2010). The adoption of BIM is also perceived as slow within the construction industry (Gu, 2010, Smith 2014). An unwillingness to adopt BIM has been observed, firms are satisfied with continuing using traditional CAD (Khosrowshahi & Arayici, 2012). Together, this has open for suggestions that public client organisations and governments should intervene and support BIM use. A study by Wong et al.

(2011) stated that “the role of the government is critical in the implementation of BIM in any country”. It is also argued that government mandates demanding BIM in their projects is effective in driving implementation (Smith 2014). These types of initiatives are taking place in many different countries, where the different governments are involved with setting up BIM policies (Wong et al. 2010).

Several papers discuss how BIM implementation rates can be increased in the construction industry. Wong et al. (2011) presents six steps for BIM implementation by the government. The initial step is the need for a specific BIM policy, establishing BIM as something that should be implemented and used in all new projects. Further these steps focus supporting BIM-use by external actors, such as contractors and consultants, thereby enabling inter-organisational use of BIM (Wong et al. 2011). One major issue is interoperability between different software and formats, governments have been shown to be able drive the development towards more open standards to increase interoperability (Porwal & Hewage, 2013). Khosrowshahi and Arayici (2012) state that education and awareness about BIM is critical to address resistance to change. Further they state, as BIM implementation is often supplemented with process improvement, a need for support services for actors implementing BIM processes in their organisation.

3.2 Information technology and increased productivity

The main reason for the BIM interest is the expected increase in productivity. Such an influence on productivity has been shown in several case studies (e.g. Azhar, S. 2011; Eastman et al. 2011). The actor who is expected to acquire the greatest benefits is the client (Eadie et al., 2013; Olofsson et al., 2008), and this has been brought forward as one more argument for letting the client organisations drive the BIM implementation. However, the extent of the benefits following BIM implementation is discussed and has been questioned (Gustavsson et al., 2012; Jung & Joo, 2011; Fox, 2014).

The link between implementation of new information and communication technology (ICT) and increased productivity has been described in many different contexts. How investments in ICT influence the productivity of an organisation has been described as the “productivity paradox”, where these investments generate little or no increases in productivity (Brynjolfsson, 1993). This paradoxical connection has been suggested to stem from several different reasons for example, difficulties to measure influences of ICT and mismanagement of implementation and use of new systems (Brynjolfsson, 1993). In later studies Brynjolfsson and Hitt (1998) problematizes the concept of the “productivity paradox”. They argue that the use of ICT does not increase productivity by itself; rather, it is an essential part of a wider context of organisational changes which in turn influences productivity positively. A major part in the value of ICT is its ability to enable further investments in the organisational layout adapting business processes and work practices to the new possibilities (Brynjolfsson & Hitt, 2000). There can be found similarities between the earlier ambiguities in the link between ICT and productivity and the interest for BIM in the construction industry of today. Many potential benefits with BIM implementation have been presented and several studies presenting case-studies indicating positive outcomes of BIM-use in projects (Eastman et al., 2011). However

there is still ambiguity in how this BIM use influences the productivity of the industry. The implementation and use of BIM is currently tentative within the industry and its promised benefits have not yet been shown (Gustavsson et al., 2012; Jung, & Joo, 2011). It has been argued that there is currently hype around the concept of BIM, further that this hype can lead to suboptimal decisions throughout implementation projects (Fox, 2014).

3.3 Casual structure – information technology and organisational change

The connection between information technology and organisational change has been of interest for many decades. Markus and Robey (1988) describe how there are several different theories describing the link between information technology and organisational change, but these theories are argued to have problems with reliable generalisations regarding this relationship. Further their study describes the causal structure of these theories as composing of three dimensions: Casual agency, logical structure and level of analysis.

Casual Agency:	Logical Structure:	Level of Analysis:
<ul style="list-style-type: none"> • Technological Imperative • Organisational Imperative • Emergent perspective 	<ul style="list-style-type: none"> • Variance Theory • Process Theory 	<ul style="list-style-type: none"> • Macro • Micro

Figure 1: Dimensions of Causal Structure (Markus and Robey, 1988)

Causal agency – describes the assumptions about the causal agent and the direction of influence of this agent. The ‘technological imperative’ views technology as the causal agent which determines the behaviours of individuals in the organisation. The ‘organisational imperative’ views the human individuals within the organisation as agents of change. The ‘emergent perspective’ finds causality in complex interactions between technology and human actors within the organisation.

Logical structure – describes the relationship between elements identified as precursors and those identified as outcomes. ‘Variance theory’ views specific precursors as essential and sufficient to achieve outcomes. ‘Process theory’ however, assumes that the precursors necessary to achieve certain outcomes, but insufficient to cause them.

Level of analysis – describes the level at which theories describes the impact of information technology, and is generally either: individuals, organisations or society.

Depending on the casual agency of how information technology is predicted to generate change different strategies of how to manage the change in an organisation follow. With the

‘technological imperative’ implementers focus on the choice of information technology and its technical requirements. When the correct technology is in place and working organisational change is expected to follow. Following the ‘organisational imperative’ focus tend to be on the allocation of resources and improving implementation strategies while the results of the implementation is perceived to stem from the behaviour of managers and system designers. The ‘emergent perspective’ finds predictions of implementation impossible and to support changes extensive participation of the analysis, design and implementation by the people involved can be advised. (Markus and Robey, 1988)

4. Results

The Swedish Transport Administration is the public actor responsible for long term construction, operation and maintenance of roads and railways in Sweden. The organisation is also designated to, in its role as client, to work towards increasing productivity both for its own investments and also in the branch on the construction industry related to infrastructure (SFS 2010:185). The interest for BIM by the Swedish Transport Administration was initially brought forth in a strategy document by the Swedish government emphasising the possibilities with the use of ICT. This document was presented in late 2011 and presented the government’s aim to establish Sweden at the forefront in regards to taking advantage of the possibilities with digitalization. In a Swedish government official report in 2012, these ambitions were concretized in regard to the infrastructure sector (SOU 2012:39). This report explored ways of increasing productivity and innovation in this sector. Building information modelling takes up a large part of this report and it is expressed that BIM has large potential to increase performance for the Swedish Transport Administration. In 2013 the Swedish Transport Administration initiated a project to begin structured implementation of BIM in their organization, the ‘BIM initiation project’. According to the project specification, this project is an answer to the guidelines given by the Swedish government and to increase productivity and innovation both for the client organisation but also for the industry as a whole. At the time, BIM was explored and used by an unstructured network of projects managers at the Swedish Transport Administration. The initiatives were driven by interested project managers and not coordinated by the mother organisation. The ‘BIM initiation project’ was the first coordinated step towards BIM by this actor.

4.1 The BIM initiation project

According to the project specification the ‘BIM initiation project’ was initiated 2013, with the following goals:

- All new projects in the ‘investment’ department uses BIM to some extent from 2015 and onwards. These projects make an active choice concerning BIM based on predefined levels.
- Make the work processes more efficient and thereby saving approximately 150M SEK to the end of 2015

- Make the Swedish Transport administration a client with an obvious demand for BIM both in design and construction.

The project aimed to address the possibilities and suggestions presented in the governmental official report, but also the organizations ongoing assignment to lead innovation within the infrastructure industry. The project was scheduled to end in 2015 and at that time introduce BIM-supported work practices in all projects initiated thereafter. According to the ‘strategy for BIM implementation’ presented by The Swedish Transport Administration within the ‘BIM implementation project’, BIM is described as: “the use of information models in a continuous flow through the main processes connected with a constructed facility”. Further it is expressed that the information produced in these processes could be used for multiple purposes, for example: clash control, analysis of different design alternatives, cost calculations and time scheduling. Combined, these benefits are expected to result in a more efficient work process. The BIM concept is described as being related to three different aspects: *Product* – The planned and constructed project, *Organisation* – The actors, planning constructing and maintaining the facility and *Process* – The work process which the organisation follows in their work.

4.2 Pilot projects

Within the ‘BIM initiation project’ there were planned a total of 28 pilot projects. These projects were of varying size and complexity and were supposed to reconnect to the BIM initiation project and transfer knowledge of experiences of how BIM had been used in these pilot projects. According to interviews with several of the project managers in some of these projects, there are large differences in how BIM was used. The extent by these pilot projects influenced the ‘BIM initiation project’ also varies a lot. These pilot projects can be divided into three different groups:

- Projects using BIM extensively. These projects began their BIM use before the ‘BIM initiation project’ was started. Generally large projects with large interest for BIM within the project organization.
- Projects using BIM to some extent following the BIM initiation project.
- Projects not using BIM at all.

Among these projects the first category has been the most influential in regard to impacting the results of the BIM initiation project. In this category there are mainly two very large projects that distinguish themselves. According to the technical manager in one of these projects, much of the material presented by the ‘BIM initiation project’ was based entirely on documents produced in this project.

4.3 Results from the BIM implementation project

At its finish the ‘BIM initiation project’ resulted in a total of 32 documents, these documents contained changes to guidance documents and templates for e.g. meeting agendas. Most of these documents mainly changed the templates to include ‘BIM’ and ‘models’ rather than ‘drawings’.

In addition to these documents there are three documents describing the use of BIM within the organization. All these documents went through a referral process within the organisation before they were reworked, resolved and incorporated in the project process by this actor.

General guidelines for BIM in projects – This document seeks to manage and support the use of BIM in new projects and ensure that BIM satisfies the goals presented in earlier visions. Within this document, changing roles and responsibilities following BIM implementation is described. The project manager in every project will be responsible for: (1) assuring that BIM will be used in a current extent to ensure efficient information management (2) ensure that the project organization reserves education regarding BIM and (3) to define BIM in relation to the specific project. This document also describes a ‘base level of BIM’ that should be fulfilled in all construction projects. There are however room to increase this level and use BIM at a larger extent in projects where it is deemed suitable.

Tutorial document for BIM-use in projects – This document is supposed to provide guidance for the actor responsible for BIM-use in the project (BIM-coordinator for example). It provides recommendations and descriptions of BIM and how it can be used in relation to process, organization and product. The document supports BIM-users and is supposed to be used as a compliment to other guiding documents.

Requirements on object oriented information – This document defines how information should be generated and managed to ensure use of object-oriented information in projects in a life cycle perspective. The document contains demands on technical aspects of the generation of object-oriented information and is supposed to be used in procurement processes. These are demands that should be used both in-house but also in contracts with external contractors. The document defines the file formats for exchange of model based information between actors to be DWG (AutoCAD) or DGN (MicroStation). Information should be classified according to BSAB 96 (Swedish standard).

Among the documents presented by the ‘BIM initiation project’ there is a focus on the technical aspects. How models should be produced and shared and what types of file-formats that can be used are well described. The documents regarding this information is categorised as requirements. On the other hand, the work practices when using these models are described more vaguely, with large degrees of freedom for the project managers in the actual construction projects. These documents are categorised as general guidelines or tutorial documents.

4.4 ‘Base level’ of BIM

The ‘base level’ of BIM defined by the ‘BIM initiation project’ is supposed to be used in all projects. As the description of the BIM concept, this ‘base level’ of BIM relates to both: *Product*, *Organisation* and *Process*. This level of BIM is defined in a list of 17 points supposed to be fulfilled in all projects. This level of BIM emphasises on enabling the shift towards an object-oriented work-practice, the use of models to ensure the quality of information. The ‘base level’ of BIM is presented as changing the current practice of presenting project related

information in drawings, lists and descriptions into an object-oriented practice. Information should be stored in one or multiple models instead of the traditional alternatives. The details of this lowest level of BIM is affected both by the technical limitations such as problems with interoperability as well as organisational preconditions both internally and externally where lack of experience with the new work-practices is argued to hinder the implementation. The Swedish Transport Administration describes BIM as a structured way of managing information of good quality related to a constructed facility. With BIM this will give an unbroken information flow throughout the whole lifecycle of the constructed facility. This holistic perspective is said to bring conditions to minimise costs and time in: planning, design, construction and maintenance of the facility.

According to the BIM-coordinator in one of the most influential pilot-projects this base level of BIM implementation is a compromise between what is possible to achieve in the industry with the current level of BIM experience and possible benefits with BIM use. This level is further presented as an enabler for actors, wanting to use the collaborative aspects of BIM. By demanding models as a client, models can be available for exchange between contractors and consultants, supporting BIM oriented work practices by these actors.

5. Analysis

Prior research argues that the main role of public client organisations is to demand BIM use in their projects, thereby forcing other actors in the construction industry to adopt BIM if they want to continue to work for these clients. The BIM initiative in Sweden very closely resembles what other studies have found governments and public clients are doing in other countries. In order to increase productivity and innovation the Swedish Transport Administration is promoting the use of BIM. Similar to for example the UK, the Swedish Transport Administration is developing demands stating that project related information should be delivered in object oriented formats, de-facto demanding BIM-use. There is a view within the 'BIM initiation project' that, by following these requirements contractors and consultants are enabled to work collaboratively with the new possibilities that BIM enables. As in some BIM related research the 'BIM initiation project' assumes that such BIM requirements will result in higher BIM use in the industry. However, as studies by Brynjolfsson and Hitt, (2000) have concluded, in order to achieve the full potential of new IS/IT solutions there are a need for organisational change. It has been described that changes to work practices, enabled by new technology, is generating the sought after increases in productivity, rather than the technology itself. These conclusions are in line with research on BIM implementation describing the guidelines for high level BIM implementation. For example, Khosrowshahi and Arayici (2012) described the need for an effective implementation strategy as BIM requires substantial changes to how construction business is conducted.

As described by Markus and Robey (1988) there are many different theories describing the relationship between implementation of new technology and organisational change. Depending on the causal structure of the theory chosen, different focus will be taken and different results are expected. The 'BIM initiation project' by the Swedish Transport Administration is described

as a structured first step towards implementing BIM in all new projects initiated by the organization from 2015 and onwards. The main deliverable from this project is the documents with proposed changes to how projects should be conducted. These documents mainly focus on the technical preconditions needed in order to use BIM. The technical requirements for how 'object based models' should be produced and managed. This information is described in detail within the requirement document, defining formats etc. The requirement document (Requirements on object oriented information) is supposed to be referred in the tender templates used in all newly started projects. Thereby, this document influences how information is managed in projects. A 'basic BIM' level, which should be used in all projects, is defined. This 'basic level' mainly focuses on a shift from drawings to models in order to support object oriented work practices. However, how these models should influence changes to work practices in projects using BIM is not focused upon. Instead the responsibility for these changes is delegated to each responsible project manager in the respective projects.

The results from the 'BIM initiation project' are based extensively on input from the pilot projects connected to this BIM implementation project. These projects differ widely in extent of BIM use. Most of the smaller projects on the list do not use BIM at all or at a very limited extent. The two large projects used BIM even before the 'BIM initiation project' started and it is mainly experiences from these projects that have influenced the referral material produced in the 'BIM initiation project'. The individuals responsible for BIM in these projects have an extensive insight and knowledge in how BIM is and can be used as well as how it can influence work practices. This is however not defined and stored in the documents presented by the 'BIM initiation project'. The importance of training in relation to BIM implementation presented by e.g. Khosrowshahi and Arayici (2012) is not addressed in this implementation project.

6. Conclusions

With the opinion that governments and public actors should drive BIM implementation it becomes relevant to study how these actors organise the implementation processes. Based on the study of the 'BIM initiation project' by the Swedish Transport Administration, it can be argued that this actor organises their BIM implementation based on the 'technological imperative'. The technology is viewed as a causal agent for organisational change; in this case the use of object oriented models is expected to act as a driving force towards change in work practices. Following this view of BIM, the focus in this implementation process has been on ensuring the right preconditions for enabling a shift towards using object oriented models to store and manage information. The use of a 'basic BIM level' which should be used in all projects is expected to act as driving force for changing work practices. The project manager in infrastructure projects is given the role of change agent, responsible for ensuring the use of BIM within their projects. The 'technological imperative' view of BIM implementation addresses some of the barriers described in research in regards to the slow implementation of BIM. For example the issue of BIM training is not as well discussed in this stage of the BIM implementation by this actor. By demanding models as deliverables in construction projects there will have to be a shift towards producing models. However, this view does not address many other barriers in relation to BIM implementation. In order to evaluate which 'causal

structure' is most suitable in relation to BIM implementation, further research should study the results BIM implementation initiatives and relate them to the implementing actor's view of BIM in terms of causal structure.

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A Predictive Semantic Inference System Using BIM Collaboration Format (BCF) Cases and Machine Learning

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Abstract

Building Information Modelling (BIM) has been hailed as an artefact of collaboration, where all project participants are able to create, modify and implement design/construction configurations within the same virtual environment codified by International Foundation Classes (IFC). To facilitate communication between human participants during project development, the BIM Collaboration Format (BCF) was developed, enabling users of BIM applications to communicate issues and refer those to specific objects. A single BCF entity holds a textual description of the issue, a status, links to a BIM IFC model and objects, a picture of the issue, and a camera orientation. Therefore, BCF poses a rich repository of complex fuzzy semantic knowledge concerning design risks, such as change requests and rework proposals, in a readily accessible format based in the XML schema. This research investigates how data in BCF files can be extracted, and processed using a linear algebra method known as singular value decomposition (SVD). SVD is extensively used, along with dimensionality reduction, for pattern recognition applications and has been shown to infer semantic correlations amidst a variety of different unstructured data (e.g. texts, images, signals etc.), comparable to that of human cognitive associations. Consequently, a dynamic knowledge-base is established of past BCF cases, whereby designers can flexibly query and systematically retrieve most relevant past issues and related objects, given any known current parameter – reminiscent of how a human may recall past experiences upon inquiry or design review. This paper introduces the BCF structure, describes the machine learning steps taken to extract and process BCF data, and presents the conceptual framework of a queryable knowledge-discovery system. This allows for relevant past issues to be recalled and the knowledge integrated in future designs as problem- and change-prediction. It is of particular pertinence for users of BIM, in sight of the ever-growing masses of BCF data generated from project to project.

Keywords: BIM collaboration format, singular value decomposition, latent semantic analysis, change management, knowledge management.

1. Introduction

Design changes are very common in the building industry, where dynamic feedback, due to iterative cycles, are ubiquitous (Lyneis, Cooper, & Els, 2001). Change is a major cause of delay, disruption, and disputes (Motawa, Anumba, Lee, & Peña-Mora, 2007). Furthermore, it is hard to predict changes in construction projects, given the uniqueness of each project and the limited resources (Hanna, Camlic, Peterson, & Lee, 2004). There is thus an obvious need to better manage change, as well as to garner competence to predict and avoid unnecessary changes early during the design stage. The one-off nature of construction projects have often been used to justify unpredictable changes, however, even in such contexts many repetitive issues occur from project to project. Many of such potential change issues could well have been anticipated in advance and thus avoided given the tacit knowledge of experienced designers, and close collaboration between different design parties.

In the advent and increasing adoption of Building Information Modelling (BIM), the design reviews and change issue prediction are often done in the BIM environment. BIM is used to produce building models of different aspects of the building: architecture, structures, plumbing, heating, air-conditioning, and so on (Eastman, Teicholz, Sacks, & Liston, 2011). Therefore during the design, multiple interrelated models are produced in individual design tasks by different disciplines/parties. This creates great a challenge for the management of change across different models, in sight of change prompts and requests for information (RFIs) from both designers and contractors on site.

In recent years, the introduction of the BIM Collaboration Format (BCF) into the BIM ecosystem has enabled an additional layer of semantically rich communication between different project participants. It introduces a workflow communication capability connected to models based in the International Foundation Classes (IFC). The idea is to separate the “communication” aspects from the actual model. In particular, it was envisioned to enable the conveyance of RFIs, proposals, change prompts, or other queries/requests related to the model, collectively referred to as *issues*. It was also to allow such issues to be exchanged in collaborative work without the need to transfer the whole BIM-model as bulk data, as in the past. The BCF is an Open BIM standard format developed by BIM companies Solibri and Tekla in 2010 as “bcfXML v1”, and later “bcfXML v2” became released in October 2014 and adopted by BuildingSMART (BuildingSmart, n.d.).

The BCF presents a repository of semantically rich issues of change-related knowledge. Alluding to knowledge management concepts of Nonaka & Takeuchi (1995), the BCF presents a codified form of, otherwise tacit, knowledge, which can then be *internalized* by the designers to be applied in value creating work, as part of the knowledge management lifecycle. However, *internalizing* these issues as human practitioners currently requires much time and effort as it occurs organically through the acquisition of experience dealing with such change cases from project to project. In order to aid this process, this study proposes the mining/extraction of textual natural language descriptions in BCF issues and process the dataset using the machine learning textual processing technique known as latent semantic analysis (LSA). LSA is based on a linear algebra operation

called singular value decomposition (SVD) and has been shown to infer conceptual links amid natural language texts comparable to human semantic intuition (Landauer, McNamara, Dennis, & Kintsch, 2007) and similar techniques have been used in a variety of other pattern recognition problems (Deerwester, Dumais, Furnas, Landauer, & Harshman, 1990). This allows the matching of texts on semantic/conceptual level rather than explicit string matching used in word search-functions, where semantic relationships between texts are not involved. This ability of LSA is cardinal in managing and retrieving possible future change cases, where different building elements may be related to each other through different types of issues qualified by a variety of parameters. Consequently, this enables change cases to be automatically captured and stored in such a way that future designers are able to effectively query the system for past similar and/or related issues. This helps to enhance the designers' capacity to learn or *internalize* historical change-related knowledge and thus improves future design decisions in avoiding change.

In the Section 2 we cover some preliminaries regarding the background and mathematical basis of the latent semantic analysis method. Section 3 describes the methodology applied in our particular case, the nature of the textual *issue* descriptors extracted from the BCF of a specific project, and the pre-processing steps taken before the analysis. We then discuss the results in Section 4 with reference to other potential developments. Section 5 concludes by drawing up a brief summary and reiterating the value of our proposal in the BIM-based design change management context.

2. Theoretical preliminaries of LSA and SVD

Latent semantic analysis (LSA) is a techniques for creating vector-based representations of texts, which are claimed to capture their semantic content. The primary function of LSA is to compute the similarity of text pairs by comparing their vector representations, and has been shown to closely match human capabilities on a variety of tasks. It extends the vector-based approach by using Singular Value Decomposition (SVD) to reconfigure the data.

2.1 Pre-processing

LSA starts with a text quantification method based on what is known as Vector Space Model (VSM) (Salton, Wong, & Yang, 1975), where a corpus of d documents using a vocabulary of t terms is used to compile a $t \times d$ matrix \mathbf{A} , containing the number of times each term appears in each document (term frequencies). Some trivial terms such as “the”, “of”, etc. (the stopwords) are excluded, and some others are consolidated, because they share a common stem (Porter, 1980) or some other lexical quality. The frequency counts in \mathbf{A} typically undergo some transformation (term weighting) known as TF-IDF that penalizes common terms and promotes rare ones. After weighting, the term frequencies are also normalized so that the sum of squared weighted term occurrences within each document is equal to one (Salton, 1989). Subsequently, \mathbf{A} is subjected to Singular Value Decomposition (SVD).

2.2 Singular Value Decomposition

Matrix \mathbf{A} of dimensions $t \times d$ is decomposed into the product of three other component matrices \mathbf{U} ($t \times t$), \mathbf{S} ($t \times d$) and \mathbf{V}^T ($d \times d$), that is, $\mathbf{A} = \mathbf{USV}^T$. \mathbf{U} columns consist of the *term* eigenvectors, and \mathbf{V} columns are the *document* eigenvectors, and \mathbf{S} is a diagonal matrix of singular values (i.e. square roots of common eigenvalues between terms and documents). In other words, matrix \mathbf{U} describes the original \mathbf{A} row entities as vectors of derived orthogonal factor values, matrix \mathbf{V} describes the original \mathbf{A} column entities in the same way, and the middle \mathbf{S} matrix is a singular diagonal matrix containing scaling values in descending order along the diagonal of the matrix. When the three component matrices are multiplied the original \mathbf{A} matrix can be reconstructed. The \mathbf{U} and \mathbf{V} matrices are thus regarded as all the constituent patterns that determine the original matrix \mathbf{A} . The columns in \mathbf{U} and \mathbf{V} are orthonormal vectors that describe these patterns and are arranged in descending order of significance.

2.3 Dimensionality reduction

Dimensionality reduction is carried out in order to remove noise (small irrelevant patterns) inherent in natural language. This step is done by removing column vectors from \mathbf{U} and \mathbf{V} starting from the least significant, and retaining the most significant vectors. This corresponds also to the same number of diagonal singular values retained in the \mathbf{S} matrix. The reconstruction of the truncated/reduced component matrices produces another matrix (essentially an approximation of matrix \mathbf{A}), which exhibits latent semantic relationship between words and documents not evident in the original matrix \mathbf{A} . The number of dimensions to keep is a difficult question as it depends on how much of the original variance is desired to be kept without loss of relevant data. In linguistic terms, it is difficult to interpret intuitively. However, many case-specific guidelines are given within different contexts. A very common technique is to plot the square of singular values of the \mathbf{S} matrix against the number of dimensions (Sidorova, Evangelopoulos, Valacich, & Ramakrishnan, 2008). One may choose the number of dimensions corresponding to where the singular values decrease substantially (elbow of the graph) indicating the point where the patterns become insignificant. Generally, the more noise is removed (dimensions reduced), the clearer will the semantic relationships be revealed in the reconstructed approximate matrix.

2.4 Cosine similarity

The reduced \mathbf{U} and \mathbf{V} row vectors represent the semantic space of the words and documents. Thus a similarity function can be used to measure semantic correlations between term-term, document-document, and term-document relationships. The cosine similarity function tends to work well empirically (Landauer et al., 2007) and is widely used for vector matching in many applications. Cosine similarity is denoted by the cosine of the angle between two vectors (suppose vectors a and b) and can be calculated by dividing the dot product of a and b by the product of their magnitudes, that is, $a \cdot b / (\|a\| \|b\|)$.

3. Methodology

Broadly, this study involves the automatic extraction of natural language information from BCF issues and processing it using latent semantic analysis. This is used to demonstrate how higher level semantics and linked data may be inferred automatically from existing data or documentation embodying some level of professional knowledge. The semantics inferred can then be fed back to the workflow to augment the knowledge of practitioners for future work. The BIM data acquired for this study is from a large renovation project of a heritage complex in downtown Helsinki, and the BCF issues thus reflect the nature of changes accordingly - predominantly related to mechanical, electrical, and plumbing (MEP) services. The steps of this study are covered in the subsections below.

3.1 Extract issues from XML schema of BCF

As described in Paasiala et al. (2015) a BIM Collaboration Format v2.0 formatted bcfzip file contains a folder for each issue. The issues correspond to proposals and change requests in BIM-data-models (BuildingSmart, n.d.). Each folder contains a markup.bcf file that embodies textual information about the issue, a viewpoint.bcfv file that specifies the related elements, the viewpoint, and the camera angle, and snapshot.png pictures describes the issue.

Only markup.bcf files contain human written sentences. In that XML file, although title and description tags can contain clauses, in practice, only comment tags had any content. A small program was written in the Java programming language to extract the comments from the files. The full source code of the program is available in (Oraskari, 2015). When extracting the bcfzip file, the program follows the first steps that was presented in (BIMServer, 2015). However, instead of marshalling the XML documents into Java objects, we parse the files using a JDOM XML parser (Hunter & Lear, 2015). The XML document tree of the markup.bcf is traversed recursively. Whenever there is a comment tag in the graph, the content is copied. A total of 71 passages of text from BCF issues were extracted as natural language descriptions for each issue logged by human project participants.

3.2 Textual parsing and term-document matrix

The extracted text passages (documents) are then parsed into words. The words are filtered in order to remove stopwords – such as “the”, “a”, “an”, “is”, “in” etc. – that supposedly do not contribute to the semantic value of each document. A standard “stoplist” is used for the English language. The words then undergo morphological stemming, where the words with different morphological conjugations would be reduced to the root of the word. For instance, “ventilate”, “ventilating”, “ventilated” etc, would be reduced to be the same stem or root of the words. As an example, the document “Office area: Electric duct location? Radiators hot water piping penetrates electric duct” are parsed into the following terms: “are”, “duct”, “electr”, “hot”, “locat”, “office”, “penetr”, “pipe”, “radiat”, “water”. The resulting words are now considered the terms in the term-document matrix ($t \times d$), consisting of the occurrences of term t in document d .

The term-document matrix is transformed through TF-IDF (term-frequency, inverse document frequency) weighting to enhance the discrimination between documents, by discounting the weight of very common terms and promoting the weight of less occurring terms (Salton, 1989). The term-document matrix's raw occurrence values are replaced by the product, $w_{td} = tf_{td} * idf_t$, where tf_{td} is the normalized term occurrence in each document d ; and $idf_t = \log(N/df_t)$, where N is the total number of documents in the collection, and df_t is the number of documents that contains term t . After TF-IDF weighting, the document vectors are normalized to remove the advantage that longer documents have over the short documents. Cosine normalization is an effective normalization technique and is computed, by dividing the TF-IDF weights by the Euclidean length of the respective document vector (Salton, 1989).

3.3 SVD, dimensionality reduction, cosine similarity, and query

The term-document matrix ($t \times d$) undergoes singular value decomposition to yield the U , S and V matrices. Effectively, the terms and documents are vectorised and transformed or mapped to the same vector-space through dimensionality reduction. To choose how many dimensions to retain, the squares of the diagonal values of the singular S matrix are plotted against the number of dimensions (the number of singular values to retain) as shown in Figure 1. The number of dimensions to retain is chosen to be 13, after which the graph starts to flatten out, indicating that the patterns before dimension 13 contributes most to the variance of the original matrix A . Singular values after dimension 13 is therefore assumed to constitute “noise”.

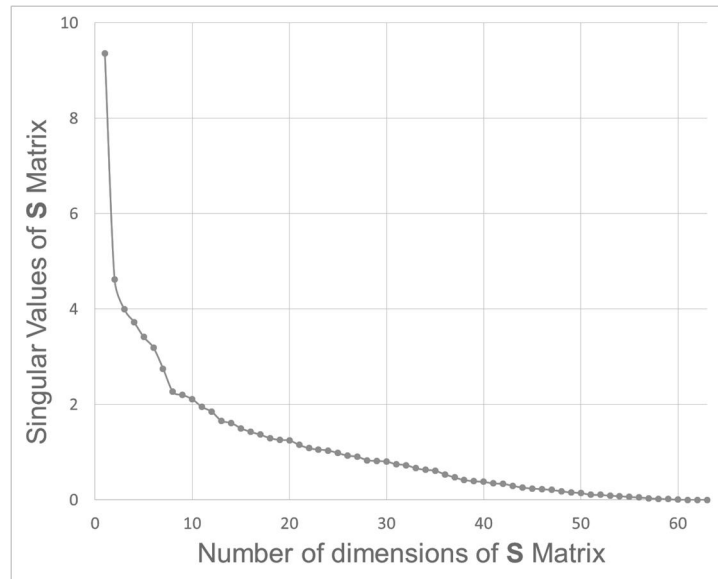


Figure 1: Plot of squares of singular values against the number of dimensions

3.4 Cosine similarity and query

The terms and documents can now be represented as vectors of 13 dimensions, as the rows of the reduced U and V matrices respectively. The similarity between any two vectors can thus be computed (through cosine similarity as earlier explained). If the two vectors are identical, the cosine similarity is 1 since the angle between them is 0° . Vectors that are totally uncorrelated has

a cosine similarity of 0 (angle 90°), while cosine similarity of -1 implies that the two vectors are total opposites (angle 180°) or inversely proportional intuitively. The cosine similarity between vectors of the reduced \mathbf{U} and \mathbf{V} matrices equates to semantic similarity between them. Since this process is automated, it allows the system to calculate similarities upon query and recommend similar terms or documents from the database. The query is achieved by creating a pseudo-document consisting of a set of terms as query input. This pseudo-document can be represented as an explicit vector (q) of term occurrences, which can be mapped to the semantic space. The semantic query vector (q_s) can be obtained, through a simple algebraic manipulation following $\mathbf{A}=\mathbf{U}\mathbf{S}\mathbf{V}^T$, to be $q_s = q^T\mathbf{U}\mathbf{S}^{-1}$. Cosine similarity can then be applied to gauge the similarity between the query vector q_s and all the other semantic term and document vectors represented by the dimensionality reduced rows of \mathbf{U} and \mathbf{V} matrices.

4. Discussions

In principle, the cosine similarity values between term and document vectors depends on the degree of correlations between the row and column spaces of the original \mathbf{A} matrix, in particular, how co-occurrence of terms within the same documents indicates some level of relationships between these terms. The fundamental concept of semantic inference in human text is that similar/related terms would have much higher co-occurrence within documents than unrelated terms. For instance, considering the hypothetical corpora consisting of all of human literature, it is understandable that the terms “pear” and “apple” would have a much higher chance of occurring together in the same sentence, than “pear” and, for instance, “radiochemistry”, to name an arbitrary example. The semantic meaning of certain terms, and their potentially numerous metaphorical or ambiguous nuances in natural language, can be qualified by other terms that occur together with it. In the same way, a semantic space can be established for domain knowledge, such as design change issues in this case, and co-relationships between the constituents of these issues can be automatically inferred, even to reveal non-apparent associations. To demonstrate the logic, some results of the analysis are shown with more specific detailed discussions covering the interpretation of the output of the proposed data extraction and latent semantic method on change issue management, integrated in BIM.

4.1 Interpretation of query and matching

Queries can be made to the system by inputting any number of terms. Some arbitrary query and results are shown in Figure 2. One- and two-term queries are shown and the top 10 semantically related documents (issues) are tabulated. One can very quickly use simple data visualizations to gain an overview of the nature of the spectrum of issues with relation to specific concepts. For instance, issues related to “corridor” are high in similarity though not as spread out as say “window”, which seems to have one very similar issue, while the rest are spread out. Issues related to “electric cable” and “ventilation ducts” do not have as high semantic similarities as others, implying that even though the issues related to both concepts are widespread, they are not very specific. “Ablution area” has quite a few issues that are very semantically relevant, but not as widespread as the others. Such a table gives a strategic view about the how common certain issues occur with respect to specific concepts queried by the user, as well as how much semantic

similarity there is between the issues and the queried concepts. This poses a suggestive function for the user to gauge the likelihood that certain change issues may arise in a new project given certain parameters as concepts to query the historical knowledge.

"Electric cable"		"Ventilation ducts"		"Ablution area"		"Windows"		"Corridor"	
Issue24	0.664	Issue54	0.747	Issue57	0.909	Issue53	0.851	Issue1	0.857
Issue62	0.618	Issue33	0.697	Issue68	0.902	Issue50	0.657	Issue27	0.805
Issue63	0.588	Issue11	0.683	Issue67	0.775	Issue44	0.617	Issue28	0.777
Issue38	0.544	Issue65	0.643	Issue60	0.767	Issue54	0.591	Issue7	0.682
Issue39	0.538	Issue70	0.603	Issue16	0.648	Issue30	0.575	Issue36	0.607
Issue8	0.532	Issue53	0.560	Issue14	0.353	Issue14	0.540	Issue20	0.576
Issue57	0.424	Issue50	0.545	Issue44	0.302	Issue11	0.493	Issue49	0.454
Issue32	0.400	Issue71	0.540	Issue17	0.290	Issue65	0.446	Issue18	0.315
Issue20	0.334	Issue15	0.527	Issue49	0.226	Issue67	0.431	Issue11	0.296
Issue2	0.318	Issue38	0.480	Issue19	0.195	Issue70	0.320	Issue59	0.275

Figure 2: Top 10 semantically related document/issues with respect to specific concept queries

"Electric cable"		
Issue24	0.664	Technical area: Electric cable tray through ventilation duct
Issue62	0.618	Technical area: Electrical box through ventilation pipe and ventilation pipe through cable tray
Issue63	0.588	Technical area: Cable tray through sewage pipe
Issue38	0.544	Business area: Electric cable tray through ventilation duct
Issue39	0.538	Business area: Electric cable tray location
Issue8	0.532	Technical area: Electric cable tray penetrates inside ventilation pipes
Issue57	0.424	Ablution area: Electric cable tray underneath the ceiling
Issue32	0.400	Sewage drain through electric cable tray?
Issue20	0.334	Corridor area: Electric cable tray through the hot water pipe
Issue2	0.318	Office area: Electric duct location? Radiators hot water piping penetrates electric duct
"Windows"		
Issue53	0.851	Window and ceiling height? Architect model space object is missing
Issue50	0.657	Social area: ventilation duct door and water drain are at the same point. Floor is missing.
Issue44	0.617	Lobby area: ventilation piping in the same place as the front surface of the ceiling
Issue54	0.591	Ventilation duct and ventilation terminal clashes with electric duct and cooling pipes. Space object is missing
Issue30	0.575	Display area: Radiators in front of windows and door
Issue14	0.540	Stairwell: modelled staircase elevations dimensions?
Issue11	0.493	Drainage pipe penetrates ventilation ducts.
Issue65	0.446	Utility area: Cooling coil penetrates ventilation duct and electric cable tray
Issue67	0.431	Stairwell: ventilation duct is underneath the ceiling and goes through the building structure
Issue70	0.320	Technical area: Cooling pipe and electric cable tray penetrate the ventilation duct

Figure 3: Full issues semantically similar to queries: "electric cable" and "windows"

Figure 3 tabulates more detail about the "electric cable" and "windows" queries for further interpretation. For "electric cable" the top 10 semantically similar issues all contain some form of the terms "electric" or "cable", but it doesn't necessarily need to be the case, as the system uses "concept matching" rather than "string matching". Nevertheless, it is of course expected that issues explicitly containing the query terms would have high semantic similarity. A few explanations need to be given for how the issues are ranked for "electric cable". One sees that cases to do with clashes with ventilation related elements seem to be placed higher than other issues related to electric cables. This is due to the terms being weighted differently. "Ventilation" related terms appear many times in the corpus, so much so that the weight of those terms have been reduced as they are deemed non-unique (through TF-IDF and normalization). Therefore the contribution of "ventilation" to the semantic value of the issue is low, thus leaving the semantic weights of the electric cable to be prominent in that specific issue. A bit lower down (Issue57, 32,

and 20 for instance) all contain “electric cable”, but because of the contributing semantic weight of the other related elements, the share of the weight of “electric cable” is reduced with respect to the issue. Therefore, as one can see, the method is able to cater for different semantic weights of terms and aggregation of terms to match whole issues to a concept, and not merely wherever a term appears within an issue. This is the property of LSA that allows latent semantic traits of passages of texts to be identified and mapped to other passages of text, as concepts denoted by the aggregation of semantic vectors.

The results for “windows” (Figure 3) can be interpreted in a similar way. However, one sees that only Issue53 contain “window” and is expectedly semantically significant, while the rest is somehow related even though “window” doesn’t occur explicitly. Issue 50 for instance is matched, because Issue53 (where “window” is evident) also is related to some object being “missing”, while Issue50 has similar (i.e. floor is “missing”). This co-occurrence of concepts has created a link between “window” and some problem related to “missing” objects or information. Issue44 is linked probably due to the relation to “ceiling” which also occurs in Issue53. LSA has the ability to take into account the complex second order relationships of concepts, in fact, all latent relationships identified are based on aggregates of multiple orders of semantic associations across all the issues in the corpus.

Of course, it is also possible for the system to return the most semantically related terms rather than issues as shown above. However, in this particular exercise, the terms by themselves (being out of context) are difficult to infer meaning. It is therefore more meaningful for this particular renovation orientated context to retrieve the issues. Other cases, for instance, colloquial discourse within large corpora of literature, term retrievals usually reveal synonymy – multiple terms describing similar concepts.

"in the conference area, the hot water pipe is below the ceiling"		
Issue20	0.734	Corridor area: Electric cable tray through the hot water pipe
Issue7	0.677	Corridor area: Hot water pipes penetrates through the electric cable tray.
Issue41	0.567	Office area: Lighting rail clashes with ventilation terminal. Electric cable tray clashes with ventilation pipe and hot water pipe.
Issue42	0.474	Office area: Electric duct and radiator clash
Issue59	0.465	Corridor: Level and the stair in the same place? Cable tray and water pipe clash

Figure 4: Example of a natural language query

Due to the limited length of the paper, more detailed discussions and interpretations will be reserved. However, it is worth mentioning that given the nature of how query vectors are established, the queries can be indeed done in natural language. An example in Figure 4 shows the most semantically related issues returned given the arbitrary natural language query. Such queries will be much more accurate and valuable when the training corpus is big. In our case, we only have 71 issues (for one change review cycle) consisting of 78 terms. If, for instance, the BCF knowledge regarding change management is extracted from 10 projects, each having just 100 change issues, 1000 issues could be processed and vectorised semantically in the database, and used as suggestive knowledge augmentation for future engineers’ decisions. The benefit is that the system can handle datasets of change cases that are ever growing from project to project and the latent semantic structure of the data also updates accordingly. This is comparable to how a

human engineer may accumulate experience over time through experience, and apply the lessons learnt to new decisions and predictions to avoid problems.

Currently, with only 71 issues, consisting of 78 terms (4430 characters, thus supposedly 4.3 kB of data), it is remarkable how intuitive semantic relationships between terms and documents can be inferred through the proposed semantic system. This is noteworthy in sight of the association of machine learning techniques with “big data”, where large datasets (in the order of Gigabytes) apparently needs to be mined to train algorithms. Our proposed technique demonstrates effective results even given small sets of data, available in all segments of the construction context.

4.2 Extended BIM possibilities

It is useful to enrich the textual comments used in this study with some further explicit contextual information. They can be added in the sentences in the form of “keywords” or even include ontological entities from IFC schema. The sample sentences would contain not only more information, but also it would allow the learning algorithm to use the information that is available in the BIM models.

The BCF specification makes it possible to obtain a list of identifiers of entities that are related to a BCF issue. In principle, those identifiers can be used to fetch information from the relevant BIM models. This can be done either manually using a BIM tool or using a program to automate the task. In practice, the relevant identifiers are listed in the `viewpoint.bcfv` files, the corresponding entities can be marked visible or selected using tags. The `viewpoint.bcfv` files further specify a camera view inside a BIM model. That makes it possible to use standard 3D graphics processing to calculate which parts of the model are visible for the camera. For example, ray tracing (Glassner, 1989) can be used. The parts could be used to infer the affected BIM entities. They could, in turn, be used to enrich the issue descriptions, so as to allow these BIM entities to be included in the latent semantic analysis.

Additionally, if we had a series of changes in the model that has taken place after the BCF is time stamped, and possibly before the next BCF prompt, the series can automatically convey information of the actual changes that were imposed upon the BIM model, following the requests in the previous BCF issues. In principle, BIM tools could keep track of changes in the model, which is possible if the BIM tool can be changed. Otherwise, a more generic way is to export the model versions into IFC/RDF representation (Pauwels & van Deursen, 2012) and use algorithms presented in Oraskari and Törmä (2015) to provide change sets of added and removed RDF triples. The triples include identifiers of entities in the model and they have location in the graph. It makes it possible to deduce the affected entities in the BIM model and the triples express the changes made. The change description could be used as a context for a BCF issue comment. In other words, these change events identified can be attached to the change requests in BCF issues, therefore establishing the possibility for the semantic retrieval of not only change requests, but as well as the change actions taken in response. For instance, the natural language query in Figure 4 may be used to retrieve similar past issues, and if the past issues also include the following change events, it poses a suggestive function to respond to future change requests/prompts, be it in BCF

or otherwise. This is especially useful for a novice engineer who may query possible change risks, and the system adds an additional layer to suggest the possible actions to be taken in response to the risk, thus catering both for the prediction (change avoidance), as well as mitigation (change cost alleviation) functions.

5. Conclusions

Design change management poses a huge challenge in any civil engineering project. This study sets out to investigate how to better manage design changes in a BIM integrated environment, in sight of the growing adoption of BIM in typical workflows. In particular, this study demonstrates how data from existing BCF files in the BIM environment can be extracted and semantic inferences made to predict future changes given natural language queries by the user. Natural language is particularly interesting as it is able to capture specifics, as well as fuzzy semantic dimensions, required to describe complex change prompts and issues. The proposed method uses data extraction techniques to obtain textual data from BCF issues, processes the texts via latent semantic analysis and establishes a semantic knowledge repository, which can be flexibly queried by future users. The types of semantic inference is shown and discussions are made on how retrieval results can be interpreted to illustrate the reasoning of the technique. This semantic knowledge repository, in the form of vectorised terms and issues, is to some extent an analogy for how human tacit experience in change prediction and mitigation can be captured and presented in an intuitive manner, that is also both scalable in size and flexible for multiple domains. The computational technique thus simplifies the complexity of knowledge/information modelling, by harnessing the properties of linear algebra decomposition, thus enabling an inductive logic to be applied to complex, unstructured data. It is remarkable that with as little as 4.43kB of training data in this exercise, intuitive semantic associations can be inferred and thus used for matching intuitive concepts, otherwise tacit in expert reasoning. On a fundamental level, the simplicity and effectiveness of the prototype democratizes artificial intelligence for construction contexts, and shows the possibilities beyond natural language texts to include specific BIM or IFC entities, made possible by innovations in linked-data and ontology-related research. Ultimately, the effectiveness of the system can be enhanced given more data over time, which also caters for the adaptability of the system by considering the shifting trends of the industry or domain with respect to how design changes are managed.

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Construction Supply Chain Coordination Leveraging 4D BIM and GIS Integration

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Abstract

Construction supply chain management (CSCM) is challenging and information demanding due to the fragmentation of project participants and one-of-a-kind nature of construction projects. Construction supply chain coordination is the core issue to improve the performance of CSCM. Coordination of construction supply chains requires tracking of construction activities, an integrated platform, and certain coordination mechanisms. Some researchers have suggested the use of building information modeling (BIM) to monitor construction activities and manage construction supply chains. However, since material warehousing and delivery are mostly performed outside construction sites, a single BIM model is not sufficient to coordinate the entire construction supply chains over a wide region. In this research, an integrated framework was developed based on 4D BIM and geographic information sciences (GIS) for coordination of construction supply chains between the construction site and other project related locations, such as supplier sites and material consolidation centers. The integrated platform was used to solve three critical problems in CSCM, namely selection of supplier sites, number of deliveries, and the location-allocation of consolidation centers for multiple sites using information from BIM and GIS. The framework will be demonstrated using scenario examples in San Francisco.

Keywords: Construction supply chain management, Building information modeling, GIS, Coordination mechanism, Lean construction

1. Introduction

The construction supply chain is a converging supply chain directing all materials to the construction site where objects are assembled from incoming materials. Moreover, the construction supply chain is a temporary supply chain producing one-off construction projects. As a result, the construction supply chain is typified by instability, fragmentation, and especially by the separation between the design and construction of built objects. A closer look at the construction industry shows that a considerable amount of waste produced is rooted in poor management of the material supply chain (e.g. delivery services, inventory, communications). Therefore, since the end of the 1980s, the construction industry has seen the launch of a number of CSCM initiatives.

While there is abundant literature on the design, application and evaluation of construction supply chains, the effective use of geographic data in CSCM has not been fully explored. Jadid and Idrees (2013) argued that traditional SCM had no effective mechanism for locating the nearest suppliers for particular materials. Li et al. (2003) pointed out that location-related information plays an essential role in all kinds of business activities, including an E-commerce system for construction activities. GIS is potentially applicable in construction supply chain management to manage spatial information, and provides an ideal solution to manage costs of transportation and market analysis in the overall E-commercial activities. Irizarry et al. (2013) revealed that the traditional way of managing the supply chain with a focus on the site activities (e.g. to reduce costs or the duration of site activities) or on the supply chain itself (e.g. to reduce logistics costs, lead time and inventory) are not adequate anymore and the processing of information for any other section of the supply network using a BIM and GIS integration framework should be clearly studied.

In this research, three problems are identified as only solvable when considering geographic data in the CSCM system. The first problem is the selection of supplier, when the supplier with the lowest cost may not be the nearest supplier. The second problem is to determine the number of deliveries, as there is an adverse relationship between the number of deliveries and inventory cost. Increasing the number of material deliveries will decrease the need for onsite inventory, but it will increase the fees for delivery. The third problem is the location allocation problems for consolidation centers (CC) for construction material for multiple sites. An integrated framework was developed based on four-dimensional BIM (4D BIM) and GIS for the coordination of construction supply chains between the construction site and other project-related locations, such as supplier sites and material consolidation centers. 4D BIM provides schedule information for pull-based CSCM and material demand information, while GIS provides related geospatial data such as delivery distance estimation, material tracking and consolidation center information. The objective of the integrated framework is to minimize costs in construction supply chains by generating optimized solutions for selecting supplier sites, determining the number of deliveries and allocating consolidation centers. Information from 4D BIM is used to determine the construction activities and their material demands. A bidding and requisition module is developed based on GIS to allow suppliers to bid for material orders. Based on the actual travel distances from the supplier sites to the construction sites, the integrated framework calculates the delivery

fees that are used to optimize three solutions, namely the supplier selection, the number of deliveries and the allocation of consolidation centers.

2. Literature Review

The study of supplier selection is an important part of SCM research. The information in 4D BIM can be used to determine the products and quantities to be ordered. There are extensive studies on supplier selection and inventory lot sizing. Kasilingam and Lee (1996) examined the development of a chance-constrained integer programming formulation to address the vendor selection problem and the determination of order quantities to be placed. However, in their model, the unit cost of each item already includes the transportation cost and does not change according to delivery distance. Jayaraman et al. (1999) presented a mixed integer programming formulation of the supplier selection problem. The model could help an organization choose an optimal set of suppliers, taking into account quality requirements, restrictions in storage and production capacity, and production lead time. However, this study did not consider the delivery fees of products while it is estimated that transportation costs account for 10-20% of construction costs (Shakantu et al., 2003). In this regard, the locations of suppliers and construction sites and transportation distances should be retrieved. Thus, a GIS should be introduced in the CSCM process to support the wide range of network/spatial analysis used in the supply chain coordination process.

The setting up and allocation of consolidation centers are seldom studied in CSCM. Kasim (2008) reported the setting up of consolidation centers in an airport terminal and airfield modification project. The implementation of the consolidation center ensured that the correct construction materials were efficiently delivered to the correct construction site at the required time. In this method all materials are transported to the consolidation center before distribution to the construction site, in order to avoid the congestion of materials at the site loading area. The implementation of the consolidation center also solves the problem of lack of storage space at the construction site. However, to our knowledge there is no more literature concerning the design and allocation of consolidation centers in the construction industry. In the area of SCM for the manufacturing industry, there is a rich body of literature focusing on the design and operations of consolidation centers. Song et al. (2008) developed coordination mechanisms for shipments while considering the product release times at the source locations, the latest arrival times at the destinations, the routes and options used for the transportation, the storage cost at the consolidation center, and the consolidation policies (as early as possible or as late as possible). The objective of the study was to minimize the sum of the transportation cost and the storage cost through optimizing shipment coordination. While there are a lot of studies on the coordination mechanisms in consolidation centers, the allocation of consolidation centers has not been studied. Specifically, we will show that consolidation centers are cost-effective when onsite inventory is limited. Thus the problem remaining is that given project information and supply chain network, how is it possible to determine the location of consolidation centers so that the cost for inventory and delivery is minimized. In this regard, the project information can be retrieved from BIM, and the allocation problem can be solved using network analysis functions in GIS.

3. Construction Supply Chain Management Problems

3.1 Supplier selection and finding the optimal number of deliveries

By introducing GIS in the problem setting, we added one more constraint to the CSCM problem, which is delivery distance from different suppliers to construction sites. With this new setting, we first formulate the CSCM problem in mathematical form and then discuss solutions to the problem.

Some notations used in the problem formulation (capital letter plus subscript) are introduced here:

Construction Sites: CS [CS_a, CS_b, CS_c]

Activities in construction retrieved from BIM: A [A_{ai}, A_{aj}, A_{ak}]

Starting time of activity A_{ai} : ST [$ST_{ai}, ST_{aj}, ST_{ak}$]

End time of activity A_{ai} : ET [$ET_{ai}, ET_{aj}, ET_{ak}$]

Task duration retrieved from BIM: D [D_{ai}, D_{aj}, D_{ak}]

$$D_{ai} = ET_{ai} - ST_{ai} \quad (1)$$

Quantity of required material used in each task: Q [$Q_{ail}, Q_{aim}, Q_{ain}$]

Supplier Sites SS [SS_l, SS_m, SS_n]

Onsite inventory for each material I [I_l, I_m, I_n]

We assume that all the materials are delivered right on time in the ordered amount, so in a case where only one order is needed, the normal ordering time will be related to the lead time of material delivery. For each construction activity, at the beginning of material purchasing, based on information from BIM (material demand and scheduling information) and GIS (geolocations, true travel distances), we want to find an arrangement of ordering of material that aims to:

Find the supplier site SS_l for activity A_{ai} (as ordering cost OC (Irizarry et al., 2013), material price and delivery cost may vary according to supply and the location of suppliers)

Compute the optimal number of orders N for each activity A_{ai} considering inventory cost, delivery cost and ordering cost

Following the principle of Just-In-Time, the ordering cost can be calculated as:

$$OC = OCR \cdot Q_{ail} \quad (2)$$

where OC is Ordering Cost, and OCR is ordering cost rate proportional to the quantity of material ordered.

The delivery cost can be calculated as:

$$DC_N = \left\{ \begin{array}{l} N \cdot DD_{al} \cdot DFT_l \\ DD_{al} \cdot DFT_l \end{array} \right. \quad (3)$$

where N is the number of deliveries, $N \geq Q_{al} / CP_l$, CP_l is the capacity of one delivery (i.e. number of material l that can be delivered each time)

The material cost can be calculated as:

$$MC = Q_{ail} \cdot P_{sl} \quad (4)$$

In an ideal case, the onsite inventory is reloaded when the inventory level hits zero. In this case, the inventory cost can be calculated as:

$$IC_N = \left\{ \begin{array}{l} \frac{QD_{ai}}{2N} \cdot ICR \\ \frac{I_{ai}D_{ai}}{2} \cdot ICR \end{array} \right. \quad (5)$$

Where ICR is the inventory cost rate, proportional to the inventory level.

So the problem of selecting supplier site and finding the optimal number of deliveries becomes finding S and N to:

$$\text{Min}(OC + DC + MC + IC_N) \quad (6)$$

Subject to constraints of onsite inventory and the delivery capacity of suppliers.

$$Q_{ail} / N \leq I_l \quad (7)$$

$$Q_{ail} / N \leq DC_l \quad (8)$$

Since only a finite number of potential suppliers and finite discrete number of orders are considered in the solution, to find the solution for (6), a Monte-Carlo simulation is used to find the value of S and N .

3.2 Allocation of consolidation centers using BIM-GIS integration

Kasim (2008) investigated two construction projects involving the use of consolidation centers. It is revealed in this study that the implementation of consolidation solved the problem of a lack of storage space at the construction site, provided a solution for improvement of site security and safety, reduced congestion from construction traffic within the airport perimeter, improved delivery reliability, and there was an associated environmental benefit, improved workforce efficiency, and reduced materials losses. However, Kasim (2008) did not provide details as to why consolidation centers should be set up and how to allocate them. In this study, we first show how consolidation centers can reduce the cost of inventory and delivery, and solve the allocation problem of consolidation centers using GIS.

In Equation (6), since Ordering Cost and Material Cost are fixed for a given amount of material, the flexible part of costs related to geolocations of facilities are:

$$LoationSensitiveCost = DC + IC_N \quad (9)$$

which can be further elaborated as:

$$LoationSensitiveCost = N' DD_{al}' DFT_l + \frac{QD_{ai}}{2N} ICR \quad (10)$$

In a congested site (when I is small), we assume:

$$I_{ail} = Q_{ail} / N \quad (11)$$

Then:

$$LoationSensitiveCost = \frac{Q_{ail}}{I_{ail}} DD_{al}' DFT_l + \frac{I_{ail} D_{ai}}{2} ICR \quad (12)$$

The tipping point where cost is at minimum is:

$$I_{ail}' = \sqrt[4]{\frac{8' Q_{ail}' DD_{al}' DFT_l}{D_{ai}' ICR}} \quad (13)$$

This equation reveals the relationship between inventory space and project conditions. I_{ail}' can be seen as a critical inventory value. If onsite inventory $I_{ail} < I_{ail}'$, the total cost will increase rapidly. In a construction market where DFT is small, this critical value I_{ail}' is small as well. This implies that if contractors can find suppliers nearby, the inventory level on construction sites could be smaller. However, if some suppliers for some materials are far away, then I_{ail}' is large, which implies that site inventory must be large as well; otherwise cost will increase dramatically. Therefore, the setting up of consolidation centers is essential.

Finding the optimal location for a consolidation center is challenging, as this problem is affected by the location of construction sites, supplier sites and the traffic network itself. Assume that we set up a consolidation center Z, with distance to site a as D_{Za} , to supplier S as D_{Zs} (distance as actual travel distance calculated from GIS). The capacity of inventory of Z for material l is I_{Zl} .

It is reasonable to assume that:

$$I_{Zl} > I_{ail} \quad (14)$$

With a buffer zone, the total cost of delivery and inventory can be calculated as:

$$\begin{aligned} TotalCost = & \left(\frac{Q_{ail}}{I_{ail}} \cdot DD_{al} \cdot DFT_l + \frac{I_{ail} D_{ai}}{2} \cdot ICR \right) \\ & + \left(\frac{Q_{ail}}{I_{Zl}} \cdot DD_{Zl} \cdot DFT_l + \frac{I_{Zl} D_{ai}}{2} \cdot ICR \right) + ZC \end{aligned} \quad (15)$$

where ZC is the cost to set up the consolidation center.

Denote

$$F_{aiZ} = \frac{Q_{ail}}{I_{ail}} \cdot DFT_l \quad (16)$$

$$F_{SiZ} = \frac{Q_{ail}}{I_{Zl}} \cdot DFT_l \quad (17)$$

$$F_Z = \frac{I_{ail} D_{ai}}{2} \cdot ICR + \frac{I_{Zl} D_{ai}}{2} \cdot ICR + ZC \quad (18)$$

Then

$$TotalCost = F_{aiZ} \cdot DD_{al} + F_{SiZ} \cdot DD_{Zl} + F_Z \quad (19)$$

Since F_Z is fixed, F_{aiZ} and F_{SiZ} are cost ratios proportional to the distance between a consolidation center and site and supplier. F_{aiZ} and F_{SiZ} are only affected by project parameters. Consider a consolidation center serving different construction projects. For a project, the total cost ratio factor is:

$$F_a = \sum_{i=1}^m F_{aiZ} \quad (20)$$

where m is the total number of activities

For multiple projects, the total cost for setting up a consolidation center is:

$$TotalCost = \sum_{a=1}^n F_{aZ} \cdot DD_{al} + \sum_{S=1}^k F_{SZ} \cdot DD_{Zl} + F_Z \quad (21)$$

So the problem of finding an optimized location for a consolidation center becomes:

$$\min(\sum_{a=1}^n F_{aZ} \cdot DD_{al} + \sum_{S=1}^k F_{SZ} \cdot DD_{Zl} + F_{ZZ}) \quad (22)$$

We can use Equation (21) to evaluate different candidate locations for setting up consolidation centers. Or, if certain areas are considered for consolidation centers, we can turn it into a discrete simulation problem using point sampling in the given area. Later we use a case study to show the work flow for finding the optimal location of consolidation centers.

4. Framework Development and Validation

4.1 Framework Description

The construction supply chain management process requires massive data input as well as reliable analytical functions to provide management decision-making. Therefore, a CSCM framework should at least have three layers: the data retrieval and storage layer, the analysis layer, and management interface. The use of 4D BIM and GIS provides opportunities to minimize the manual efforts for data input, and all data can be stored in the geodatabases in GIS with customized analytical functions. A comprehensive 4D BIM model stores the full range of information about activities with associated material demand and duration. In the proposed BIM-GIS integration CSCM framework, a detailed quantity takeoff of the construction project is executed at the early stage of procurements from BIM, and GIS is used to support the wide range of analysis functions to provide decision-making in the CSCM process. The data from BIM are exported to databases linked to GIS, which will be used for analysis. The manually input data are mostly related to the quotations for material from multiple suppliers and changes in current project plans. It is possible that some of the construction activities, for example scaffolding, are not present in the 4D BIM. In this case, manual inputs of such activities along with their material demand and time duration are needed. In the proposed CSCM framework, the data storage, analysis and decision-making are performed in a GIS system. GIS has the capacity to store massive amounts of data and the ability to access fundamental analysis tools such as route finding for delivery cost analysis.

The architecture of the proposed CSCM framework is shown in Figure 1. The data input layer consists of data sources (BIM, GIS and user input) and data retrieval functions. The retrieved data are used by various analysis functions such as cost analysis and network analysis to support solutions of CSCM problems.

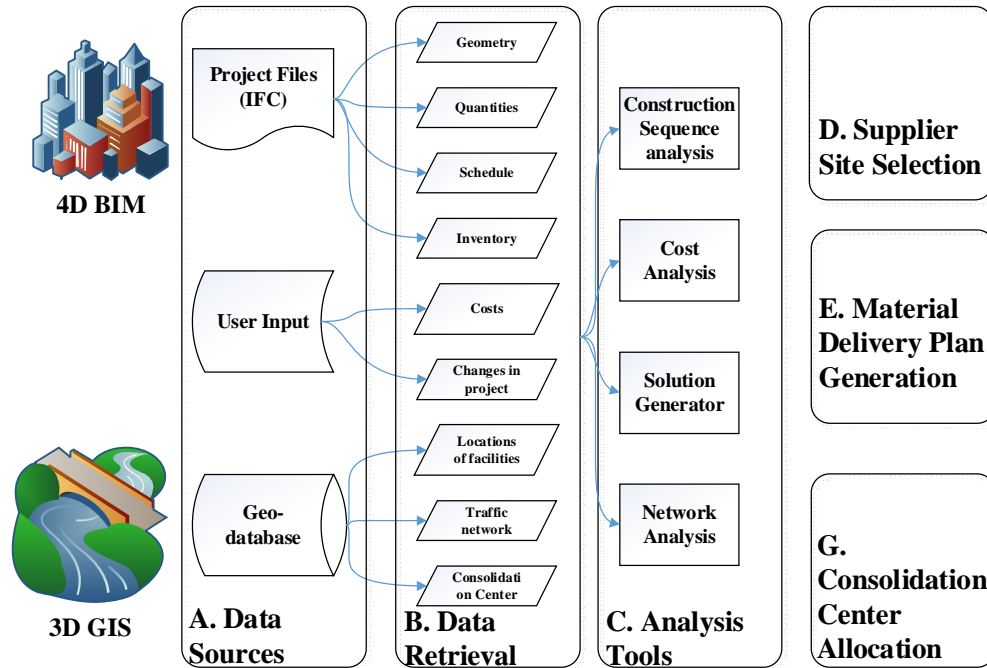


Figure 1 Framework Overview

4.2 Validation of Framework

In order to demonstrate the BIM-GIS integration CSCM framework, we use the road network data in San Francisco, USA as a base map. A five-storey building construction project is used to demonstrate the problem of the selection of suppliers and number of deliveries. Specifically, we show that the delivery fees and inventory fees are critical in calculating the total cost incurred in the supply chain. Selection of material supplier cannot only rely on the unit prices or nearest delivery distances. We use another supply network with five construction sites and 15 suppliers to demonstrate the location-allocation problem of setting up consolidation centers.

We first validate the effectiveness of BIM and GIS integration in supplier selection and number of order optimization. In the design phase, a 3D model of the building was created using BIM software Autodesk Revit. The schedule information was added to the BIM later by linking to project databases using Navisworks. The generated 4D model was exported to IFC format, which was then parsed by our developed parser. All the relevant information for CSCM was finally exported to data tables in the GIS system, which is based on ArcGIS.

We used the material Brick (230 mm) in Level 1: Interior wall construction to demonstrate the material selection process. The potential suppliers that are willing to supply this material and their location along with the location of the construction site is shown in **Figure 2**. The GIS network analysis function allows route finding with the shortest distance, which is used for delivery fee estimation. The route finding results are also shown in **Figure 2**. The manual input function is used to enter the information of different potential suppliers. The delivery distances are obtained from the network work analysis to represent the actual delivery distance. The cost analysis function in the framework computes the delivery cost and onsite inventory cost for every potential

supplier considering different numbers of deliveries. In order to find the supplier with the lowest cost, the total costs were analyzed. The results are shown in Figure 3.

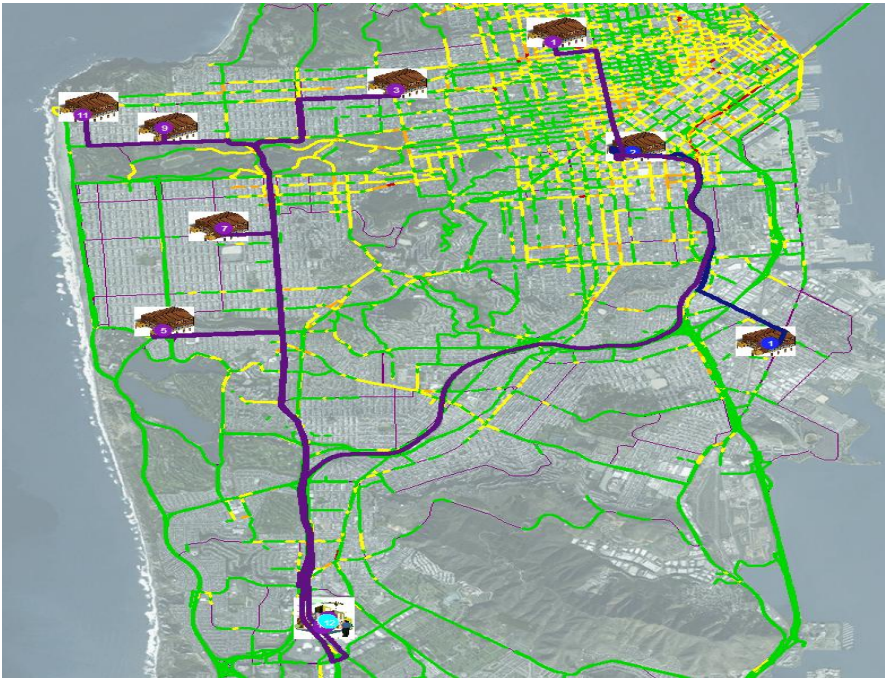


Figure 2 The route finding to calculate delivery fees

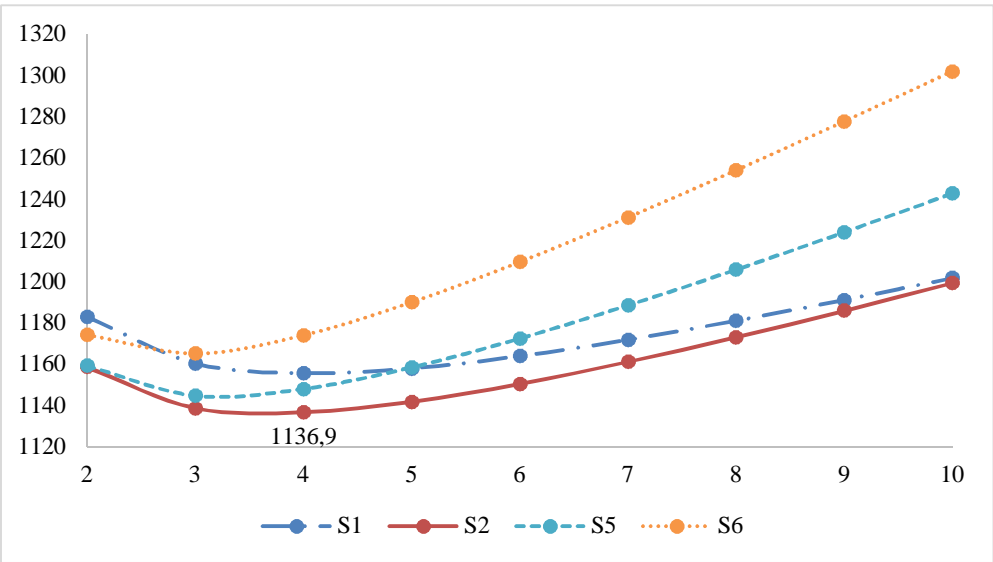


Figure 3 Total cost analysis for different suppliers and different number of deliveries

The second case study considers a supply chain network consisting of five construction sites and 15 suppliers in different locations supplying different material. The road network data in San Francisco are used here to calculate delivery costs. The first step of the consolidation allocation problem is to determine the cost ratio F_{az} and F_{sz} using Equations (16) and (17) with data from

these five projects.. With the calculation of F_{az} and F_{sz} from project data, the allocation problem of consolidation centers has been transformed to a location-allocation problem in GIS. The process of consolidation center allocation starts from generating unified distributed sample points on the base map. Here we set the resolution of sample points to 100 meters. After acquiring the sample points, the cost for each sample point is calculated using Equation (21). After calculation of each sample point, it is possible to generate a cost map which represents the cost of setting up a consolidation center in a given location, as shown in *Figure 4*. The location with the lowest cost after setting up the consolidation center is shown by a star symbol. *Figure 4* also provides guidelines for project managers to find an optimal location for setting up consolidation centers. It is noticeable that near the optimal location in *Figure 4*, there is a zone with a consolidation center cost. The reason is that in this area the traffic network becomes less dense, and the transportation cost will increase dramatically in this area. This is more evidence that GIS network analysis should be used in calculating delivery costs.

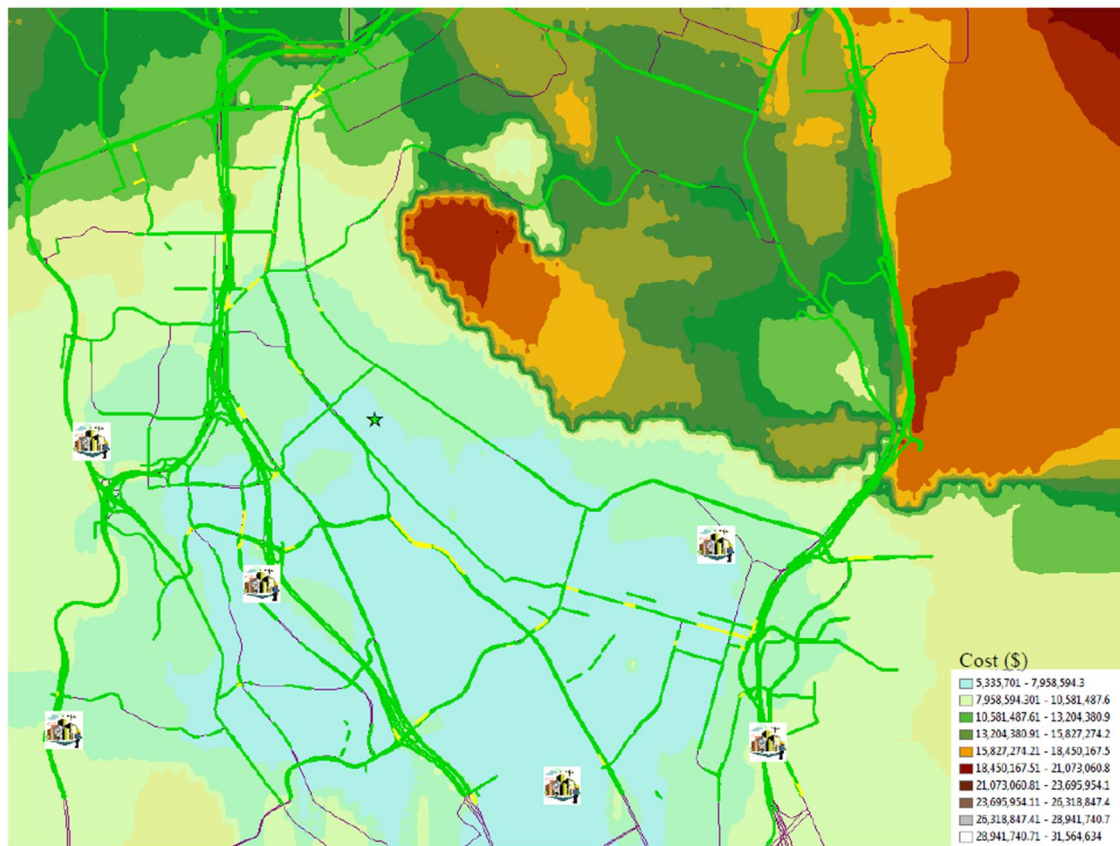


Figure 4 Finding an optimal consolidation center location

5. Conclusion

By using data from BIM and GIS, we formulate the three problems in mathematical form and provide solutions to these problems. Specifically, we make the following contributions to these three problems: firstly, we prove that selection of suppliers should not only consider factors such

as delivery distance or unit price solely. Secondly, we should understand that the number of material deliveries has impacts on the total invoice cost of the supply chain, and we provide a Monte-Carlo Simulation solution to this problem. Thirdly, we prove the necessity of setting up of consolidation centers given the congested sites and long delivery distances using mathematical modelling. And finally, we provide a solution to the location-allocation problem of the setting up of consolidation centers. It is noticeable that all the contributions could not be made without the data inputs and analysis functions in BIM and GIS.

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Knowledge Acquisition to Address Skills Challenges in UK Construction Industry

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Abstract

The successful implementation of new technologies plays a major role in the economic growth of the country. Building Information Modelling (BIM) is considered to be one of the most recent technologies introduced within the Architecture, Engineering and Construction (AEC) industry. However people who are involved in BIM based construction projects are struggling to achieve their project outcomes due to not having enough knowledge and skills to work with this new technology. The main aim of the paper is to explore how knowledge can be distributed among the project participants to acquire the appropriate knowledge and skills during the implementation of new technologies. Connectivism theory has been adopted in this study to understand the distribution of knowledge and the learning process in the BIM construction projects. Following that, data was obtained through conducting the interviews with the professionals who have used BIM in their construction projects. The collected data focused on the knowledge acquisition in the implementation of BIM technology. In addition the learning process within BIM construction projects was also looked in terms of achieving the knowledge and appropriate skills which is essential to support the various stakeholders to efficiently use BIM technology.

Keywords: Building information Modelling (BIM), Connectivism, Construction, Learning, Skills, Knowledge.

1. Introduction

Productivity in a country influences in determining the competitiveness for the businesses and wages for people at work (UKCES, 2015). According to HM Treasury (1988) productivity is ‘a fundamental yardstick of economic performance’ however the UK significantly lags the best performing OECD countries due to poor productivity records (Allen, 2015). The construction industry has been one of the main engines of UK economic growth nevertheless still UK’s productivity gap is driven back due to skills challenges faced in the construction industry. One

of the reasons for the construction industry to face these skills challenges is due to its resistance to adopt new technologies. However, the purpose of introducing these new technologies is to improve productivity (UKCES, 2015) which also leads to alter and create quicker ways to deliver goods and services (Corney, 1997), high performance work practices (Bresnahan *et al*, 2002) and economic well-being (Hansushek and Woessmann, 2008). The studies in construction industry highlight the skills challenges as a major barrier in improving productivity (UKCES, 2015). Supporting this construction skills report (CITB, 2004) suggests that employer's skills requirements need to be taken into consideration to enhance efficiency of the construction projects to cope up with continuous changes in construction industry. Even though skills challenges have been highlighted in many construction studies lack of knowledge is the key factor that leads to these skills issues in the construction. Therefore distribution of knowledge is important within the project participants to acquire the appropriate skills to achieve the project outcomes. Therefore the aim of the study is to explore how knowledge can be distributed to acquire the appropriate skills during the implementation of new technologies within the construction industry.

2. Literature Review

2.1 Importance of skills and knowledge in construction industry

Acquiring appropriate skills encourages economic performance (O'mahoney and de Boer, 2002), innovation and flexibility (Leiponen, 2005). Moreover it helps to determine individual's employability to productivity (HM Treasury, 2006) and business profitability (Bosworth, 2013). This has been highlighted in Sami's (2008) study where he claimed more attention is needed to reskill, multi-skill or upskill professionals in construction industry to successfully achieve project targets. However, skills must be grounded and the meaning might differ according to its reference to context (Spencer, 1990) as shown below.

Table 1: A summary of the skills definition

<i>Author/s</i>	<i>Year</i>	<i>Definition</i>
<i>Becker</i>	<i>1964</i>	<i>Capabilities of workers that they acquire outside the work place and the job on and the capabilities have meaning only when they translate into productivity and job rewards, such as earning.</i>
<i>Mangham and Silver</i>	<i>1986</i>	<i>Dexterity and knowledge of the workforce.</i>
<i>Wood</i>	<i>1988</i>	<i>Expertise that describes the quality of overt behaviour in a particular job.</i>
<i>Odusami</i>	<i>2002</i>	<i>Ability to perform the task well or better than average. Skills can also be described as the ability to translate knowledge into action.</i>
<i>Boyatzis et al</i>	<i>2002</i>	<i>Emotional intelligence which includes both self-awareness of one's emotional reaction to specific events, situations and unexpected circumstances and the coping strategies that may be developed to handle those feelings and concomitant reactions effectively.</i>
<i>HM Treasury</i>	<i>2006</i>	<i>Capabilities and expertise in a particular occupation or activity.</i>

These definitions state that skills are centred on various different factors such as capabilities, people, physical and practical activities. However, Odusami's (2002) definition is adopted in this study which states that skills are not only about completing the task better than average but also translating the knowledge into action. The UK Commission's Employer Skills Survey 2013 (UKCESS 2013) and CITB (2015) have discussed about the skill deficiencies and highlighted the need for people with appropriate skills and knowledge. Moreover these studies show that knowledge should be developed along the process to acquire the appropriate skills to complete the task. Therefore to resolve this current situation there is a need for people who are capable, agile and able to respond to the challenges presented by new technologies.

2.1.1 Skills gaps, Skills shortages and Latent Skills shortages

Current skills challenges within the construction industry are mainly due to skill gaps, skills shortage and latent skills shortages. Skills gap happens due to employees in workplace not having appropriate skills to achieve the organisation's objectives (Campbell *et al.*, 2001). On the other hand skills shortages also occur when there is shortage of skilled people in labour market to fill in the vacancies (Barnes and Hogarth, 2001). Campbell *et al* (2001) argued that there are more skills gaps in construction industry and Bloom *et al* (2004) believed skills shortage plays a significant role towards the economic growth. Apart from this, latent skills shortage is also an issue, which is a situation where establishment fall short of what might be considered good or best practice. This might be the reflection of low skills or poor business performance, even though there is no report of recruited problem or skills gap (Hogarth, 2001). Generally this occurs when the organisation starts to manage a project with existing skills without being aware of necessary skills. Chan and Cooper (2006) claimed that this situation is more frequent in construction industry because construction practitioners often do not know what skills they need to produce to achieve their project outcomes. Therefore skills challenges are problematic to move towards the digital world. Building Information Modelling (BIM) is a recent technological development introduced within the AEC industry to integrate processes throughout the entire project lifecycle (Aouad and Arayici, 2010). Moreover BIM also helps to drive a step-change to increase the productivity of the construction process, tangible quality improvement in the end product and associated reduction in true cost (O'Rourke, 2015). Recently the UK government has mandated to use BIM in public sector projects since 2016 (Cabinet Office, 2011) therefore construction companies have slowly started to adopt BIM in their construction projects.

2.2 Building Information Modelling (BIM)

There are many ways of looking at BIM as shown in below in Table-2; this study has adopted the National BIM Standard (2014) definition that looks from a knowledge point of view. Here BIM is about unlocking knowledge and insight, creating the platform for more efficient and sustainable solutions through sharing the information. While the information is shared through BIM, knowledge needs to be distributed among the project participants for the decision making

to achieve the project targets. Therefore this paper is looking at how knowledge is shared and distributed among the project participants using BIM in construction projects. Furthermore Connectivism theory has been adopted in this paper to study the knowledge distribution and learning process to achieve the project outcomes.

Table 2: A summary of the BIM definition

<i>Author/s</i>	<i>Year</i>	<i>Definition</i>
<i>Autodesk</i>	<i>2007</i>	<i>A building design and documentation methodology characterized by the creation and use of coordinated, internally consistent computable information about a building project in design and construction.</i>
<i>Eastman et al</i>	<i>2008</i>	<i>A computer aided modelling technology for managing and generating building information, with the related processes of producing, communicating, and analysing building information models.</i>
<i>Vanlande et al</i>	<i>2008</i>	<i>The process of generating, storing, managing, exchanging, and sharing building information in interoperable and usable way.</i>
<i>McGraw Hill</i>	<i>2009</i>	<i>The process of creating and using digital models for design, construction and or operations of projects.</i>
<i>Nisbet and Dinesen</i>	<i>2010</i>	<i>A digital model of a building in which information about a project is stored. It can be 3D, 4D (integrating time) or even 5D (including cost) – right up to ‘nD’ (a term that covers any other information).</i>
<i>National BIM Standard (NBIMS)</i>	<i>2014</i>	<i>A digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition.</i>

The impact of technology on humanity continues to grow in greater prominence which allows entering into a new form of ‘knowledge society’. Moreover Bloom *et al* (2004) claimed that even though new technologies are out there, significant amount of knowledge and skills are not there to work with those new technologies. Therefore, there is a need for a suitable learning theory to increase human cognitive functioning to cope with this changing society. Connectivism is a theory introduced by Siemens and Downes (2009) for the digital world.

2.3 Connectivism

Connectivism is an application of network premises that define both knowledge and process of learning. In this, knowledge is defined as a particular pattern of relationship whereas learning is defined as the creation of new connections and patterns along with the ability to maneuver around existing networks/ patterns. Moreover Connectivism focuses on the presence of technology as a part of cognition and knowledge. Previously philosophers and theorist had different views of learning where they failed to address the learning that occurs outside the individual and to discuss the learning process that happens among the group of people or organisation. According to Sieman (2004) Connectivism is an intriguing development where learning happens with the knowledge and perception gained through the additional personal network. Even though it is impossible to experience everything, there is an opportunity to

develop the knowledge through sharing and collaboration. In this digitalised world there is a necessity for further knowledge to understand the amount of the data available to complete specific tasks. Therefore Connectivism which is an actionable knowledge can be considered as a learning theory, where understanding of where to find the knowledge is more important instead of answering how and what the knowledge incorporates. According to Siemens (2005) and Downes (2005) Connectivism theory is appropriate to handle this digital world where its main principle is linking ideas and connecting people and information sources. However opposing this Duke *et al* (2013) state that in comparison to existing learning theories there is an overlap of ideas and therefore this cannot be accepted as new learning theory.

Learning process in Connectivism is not entirely focused on the control of the individual and more focused on connecting the specialised information sets and enable people to learn more than their current status of knowing. In this process information flow is a key factor where new information will be continuously acquired. In Connectivism, the starting point for learning occurs when knowledge is actuated through the process of learners and then connecting and feeding information into learning community. This begins with an individual and the personal knowledge is included of a network which feed into organisations and institutions, which in turn feed back into the network, and then continue to provide learning to individual. This cycle of knowledge development allows the learners to be up to date in their field through the connections they have formed. Therefore the fundamental idea of this is about 'Distribution of knowledge'. This means a property of one entity must lead to or become a property of another entity in order for them to be connected; the knowledge that results from such connections is referred as connective knowledge.

The Diagram-1 generated by García (2008) shows the Connectivist view of learning as a network creation process that impacts the way learning is designed and developed. Diagram-1 emphasis the central principle of Connectivism which is the creations with usual nodes (element connected to any vertices, elements, or entities) supports and strengthens existing large effort activities. The integration of learning, knowledge and understanding through the personal extension of a personal network is the key of Connectivism.



Diagram 1: Connectivism: Process of creating network (García, 2008)

Supporting the Connectivism theory several studies have highlighted the importance of the knowledge to successfully complete the tasks. Hutchins (1993) in his study emphasised that knowledge is necessary and it should be distributed among the team to carry out a certain task. Moreover Lave (1988) suggested that relationships between human thoughts, human action and the environment is so tightly interwoven that the mind cannot be studied independently of the culturally organised settings within which people function. On the other hand Nonaka and Takeuchi (1995) believe that the knowledge is created and expanded through social interaction between tacit knowledge and explicit knowledge. Therefore these previous studies have highlighted the important to view the knowledge as composed of connections and network entities to encourage the interaction within these complex systems. This will then lead to the acquisition of appropriate skills to complete a task in an efficient way. From this discussion it is clear that initially knowledge needs to be acquired to gain the appropriate skills to work with the new technologies to achieve the project outcomes. However in this study the knowledge acquisition and learning process is viewed through Connectivism which is appropriate to tackle the rapid technological changes.

3. Methodology

The purpose of this research is to explore how knowledge can be distributed to acquire the appropriate skills when new technologies are introduced to achieve the project outcomes. The situations were analysed through interacting with BIM professionals by asking about their experience and their beliefs. Therefore, qualitative research is adopted as a method best suited to explore the new area. Qualitative research is “Multi-method in focus, involving an interpretive, naturalistic approach to its subject matter” (Denzin and Lincoln, 1994). Moreover this method explores and understands the meaning where individuals or groups ascribe to a social or human problem (Creswell, 2008). The purpose of this qualitative method study is to understand how construction project participants gain their knowledge and acquire skills during technology change within the construction industry.

Data for qualitative study analysis is collected through conducting 10 semi structured interviews with BIM professionals working in the UK construction industry. Firstly BIM professional's personal opinion about BIM and their BIM experiences were collected. Secondly gaps within BIM learning and their causes were discussed. Finally their learning experience to work with BIM and recommendations for future BIM professionals were discussed. These interviews were conducted to understand the significant of skills challenges and to explore the skills issues in BIM construction projects. Moreover this is also to understand how project participants within the construction projects learn and acquire the appropriate skills to work with the new technologies. During these interviews professionals engaged with BIM construction projects shared their experience and individual perception about the skills related issues faced in BIM construction projects. Two pilot studies were conducted with the construction professionals working with BIM before conducting the interviews. This has assisted to refine some of the questions with appropriate wordings and made the questions clear to the interviewees. This semi

structured interviews were conducted across the UK, open-ended questions were employed to get a wider view of the situation and interpretation was done along the way. The data collected through the semi structured interviews explained how knowledge is distributed among the project participants which have then led to the skills acquisition to work with the new technologies introduced in the construction industry.

4. Discussion

The data collected from the interviews clearly show that the way of gaining knowledge has been changed from old days. In the beginning knowledge acquisition is more focused on individual and their influences on the organisation or community. This is supported through one of the interviewee saying “learning the new software in BIM with the multidisciplinary team helped us to know the difficulties the other employees face”. Moreover another interview stated that “Learning process with other project team members provide us a wider knowledge of the new software”. Therefore it is evident that currently knowledge is not about focusing on the individual but also gaining the knowledge outside the primary knowledge.

As discussed in the literature, skills challenges can be viewed from the point of skills gap, skills shortage and latent skills shortages. BIM professionals indicated that they had to face several skills gaps such as detailing elements in BIM applications and using software , lack of understanding about family creation and detailed understanding, lack of knowledge about in putting the data into the objects and extracting it, process and standard gaps and lack of engineering. This is due to lack of knowledge within the internal workforce. On the other hand latent shortage is also a problem where skills gaps are unrecognised because project organisations have simply coped operationally without the necessary knowledge and skills. In BIM projects latent skills shortages are derived from lack of defined project process, lack of understanding of role and responsibilities and frequent change of software to work with BIM. In addition this happens more often in BIM construction projects due to lack of communications between the project team members. In other words the problems faced by the project team members are rarely discussed among them and in most situations doesn't not get reported to the top management. This clearly shows that skills gap, skills shortages and latent skills shortages are significant constraints to achieve the project outcomes. Interviewees believe that adopting a new way of gaining knowledge which will then invest in skills acquisition could produce a radical shift in employees' perception of working which can lead to achieve the project outcomes quickly.

From the interview results a similar situation is observed in BIM construction projects. In BIM construction projects individuals gained their fundamental knowledge through different learning methods such as degree programs/ education, self-learning, basic software training, attending meeting, conference and workshops. However most of them expressed that they were reluctant to use BIM due to lack of understanding of fundamental aspects of BIM enabled technologies. This involved in understanding what BIM is and some of the benefits associated with it. Therefore interviewees suggested that old learning theories that focused only on the individuals needs to be replaced to tackle the new digital world.

After the individuals have gained the fundamental knowledge BIM models were used to share the information among the project participants. In this situation knowledge needs to be distributed among the project participants to complete the necessary tasks through decision making. Therefore after connecting the information resources and people within the BIM construction projects the property of one entity leads to become a property of another entity in order for them to connect and finally connected knowledge will be generated. This will allow all the project participants involved in the project to gain the knowledge and also to understand the current situation of the project. The connections and knowledge gained allow individuals to work effectively and help to avoid mistakes during the projects. While an individual keeps repeating this process again in different BIM projects he/she is expected to become a skilled person with ability to deal with BIM issues in any project setting. However it is important to notice that every project is unique and has its own BIM related skills challenges. Therefore as interviewees suggested more training, engaging with other BIM projects, following BIM courses, getting constant feedbacks about software from the newsletters, understanding the standards and setting out the project goals in the beginning of the project needs to be done to achieve better project outcomes.

Therefore this current situation in the construction industry has confirmed that new technology such as BIM has created a new culture and it has reshaped the way of learning. In early days learning theories were only concerned of individual learning whereas currently learning as a function is not under control of learner therefore learning needs to be redesign as two-way process (García, 2008). Actuate known knowledge at the point of application is vital in a learning theory. When the knowledge is needed and not known; it is important to have the ability to plug in the sources to meet the requirements. Connectivism theory is suitable to adapt these circumstances and these interview results highlight the importance of distribution of knowledge within the construction team during the implementation of new technology. Diagram-2 explains the learning ecology in BIM construction projects. Understanding this learning process helps to improve the knowledge as well as makes the individual as a skilled person.

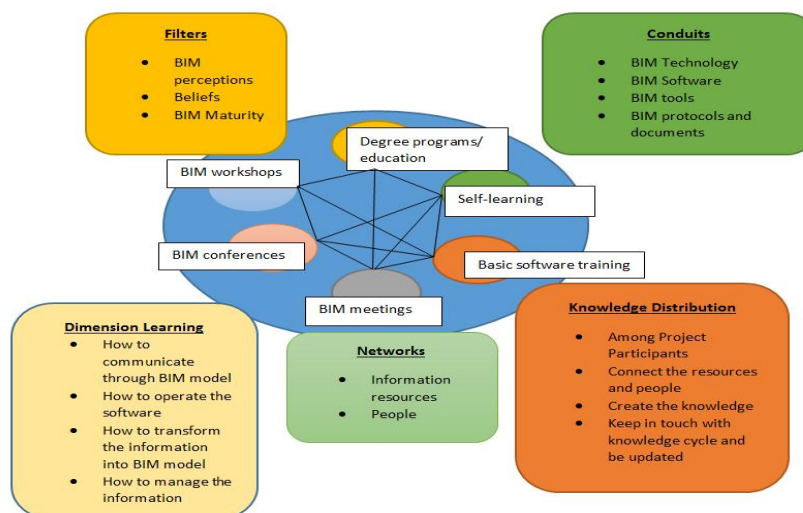


Diagram 2: Knowledge acquisition and learning process in BIM Construction projects

5. Conclusions

The construction industry has been one of the main engines of UK economic growth. Therefore several new technologies are introduced to improve productivity. BIM is one of the recently introduced technologies in the UK construction industry however it is not fully utilised due to the skills challenges. Therefore it is ever more important to focus on knowledge and skills acquisition during the technological change. The study conducted with BIM professionals working in the UK construction industry articulate that a new way of learning and knowledge acquisition needs to be introduced among the project participants to gain the appropriate skills to work with new technologies. Connectivism theory has been identified as a suitable approach to develop knowledge among project participants during the implementation of new technologies. The main principle of this theory is to distribute the knowledge through forming the connections between nodes. Therefore in this situation the knowledge acquired will be both individual learning and the learning outside the primary knowledge. This would help the project participants to achieve the project outcomes efficiently. Since a project participant keeps on accessing back to the knowledge cycle he/ she not only becomes a skilled person but also knows about the up-to date situation of their field. Therefore Connectivism theory is beneficial to understand the use of new technology and to improve the distribution of knowledge among project participants.

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Big Data in Construction Management Research

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Abstract

The paper is a literature review on Big Data in project management of construction projects. The literature shows practical examples of use and potential use of Big Data in construction management research. Big Data has become common as a business term in most businesses. However there is little published management scholarship that tackles the challenges of using Big Data, or even that explores the opportunities for new theories and practices that Big Data might bring about. There is a need for further discussion of the possible implications Big Data can have for construction management research.

The construction process can be studied in a number of dimensions. We structure documented and potential use of Big Data related to construction projects in the time perspective of a typical construction project, from concept preparation and brief, through design and construction to use.

We have identified studies describing Big Data applications and theory. Thematically they fall into three broad categories: 1) New construction equipment; generating, sharing and storing data about use. 2) Data from internal IT systems; such as planning, procurement and Building Information Modelling (BIM) can be utilised. Lastly, 3) people generate an increasing flow of information, which can be useful if handled with care. In combination this addresses the life-cycle from concept to decommissioning. We find that the construction phase appear to have received most attention from researches. We also find that several studies are applicable to more than one phase of a construction project. We find a potential for increased use of Big Data methods and applications within construction. While some data and applications have been analysed in isolation previously, there is a potential to combine different types of data.

Keywords: Big Data, Construction management, Construction projects.

1. Introduction

Big Data has become common as a business term in many industries, like manufacturing, transportation, retail, finance and IT. However, according to George et al. (2014), there is little published literature in management scholarship that deals with the challenges of using big data or even explores the opportunities for new theories and practices that Big Data might bring about. Olsson et al. (2015) discuss how Big Data can be applied in project evaluation and in project management research. But there is a need for further discussion of the possible implications Big Data can have for construction management research.

1.1 More quantitative data available

On a worldwide basis, the total amount of digital data created and replicated each year is expected to increase exponentially up to 2020 (Tien, 2013). This is also the case for data that can be applied in construction projects and management. The principles used in Big Data can also be applied on smaller quantitative data sets. This include data stored in company internal IT-systems.

The definition of Big Data is shifting as software tools become more powerful. Big Data was first defined as data sets whose sizes are too large for commonly used software tools to capture, manage and process within a tolerable elapsed time (Manyika et al., 2011; Tien, 2013; Waller & Fawcett, 2013). However, other definitions will probably be needed, as Big Data is becoming a part of commonly used software tools. The uniqueness of Big Data is the volume, velocity and variety, the three V's (Courtney, 2012; Russom, 2011). The volume refers to the size of data sets, containing a few terabytes to many petabytes. But it is the variety and velocity of the generated data that makes the data sets so big. Variety refers to the variety of sources. In addition, the data are measured and captured in more detail, such a location, time and metadata, giving both structured and unstructured data sets (Russom, 2011; Waller & Fawcett, 2013). The velocity of data refers to the speed at which the data is generated, from being recorded, updated or measured monthly and weekly to more frequent updates such as daily, hourly or continuously (Courtney, 2012). The access to real time or almost real time information makes it possible for a company to be much more agile than its competitors (McAfee & Brynjolfsson, 2012).

Courtney (2012) mentions veracity and value when describing Big Data. Veracity refers to a quality of the data sets, while value is reference to the goal from using the data sets. Veracity is a description of how the measures are reliable, referring to the accuracy and the quality of the generated data. Value refers to turning the Big Data-sets into value for the business. Size does not need to be the only defining part of Big Data, and data can be discussed along more than the mentioned three dimensions. George et al. (2014) points out that there are discussions among practitioners that “big” is no longer the defining parameter, but rather “smart”, including a fine-grained nature of the data. The data available to companies are often unstructured (Davenport et al., 2012). The sources of digital data can include retail transactions, security cameras, internally registered data in the organisation, time-stamps, GPS-tracking, sensor-data from instrumented machinery and metavalues of documents.

The main reason to carry out data analysis is to derive information from data, knowledge from information, and wisdom from knowledge (Tien, 2013). And this is the purpose of Big Data. Big Data can give new information and knowledge for decision-making. For instance, Big Data can be used to make more precise predictions, and it follows that better predictions yields better decisions (Jagadish, 2015). McAfee and Brynjolfsson (2012) found that the more companies characterized themselves as data-driven, the better they performed on objective measures of financial and operational results. More and more business activity is digitized, and new sources of information are available (McAfee & Brynjolfsson, 2012). This also applies to the construction industry.

1.2 Use of new quantitative data in construction management

Technology has always been a part of construction management, both in research and practice, but there are new technological demands. This means that new data can support the trend towards an intelligent built environment, covering the whole lifecycle of facilities. Big Data has a potential to generate new insights into the costs, designs and processes of construction management. The aim is to develop tools and approaches for intelligent, efficient and sustainable construction management. Such strategies need to be sufficiently flexible to meet requirements resulting from changes in user-demands, technology and other framework conditions, while at the same time increase efficiency. It is a potential to integrate areas such as Computer Aided Facility Management (CAFM), Building Information Modelling (BIM), and Integrated Building Control and Monitoring Systems (BCMS). Such knowledge can later be utilized in decision making support, innovation of technical systems and in the education and training of project managers.

Monitoring activity across a large, complex construction site is particularly difficult because there are so many moving parts, and because the jobs being performed change frequently. In contrast to production industry, most construction sites are also temporary by nature, often challenging the investment in production infrastructure. Several reports document (including Egan, 1998; Lo et al., 2006; Durdyev & Mbachu, 2011) that construction lags behind other industries such as manufacturing in terms of productivity, and blamed the situation on problems with planning, coordination, and communication.

Modern construction equipment also generates data through usage. Producers of equipment such as trains have for some time utilised equipment life-cycle management data, which are generated in large scales through the period of production, operation, and maintenance. There is broad recognition of value of data and information obtained through analysing it. This type of data is also possible to generate from construction equipment. The exponential growth in this type of data means that new measures are needed for data management, analysis and accessibility. MIT Technology Review (2015) reports on the use of drones to monitor construction progress. Once per day, drones automatically patrol the work site, collecting video footage. The footage is then converted into a three-dimensional picture of the site, which is fed into software that compares it to computerized architectural plans as well as the construction work plan showing when each element should be finished. The software can show managers

how the project is progressing, and can automatically highlight parts that may be falling behind schedule.

A discussion has emerged about use of Big Data and performance measurement for micro management and continuous monitoring of employees. Using drones to monitor activity continually can be controversial. Such controversies have occurred related to monitoring of employees in other sectors. As reported by the New York Times (2015), the company Amazon monitor employees in warehouses using sophisticated electronic systems to ensure they are packing enough boxes every hour. In a similar way, the Amazon also uses a self-reinforcing set of management, data and psychological tools to spur its tens of thousands of white-collar employees to do more and more.

1.3 Purpose and research questions

There is a need for broader discussions of Big Data in society and its implications for management research in general, including construction and project management. George et al. (2014) points out that even though “Big Data” has become commonplace as a business term, there is little published management scholarship that tackles the challenges of using such tools, or that explores the opportunities for new theories and practices that Big Data might bring about. The purpose of this paper is to investigate different use and potential use of Big Data in construction management research. The construction process can be studied in a number of dimensions. We structure documented and potential use of Big Data related to construction project along a time axis of a typical construction project, from concept preparation and brief, through design and construction to use.

Our research questions addressed in this paper are:

- Which applications of Big Data in construction project management have been published in recent years, based on the defined literature search criteria?
- Which time phases of a construction project are recent Big Data research relevant to?

2. Method

We review previous research and structure the papers based on the time perspective of a typical project. Several approaches were used to identify relevant literature. Searches in the Norwegian library database (Bibsys) were conducted, covering both books and academic journals. Searches were made using several search engines on the Internet, such as Emerald, Science Direct, Wiley Online Library, and Google Scholar. During the database searches, both titles and keywords were examined. In the searches in Google Scholar the entire texts are searched, consequently providing more search results of both relevant and irrelevant papers. Exclusion keywords were provided in the search, to exclude papers from non-relevant research fields. The collected material was subsequently examined in more detail. The main keywords used in the search were «big data», «construction project/industry», and (construction/project) management. Relevant literature was also found in the journal for automation in construction, as this is relevant technology and data source even though the papers do not use the phrase “big data”.

Searches were also made with capital projects and engineering projects as search keywords, but with limited additional search results. Exclusion keywords used were psychology, ecology, biology, constructionism, health, and network construction. The overview of search keywords, databases and number of results is given in Table 1.

In the search results, there are several papers that are not available or do not deal with construction industry. Most of these were excluded by the excluding keywords. However, several papers are within the areas of software development, data management, construction of data centre facilities, Big Data project etc. but are not directly related to the construction industry. The papers were excluded by the search keywords, based on headings, abstracts, or a quick search for construction, management, and Big Data within the main text. Exclusion criteria were used to exclude studies that are not relevant to answer the research questions. Only papers that give a clear contribution or are of clear relevance to Big Data in construction projects or management are of interest. The papers are limited to 2014 and 2015, and Table 1 shows that most research contribution has been published these last couple of years.

*Table 1: Overview of search keywords, databases and results. (*Year 2005-2015, **Year 2011-2015, ***Year 2014-2015)*

<i>Keyword</i>	<i>Search engine /data-base</i>	<i>No. of papers</i>
«big data» AND construction AND management	Oria	121* (95)***
«big data» AND «construction project OR industry» AND management	Google Scholar	(591)** (462)***
«big data» AND «construction project OR industry» AND management –psychology –ecology –constructionism	Google Scholar	(418)** (319)***
«big data» AND construction AND «project management» -health, -ecology, -constructionism, -“network construction”, -psychology	Google Scholar	838 (581)* (553)**
«big data» AND «construction project OR industry» AND «project management» –psychology –ecology –constructionism -biology	Google Scholar	168 (142)** (103)***

The literature that we found to be relevant to our research questions, were structured into the time perspective of a typical construction project inspired by the phases in the RIBA (The Royal Institute of British Architects) model. The RIBA Plan of Work is the definite UK model for the building design and construction process (RIBA Plan of Work 2013). The RIBA model has served as an inspiration to a recently presented Norwegian phase model for construction (bygg.no, 2015). The Norwegian model uses a time frame similar to the RIBA model, but highlights the perspectives of owner, user, supplier and society. The Norwegian model has the following phases: Strategic definition; Concept development; Concept design; Detailed design; Construction; Handover; Use and facility management and finally, Disposal. The selected literature is categorised based on this life cycle perspective. In addition to the time perspective, we found need for adding a second dimension, and discuss a number of alternatives.

3. Literature

As mentioned in the previous section, the construction phases that we structured the literature based on, are; Strategic definition; Concept development; Concept design; Detailed design; Construction; Handover; Use and facility management; and Disposal. The result of the structuring of the literature that we found to be relevant is given in Table 1.

A significant portion of Big Data is geospatial data, generated from sources such as mobile devices and RFID sensors. Geospatial Big Data gives both opportunities and challenges, as discussed by Lee and Kang (2015). Related to the construction industry, location aware data can give useful information into urban planning, by providing information in the early project phases on how people use public spaces and infrastructure.

Caron (2015) focus on the importance of an early engagement of stakeholders to improve the forecasting/planning process and manage the project. Engagement of stakeholders from the stage of the project life cycle, in which they may be involved in or be impacted by the project, can significantly increase the available amount of both explicit and tacit knowledge. Managing stakeholders is critical in large construction projects, and in infrastructure major projects this is especially difficult due to the diversity of stakeholders and interests. A study by Bakht et al. (2014) evaluate stakeholders' impact on infrastructure megaprojects through analysis of Big Data captured from online social media.

During the project phases, from early preparation to handover and the liability period, a project produces a lot of documents. Kähkönen et al. (2015) study content and characteristics of current practice of Electronic data/document management systems (EDMS) in building construction projects. This includes project cost, number of files and file accessing actions (open, view, download). They looked at 15 building development projects, which used the same data system.

According to Naderpajouh et al. (2015), effective frameworks to facilitate data-driven decision-making are noticeably lacking in the construction industry. They developed a hierarchical definition for health of the construction industry that was used to propose a framework to benchmark, interpret and analyse data associated with the status of the health of the industry. The dimensions of the framework include; positive financial performance; stability and resilience to shocks, pleasant working atmosphere, applying the best expertise, science, and technology in the production process, and producing high quality products.

Collection of new data and analytical approaches has potential to develop new insights in project management maturity, as examined by Williams et al. (2014). In particular two Big Data analytical techniques is highlighted to have potential to develop understanding of maturity in organisations. These are social network analysis and text analysis. The study by Whyte (2015) analysed change management practices in three separate organizations, including a large construction project, who all deliver complex projects, rely on digital technologies to manage large data-sets, and use configuration management to establish and maintain integrity. The organisations use for instance configuration management in the concept, product identification

and definition stages, and as control at the “as-built” stage before handover. The authors conclude that the unstructured, uncontrolled nature of Big Data presents challenges to complex projects that deliver assets. Martínez-Rojas et al. (2015) demonstrate that suitable data handling facilitates and improves the decision-making process and helps to carry out successful project management. They analysed what the main information and communication technologies are, and reviewed the proposals that exist in the literature that focused on the management of information and knowledge from a general point of view in the field of project management.

Barista (2014) presents some early successful applications of data-driven design and planning applications, and how Building Teams can benefit from this. For instance, designers can capture and analyse data from key building performance metrics, such as energy use intensity, to optimize early prototypes. Based on feedback data from building occupants, firms can evaluate design concepts against the real world, and help the building team to understand how people interact with spaces. Redmond et al. (2015) studied how social network analysis and energy usage analyses can be a source to create integrated models for green building design. The main objective was to highlight green building technologies, while at the same time engaging end-users and harnessing their collective knowledge in building design. Several papers also treat opportunities and challenges in combining BIM and Big Data (e.g. Chen et al., 2015).

Several of the papers cover the construction phase. Akhavian et al. (2015) investigate the prospect of using built-in smartphone sensors as data collection and transmission nodes in order to detect detailed construction equipment activities. The method demonstrated a perfect success in recognizing the engine off, idle, and busy states of construction equipment. The work by Teizer (2015) outlines early results for vision-based sensing technology for tracking of temporary assets on infrastructure construction sites. Research and practical industry applications demonstrate promising work towards automated visual recording and progressing of temporary construction resources. Guo et al. (2015) show that Big Data can be used for behaviour observation in China metro construction. The suggested framework was verified in an example to be able to analyse semantic information contained in images effectively, extract worker's unsafe behaviour knowledge automatically.

Automation is a field in construction that uses new data sources and technologies. Machine-to-machine (M2M) installed on construction machines could be used to recommend overhauls to end users at the optimum timing according to Vanzulli et al. (2014). To track the progress of earthwork processes at underground construction sites, Bügler et al. (2014) suggests a novel method that combines two technologies based on computer vision, photogrammetry and video analysis. Combining these data sources allows exact measurement of the productivity of the machinery and determining site-specific performance factors. The construction quality of the material roller-compacted concrete, used in construction of storehouse surfaces, is affected by factors such as the roller compaction, concrete temperature and construction climate. Liu et al. (2015) proposes a real-time construction quality monitoring method, to provide the construction operations on site with timely collection and comprehensive analysis of construction data from the construction process. Wang et al. (2015) presents a method for automatic object recognition and rapid 3D surface modelling, including point cloud data collected from a construction

jobsite. Yang et al. (2015) reviews state-of-the-art vision-based construction performance monitoring methods. According to Skibniewski et al. (2015), the construction and operation of infrastructure systems have opportunities for improvement through research on robotics and automation. Automated equipment could cut waste, improve job safety and the overall quality of construction projects. Performance monitoring can be made more effective with tools that better characterize the extent to which construction plan are being followed and the extent to which workers and equipment are being fully utilized.

Table 2: Categorisation of literature in the time perspective of a construction project.

<i>Strategic definition</i>	<i>Concept dev.</i>	<i>Concept design</i>	<i>Detailed design</i>	<i>Construction</i>	<i>Hand-over</i>	<i>Use</i>	<i>Disposal</i>
<i>Lee et al. (2015)</i>							
<i>Caron (2015), Bakht et al. (2014)</i>							
<i>Kähkönen et al. (2015), Naderpajouh et al. (2015)</i>							
	<i>Redmond et al. (2015)</i>						
	<i>Williams et al. (2014), Whyte (2015)</i>						
		<i>Martinez-Rojas et al (2015)</i>					
		<i>Barista (2014)</i>					
			<i>Chen et al. (2015)</i>				
				<i>Akhavian et al. (2015), Teizer (2015), Guo et al (2105), Vanzulli et al, 2014, Bügler et al. (2014), Liu et al. (2015), Yang et al. (2015), Wang et al. (2015)</i>			
				<i>Skibniewski et al. (2015)</i>			
				<i>Lu et al. (2015)</i>			
						<i>Hong et al. (2015), Ioannidis et al (2015), Isikdag (2015)</i>	

Lu et al. (2015) study the performance of construction waste management for the construction categories building, civil engineering, demolition, foundation, and maintenance and renovation. The study develops a set of key performance indicators (KPIs)/waste generation rates using an available Big Data set on construction waste management in Hong Kong. Demolition was found to be the most wasteful works that generate both non-inert and inert construction waste.

There have been published several examples of evaluation of buildings in use, using quantitative methods based on Big Data approaches. The study by Hong et al. (2015) reviews the state-of-the-art in the major phases for a building's dynamic energy performance, focusing on the operation and maintenance phase. Ioannidis (2015) presents Big Data and visual analytics techniques for comparing building performance under different scenarios and design. Data that provide useful information is energy consumption, building geometry, and space occupancy. Isikdag (2015) provides a method for facilitating the geographic information system (GIS) based fusion of information residing in digital building "Models" and information acquired from the city objects. The virtual BIM sensors in the proposed design pattern will provide geometric and semantic information together with information related to the state of the building elements, and the information can be used to represent the building within a GIS environment, and city monitoring/management.

4. Concluding discussion

Our first research question was related to which applications of Big Data in construction project management that have been published in recent years, based on the defined literature search criteria. We have identified studies describing Big Data applications and theory. Thematically they fall into three broad categories: 1) New construction equipment; generating, sharing and storing data about use. 2) Data from internal IT systems; such as planning, procurement and BIM can be utilised. Lastly, 3) people generate an increasing flow of information, which can be useful if handled with care. In combination this addresses the life-cycle from concept to decommissioning. We find that Big Data have been used in energy management. Data from internal IT systems, such as planning, procurement and BIM can be utilised. People generate an information flow, which can be useful but also treated with care to safeguard personal integrity. Heating, ventilation, and air conditioning (HVAC) and electricity management systems generate large volumes of data that can be applied for life-cycle management of the equipment, but also for describing the use of the building. None of the capabilities described in this study are entirely novel in inception nor unique to the construction industry, producers of major equipment such as train rolling stock have for some time utilised equipment life-cycle management data, which are generated in large scales through the period of production, operation, and maintenance.

Other categorisations of Big Data could have been applied. One alternative is to use a hierarchy of increasing aggregation; raw sensor data, databases of sensor data, reports from such systems, and different forms of presentations and reports based on input from several systems. Other alternative dimensions include different stakeholders involved in the project, type of data sources or different types of use of the data.

Our second research question was which time phases of a construction project that recent Big Data research is relevant to. The literature is presented based on a project phase perspective. We find that the construction phase appear to have received most attention from researches. We also find that several studies are applicable to more than one phase of a construction project.

We find a potential for increased use of Big Data methods and applications within construction. Typically, the power of data integration is hard to demonstrate in limited and small pilots, but requires critical mass before providing return. Big Data can be used to make more precise predictions, which can lead to better decisions. While data and applications related to different engineering disciplines, such as energy, have been analysed in isolation previously, there is a potential to combine different types of data. This creates opportunities, but also challenges related to personal privacy. Big Data appear to have a potential to generate new insights into the costs, designs and processes in project management. The aim is to develop tools and approaches for intelligent, efficient and sustainable construction project management. This research addressed Big Data. It is not necessarily the “big” part of Big Data that is key in construction applications. A possible development is that concepts from Big Data are applied on smaller datasets. Focus will then be on new data, or expanded use of existing data.

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The Implementation of Building Information Modelling within an Integrated Public Procurement Approach: The Main Contractor's Perspective

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Abstract

The purpose of this paper is to explore the impact of an Integrated Public Procurement Approach on the main contractor's attitude and to investigate how Building Information Modelling (BIM) can support emerging needs. Innovative Procurement Approaches that promote collaboration and sharing of risks among counter parties are spreading in the Public Construction Sector. However, there is still limited knowledge on what types of changes are required when these procurement models are applied. The research is based on a case study involving active participation. The Procurement Approach used is Leasing Costruendo, where a financial institution gives the money to the contractor to build public project and, only at the end of the construction phase, public administration pays the financial institution. The design team and the main contractor should work together to develop the project. Moreover, for a fixed period the main contractor carries out the facility management on an agreed bid price. The findings indicate the main contractor had to change work practices and processes and the implementation of BIM was very useful to manage emerging needs. The Procurement Approach forced the main contractor to collaborate with the designers and the suppliers, paying more attention to the quality of the building as well as to the schedule. The main contractor had to control design and construction phases in order to minimise future costs related to the facility management. Moreover, tight deadlines were respected to get money by the financial institution. Thus, higher quality public buildings have been delivered to the society. Results can be used to understand implication of an Integrated Public Procurement Approach and the role of BIM in helping the main contractor.

Keywords: Integrated Public Procurement Approach, Building Information Modelling, Leasing Costruendo, Public Construction Sector

1. Introduction

Recently, the Construction Industry has been asked to introduce some changes due to the economic crisis. Moreover, the construction activity has been reduced in the last years especially in European Countries such as Italy. This situation generates problems not only for construction companies, but also for public clients. On one hand, there are fewer projects for construction companies and, on the other hand, public clients have fewer possibilities to invest on public services and finance construction works for the community. In order to mitigate this trend, new procurement methods have been developed such as Public-Private Partnership (PPP) (Osei-Kyei and Chan, 2015). Osei-Kyei and Chan (2015) have identified the principal critical success factors of PPP in several Countries as appropriate risk allocation and sharing, strong private consortium, political support, community/public support and transparent procurement. *Leasing Costruendo* falls into the PPP category. One of the major innovation in *Leasing Costruendo* deals with the involvement of financial institutions, such as banks, to realise buildings and infrastructures. Meantime, these innovative procurement methods introduce new requirements and responsibilities for the parties involved in the process (Love et al., 2015), especially for the main contractor. Thus, new approaches are required to deal with new challenges in procurement (Love et al., 2015). However, there is still limited knowledge on what types of changes are required when these procurement models are applied. The proposed paper explores the impact of the *Leasing Costruendo* procurement method on the involvement of main contractors in design processes and how Building Information Modelling (BIM) can support emerging needs.

2. Methodology

The research approach is based on a single case study where an Integrated Public Procurement approach (*Leasing Costruendo*) has been used together with Building Information Modelling (BIM). An Italian case study has been selected to investigate main contractor's perspective. The author's team actively participated in the case study and followed the progression of the projects taking part into meetings and supporting the introduction of BIM in the workflow.

The use of a BIM methodology was not included in the tender documentation. However, the main contractor decided to implement it in order to better manage risks associated to this procurement method. The main contractor selected a design firm and a financial institution to bid together for a public tender. The object of the tender concerned the construction and the twenty-year maintenance of two new pre-primary schools (four-class and eight-class), an auditorium and a food service building. After the awarding of the tender, the main contractor, a small-to-medium enterprise (SME), started to concern on risks related to the contractual agreement with the financial institution (a bank) as well as on problems due to the maintenance activity. The main contractor, in fact, did not have any previous experience on facility management tasks. For that reason, it agreed to embrace an innovative approach that could have helped them to take into account the entire life-cycle of assets. Some years before the awarding of the tender, the main contractor attended training courses related to BIM benefits for

construction companies. Even if it did not have any direct past experience on BIM projects, the construction company decided to contact the authors' team to implement a BIM-based process. The first aim of the main contractor dealt with the realisation of a Building Information Model through which to effectively support facility management activities. After some meetings, the chair decided to involve the authors' team in the design process, that was still ongoing at the detailed design phase, in order to create a parametric model from the traditional 2D drawings. Thanks to the Building Information Model, several clashes and omissions were identified in advance and the entire process was optimised.

Research results are based on a single case study, for this reason, they cannot be generalised to the entire construction sector. In addition, the authors' team was actively involved in the decision-making process: weekly meetings were arranged in order to present and discuss critical issues with designers, main contractor and sub-contractors. The authors are aware of weaknesses of being involved in the process due to the contractual agreement with the construction company. However, this approach allowed the authors to better understand the construction company's 'way of thinking'. An active participation in the process was crucial to understand the main contractor's needs and to study the constant evolution of the project from design to construction.

3. BIM and Procurement

3.1 Overview on building procurement systems

The construction sector has a long experience in using traditional procurement methods such as Design-Bid-Build (DBB), Design-Build (DB), and Construction Management (CM) (Lahdenperä, 2008). Starting from 1990s a growing interest in Public-Private Partnership (PPP) has emerged, especially after 2007-2008 global financial crises (Osei-Kyei and Chan, 2015). Public institutions seek to use private sector's knowledge and capital to minimize their deficit and, in the same time, maximise taxpayers with value for money (Osei-Kyei and Chan, 2015). In addition, in order to reduce risks and costs associated to procurement, new procedures are spreading in the AEC industry as discussed by Bolpagni (2013). Some of them are Cost Led Procurement (CLP), Integrated Project Insurance (IPI), Two Stage Open Book, Integrated Project Delivery (IPD) and Project Alliancing (PA) (Bolpagni, 2013).

Within the UK Construction Strategy (Cabinet Office, 2012), three innovative procurement methods CLP, IPI and Two Stage Open Book, have been developed in 2011. The new procurement models are based on early contractor involvement, independent assurance and higher levels of integration and transparency (Cabinet Office, 2012). The client plays a crucial role as driver in order to promote innovation, identify waste, secure knowledge transfer and corresponding growth opportunities (Cabinet Office, 2012). Integrated Project Delivery (IPD) and Project Alliancing, also called Alliance Contracting (Petäjäniemi and Lahdenperä, 2012), are relational project delivery arrangements where all the stakeholders are committed to a mutual objective and are involved from the very beginning of the project (Halttula et al., 2015).. It is important to underline that, even if it is possible to achieve IPD without BIM, its adoption

is essential to efficiently achieve the collaboration required for IPD (AIA, 2007; Eastman et al., 2011).

3.2 Role of BIM in building procurement systems

Despite significant differences on the management of these innovative procurement procedures, all of them encourage the early involvement of counterparties and a collaborative behaviour, trying to move from an ‘everyone against everyone’ approach to ‘we are all in the same boat’ (Ciribini et. al., 2015). This is the reason why Building Information Modelling can be used to achieve these goals, as it allows cooperation and transparency (Eastman et al., 2011; Bolpagni, 2013, Halttula et. al., 2015).

Building Information Modelling can be implemented in several procurement methods, from traditional to innovative ones (Bolpagni, 2013). However, when BIM is used in traditional procurement methods full potential cannot be expressed (Salmon, 2012). According to Dave et al. (2013) traditional procurement routes and forms, such as DBB, can be the ‘biggest hindrance to a proper Lean/BIM implementation (or even individual Lean or BIM implementation)’. Actually, the maximisation of value and the minimisation of waste is difficult when the contractual structure inhibits coordination, stifles collaboration and innovation, but incentives individual goals at the expense of others (Mathews and Howell, 2005). A partnering approach, as supported by the new form of contracts (*e.g.* ConsensusDOCS, 2015), can support principles required for Lean/BIM implementation such as collaboration and integration (Dave et al., 2013). Relational contracts enable commercial relationships between the parties that not only stimulate ‘mutual trust, but also facilitate the sharing of knowledge and information to generate innovation and value’ for the parties involved (Colledge, 2005). The approach is generally ‘people oriented’ and, thanks to it, time, cost and quality risks are managed collectively focusing on the achievement of wider, shared values or purposes such as a successful outcome for a client (Colledge, 2005). Moreover, relational contracts often provide team-based incentives or reward mechanisms, placing value on successful outcomes, rather than in cost or individual performance (Colledge, 2005). Thus, relational contracts can better support co-location of teams, early contractor involvement, joint development of design and other such crucial requirements, rather than traditional contracting methods (Dave et al., 2013).

There are already contractual forms suitable for a BIM environment (McAdam, 2011). In the UK there is a long experience of collaborative procurement and currently Government is fostering it (McAdam, 2011). NEC3, PPC2000 and JCT Constructing Excellence promote working in a ‘spirit of trust and co-operation’ (McAdam, 2011). Thus, even if they have not been developed on purpose of BIM, they can be appropriate for use as part of a successful BIM process (McAdam, 2011). On the other hand, Document E202 and ConsensusDOCS 301 have been set in the US to be incorporated in a BIM project (McAdam, 2011).

Relational contracting principles are more difficult to be applied in the public sector rather than in the private one due to several limitations such as legal constraints, cultural clashes and lack of

skills (Ke et al., 2011). Thus, more attention is needed dealing with public sector in order to achieve successful results.

Nowadays, there is not an Italian governmental strategy to guide the growing implementation of information-based technologies. Thus, several Italian public calls for tender have required the use of BIM ‘tools’ without a proper change in the working process. The Legislative Decree on public work is currently being updated to include the European Directive (European Parliament, 2014). For the first time the European Directive stated that ‘for public works contracts and design competitive bids, Member States may require the use of specific electronic tools, such as of building information electronic modelling tools or similar’ (European Parliament, 2014). Thus, also the European Directive explicitly refers to the use of BIM ‘tools’ instead of a BIM-based methodology. The Italian legislator is carefully dealing with this topic to avoid the use of BIM just as a technological change.

4. Case Study

4.1 Introduction of *Leasing Costruendo*

The leasing is a financial method mainly used in the private sector. Recently, it has been used also in the public sector. It mainly involved three parties: a public administration (*e.g.* a town council), a financial institution (*e.g.* a bank) and a construction company. During the tender phase the financial institution and the construction company bid together in order to award the project. After the awarding, the public administration periodically sends the money to the financial institution and the bank gives it to the main contractor in order to build the asset (Figure 1). The construction company must respect the schedule in order to be paid by the leasing company during the construction phase. After the construction phase, the construction company is in charge of the maintenance for an agreed period (Figure 2). That is one of the reasons why the construction company has to provide a high quality building to reduce future maintenance works and organise all the information in an efficient way in order to easily access them if needed.

When the agreed maintenance period ends (in the proposed case study it lasts twenty years), the construction company has to give back the property to the public administration (Figure 3)

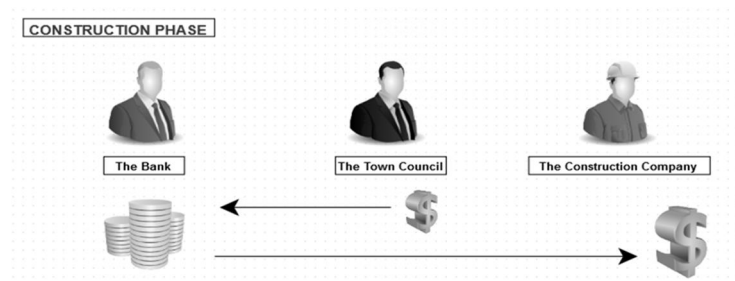


Figure 1: *Leasing Costruendo - Phase 1*

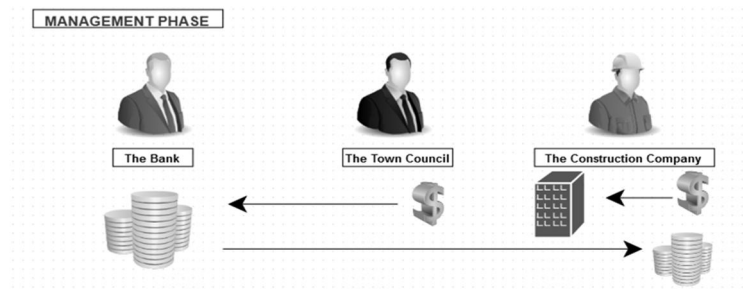


Figure 2: Leasing Costruendo - Phase 2

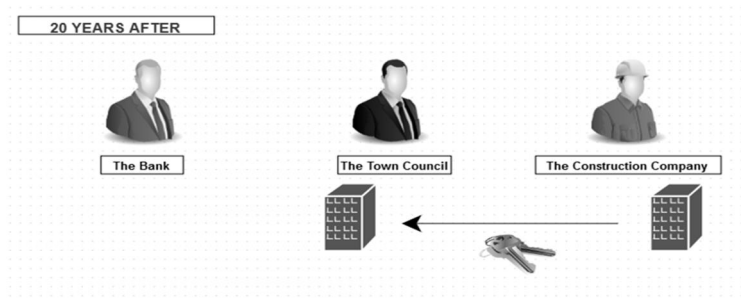


Figure 3: Leasing Costruendo - Phase 3

In the presented case study, the public administration developed the first phases of the design process and it asked bidders to present a detailed design. After the awarding phase, the public administration was in charge of monitoring the construction phase. In this procurement method the financial institution assumes all the financial risks related to the investment. On the other hand, the construction company assumes all the non-financial risks related to the construction and maintenance of assets, such as supply management and maintenance costs. *Leasing Costruendo* is a beneficial financial method for the public administration, because it can promote the realisation of high quality buildings and payments can be divided in several quotes. Moreover, usually the schedule is respected because the financial institution can receive payments only on the base of previously defined construction percentage progress. During an economic crisis as the current one, with a large number of Italian public administrations not having financial capabilities to promote new projects, the use of *Leasing Costruendo* is growing.

Leasing Costruendo could be considered as an innovative procurement method that forces the parties involved to collaborate in order to reduce risks. The main contractor, in fact, has to establish integrated and collaborative workflows with designers, subcontractors and the public client in order to define efficient solutions. *Leasing Costruendo* falls into the PPP category of procurement. A BIM approach could be beneficial to support a collaborative and a life-cycle approach as also discussed by Love et al. (2015).

4.2 Description of the project

The proposed case study is related to the construction and the twenty-year maintenance of two new pre-primary schools (four-class and eight-class), an auditorium and a food service building.

The public client divided the tender in two parcels with a different delivery deadline. The first parcel includes three buildings, two new constructions (four-class pre-primary school and food service building) and the renovation of an existing auditorium. This first parcel had to be completed in a time span of 240 consecutive days. The construction activities within the second parcel could start only once the first parcel had been completed, in accordance with some constraints such as the start of the new academic year and the necessary time to move the educational activities from the existing school to the new one. The second parcel includes the new construction of an eight-class pre-primary school. Because of this schedule, the main contractor had to carefully organise its construction activities in order to avoid penalties and delays on the starting date scheduled for the second parcel. A lack of production, in fact, would have led a payment postponement according to the construction percentage progress and, at the same time, resources that could not be relocated on other construction sites.

The four-class pre-primary school is a one-floor new construction building and it has an area of 1200 m². The structure is composed of a reinforced concrete foundation (thickness 40 cm), supporting precast wooden vertical structures. In accordance with architectural and structural designs, the MEP systems are collocated within the ventilated under-floor cavity; ducts and pipes are supposed to climb only in specific points. The construction company needed a detailed planning of the sewerage and ventilation systems installed in the ventilated under-floor cavity to be coordinated with the design of the precast vertical structures in order to optimise coordination and construction sequences on site.

The first parcel also contains an auditorium, an existing building of 1000 m² built in the nineties with a precast concrete structure. This building needed to be renovated with new architectural and MEP systems parts, including the ventilation and electrical ones. A critical issue was the coordination between architectural design and ventilation systems. In the first parcel there is also a food service building, a new construction of 1250 m² to be built next to an existing one. The structure is in cast-in-place reinforced concrete. MEP systems are mainly installed above suspended false ceilings. Finally, in the second parcel there is the eight-class pre-primary school. It is a two-floor new construction building with an area of approximately 2900 m². The structure is entirely in cast-in-place reinforced concrete and MEP systems are allocated above suspended false ceilings.

4.3 The BIM implementation

In the proposed case study, the bid was related not only to the construction phase, but also to the maintenance one and the construction company had to include costs related to both phases in the offer. Moreover, the tender selection criteria was the lowest-price one, a very common criteria in Italian public procurements. The evaluation of construction costs was a well-known activity for the main contractor; on the other hand, it was not familiar with facility management activities. For the first time, it had to consider a twenty-year maintenance project, taking into account facility management issues. Moreover, usually traditional practises do not effectively integrate different phases, such as the design, construction, operation and maintenance ones, leading lack of knowledge and inefficiencies (Eastman et al., 2011). In the proposed case study,

the required integration of design, construction and maintenance phases was a new challenge for the SME. For that reason, the main contractor thought that Building Information Modelling could have been a valuable support. Therefore, the principal needs of the construction company were related to a constructability review of the designed buildings, optimising the construction phase, and to the definition of optimal solutions for an efficient facility management in order to reduce possible future costs.

A small group of Civil and Building Engineers with competences in Information Modelling and Management (IMM) was organised in order to coordinate a BIM-based approach between designers, the main contractor and the subcontractors. Unfortunately, the use of a BIM approach started only in the final phase of the design process, between the technical design phase and the construction one. At first, in order to set up a successful process, it was necessary to answer to the following questions:

- According to the defined BIM uses of constructability review and facility management, what is the Level of Development (LOD) (AIA, 2013) required for the informative content of the Building Information Model? Which kind of geometric accuracy is needed?

For example, it was decided that a high degree of geometric accuracy was essential in order to avoid intersections and to identify and correct any problems that, otherwise, might have arisen during the installation of MEP systems (COBIM, Series 6, 2012). Moreover, the Building Information Model was managed in order to visualise construction sequences and support the installation phase, as suggested by Rischmoller et al. (2001). Facility management parameters were embedded in BIM objects according to the Construction Operations Building Information Exchange (COBie) standard (Eastman et al, 2011) and the contractor's requirements. A shared calendar between the main contractor and the suppliers was also organised in order to remind maintenance scheduled dates by means of an automatic alert e-mail system.

- Which would be the best procedure in order to exchange information among the stakeholders involved?

An iterative process of Model Checking allowed the main contractor to effectively implement the BIM methodology for improving the construction phase (AGC, 2010). Model checking was used to detect clashes and validate coordination and collaboration

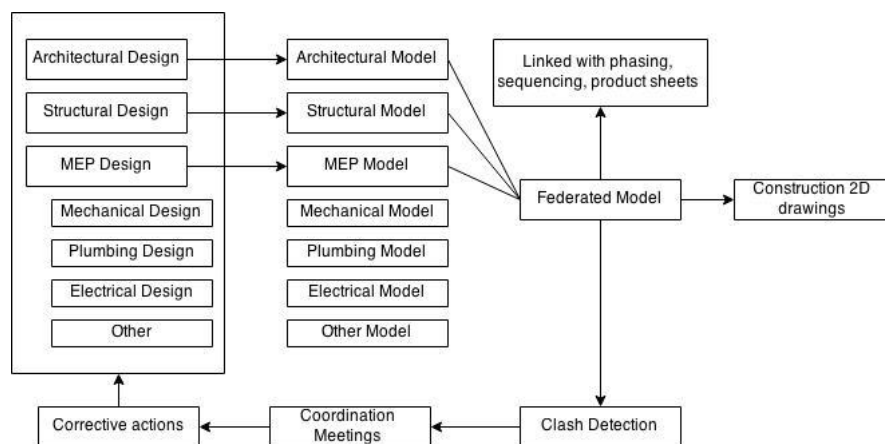


Figure 4 Ongoing discipline and multi-discipline clash detection to support the decision-making process and the constructability review (Caratozzolo et al., 2015)

between designers, main contractor and subcontractors (COBIM, Series 13, 2012). This approach allowed the optimisation of the design phase according to constructability and maintenance needs. Building Information Models of each discipline were produced based on traditional 2D designs and merged into a federated model. Clash detection results were exported in clear and effective coordination reports and documentation to be used during interdisciplinary meetings between designers, main contractor and subcontractors. After that, corrective actions were taken and the optimisation process started again (Figure 4).

5. Results and Discussion

The iterative and collaborative validation process, was essential for construction and the maintenance phases. It was strictly connected to a high level of coordination and responsibility for all the actors involved, from designers to suppliers. Subcontractors actively participated to all the coordination meetings during the constructability review process and they had the opportunity to clearly visualise what would have been realised on site. Moreover, subcontractors had an active role in the decision-making process integrating their knowledge to designers' and main contractor's. An example of the coordination achieved is related to the construction of the pre-primary school 'four-class': here the position of the ventilation vertical ducts influenced the design of the precast wooden walls. The subcontractor of the wooden structure had the opportunity to exactly know where MEP systems would have been located and their actual dimensions, so it was decided to optimise the design and the installation process by customising the precast wooden panels.

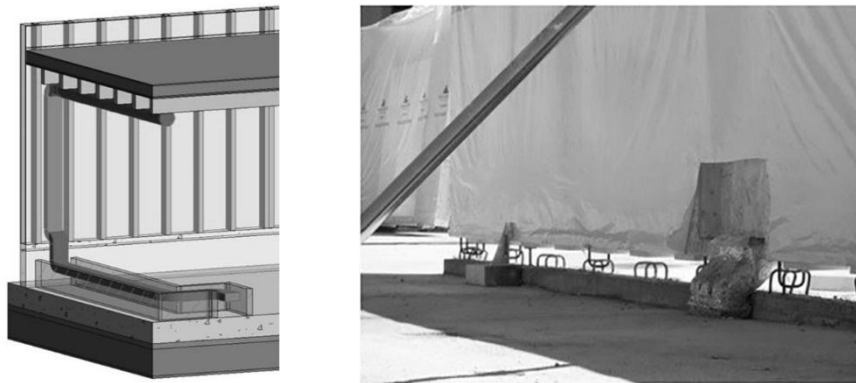


Figure 5 Customised precast wooden walls based on the BIM Model (Caratozzolo et al., 2015)

A special area to host the climbing vertical ducts within wooden panels was added (Figure 5). In this way, the energy efficiency of the wooden panels was controlled. Indeed, on site some climbing ducts in the wooden panels could have modified the dimension of the insulation layer and the final energy efficiency of the system. Moreover, MEP geometric accuracy was such that the installation of MEP components could have been conducted based on the Building Information Model. From the beginning, in fact, the main contractor understood the potentialities of this BIM-based approach, and it decided to use the Building Information Model as the unique source of data to review the project and extract shop drawings. In this way, a high level of coordination was guaranteed and the merged model was the reference point that

everyone had strictly to follow. This approach allowed subcontractors to work at the same time on different tasks, reducing construction time and costs. This result was very important to respect schedule deadlines with the bank required in *Leasing Costruendo*. Moreover, the improved collaboration between parties favoured trust in the decision-making process.

This approach is still not common in Italy, especially for SME, which traditionally use 2D drawings. The Italian law does not require the use of BIM procedures and Building Information Models are rarely considered effective due to lack of skills and trust in new approaches. *Leasing Costruendo* is an innovative procurement method and contractors are still not used to integrate design, construction and facility management phases. Finally, they are not used to work with a financial institution and respect deadline to receive the money.

6. Conclusions and Future Works

Leasing Costruendo is a quite new procurement method that creates emerging needs for construction companies such as a project life-cycle approach and respect of the schedule. In this procurement method, contractors have to deal with facility management issues that usually are not part of their business (Love et al., 2015). Moreover, even if the construction site of the proposed case study did not have large dimensions, realisation times were tightened and the different types of buildings required different skills, construction procedures and maintenance solutions to be defined. In order to meet these new needs, the implementation of the BIM methodology was crucial.

In this case study the effectiveness of the BIM implementation was limited because it was implemented in a traditional design process and required by the main contractor. More benefits would have been reached if the public owner had asked for such an integrated process since the beginning, including Employer's Information Requirements (EIRs) (BSI, 2013) in the tender documentation. The public client has to be an intelligent driver, anticipating and solving possible issues during the entire project life-cycle. Moreover, clients need to work within a single source of digital information, defined as Common Data Environment (CDE) (BSI, 2013), with the entire supply chain in order to manage a fully effective BIM process. With regard to the use of BIM, in fact, general issues depend on the level of collaboration within the project team since the early beginning. The public client has to learn how to effectively formalise the EIRs to outline issues and then collaboratively work with the entire supply chain. Thus, it is important to explore several possible solutions, taking into account issues of constructability and facility management from the design phase. In this way, clients become co-author of the process.

Moreover, information modelling is based on the management of an integrated knowledge; but today traditional procurement methods tend to put the various parties one against each other (Eastman et al., 2011; Bolpagni, 2013). For this reason, the implementation of the BIM methodology is an opportunity to improve procurement processes, promoting the digitalisation of the entire supply chain. Integration Project Delivery (IPD) and other collaborative procurement methods such as *Leasing Costruendo* allow the early involvement of contractors in the design process increasing benefits of using BIM.

Finally, the implementation of the information-based technologies needs to be consistent with an effective BIM-oriented strategy. If the awareness on the change of the entire process is not fully developed, the tendency is to use new tools of information modelling and management only to emulate traditional processes and to provide traditional documentation. This practice, however, leads to data fragmentation, invalidating the potential innovative aspect of the Information Management and Modelling (IMM) methodology. In Italy a government BIM mandate seems to be necessary for an effective implementation of new digitalised practises and integrated methodology, together with the development of standards and guidelines to support all the parties involved in the process according to their specific needs.

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The European Client's Attitude Towards the Quasi-Automation of the Procurement Processes within a Digital Environment

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Abstract

The paper shows the client's attitude towards the quasi-automation of the procurement processes in the backdrop of a digital environment in some European countries. The construction industry is increasingly competing on new bases, implementing a digital approach. The client plays a key role in defining digital requirements and controlling the entire supply chain in the very early phases. Indeed, first, an 'intelligent' digital built environment needs an 'intelligent' driver. In this scenario, clients should set digital requirements able to control the compliance of offers in a quasi-automated way during tendering and awarding stages. However, the current implementation and understanding on this new attitude is not very clear and there is a gap in literature. For this reason, a deductive approach based on an online questionnaire delivered to a sample of leading European clients has been used to investigate the state of the art. Results indicate that a large number of clients use digital tools to set digital requirements and include digital deliverables in the contract (such as Building Information Models). However, the adoption of e-Procurement platforms and the evaluation of the entire supply chain during the tendering and awarding stages are still limited. Moreover, most of the clients perceive that the quasi-automation of the procurement process can generate benefits and favour risk mitigation for banks and insurances. The results can be used to get a better understanding of the current situation and to define fields where a digital approach can be further implemented.

Keywords: Procurement Process, Digitalization, Tendering, Quasi-Automation, Building Information Modelling

1. Introduction

Several European Countries, such as the UK, Germany, France and Spain are actively working on the digitalisation of the construction sector implementing Building Information Modelling (BIM). By now, there is not an univocal definition of BIM; Eastman et al. (2011) define it as *‘a verb or adjective phrase to describe tools, processes, and technologies that are facilitated by digital machine-readable documentation about a building, its performance, its planning, its construction, and later its operation’*. It is important to underline that BIM is not just a technology change, but also a process change focused on a life-cycle approach (Eastman et al., 2011). Moreover, it promotes a high level of collaboration among project participants (Eastman et al., 2011). In the last year, several reports have been published on the impact of BIM (e.g. Dodge Data & Analytics, 2015). Even if there are still limitations on its full implementation, BIM can improve the overall process (Belpagni, 2013). For this reason, the European Parliament (2014) incorporated it in the new Directive on public procurement and several European Countries have decided to include it in their construction strategies.

In 2011 the UK Cabinet Office published a Government Construction Strategy followed by an Industry Strategy for 2025 (HM Government, 2013), a report on the digital future of the Built Environment 2050 (Philp and Thompson, 2014) and the *Digital Built Britain* initiative (HM Government, 2015). The Government will require level 2 of BIM on its projects by 2016 and it is working to promote an industry that is ‘efficient and technologically advanced’ (HM Government, 2013). Moreover, in 2015, the German Federal Ministry of Transport and Digital Infrastructure declared the creation of a Digital Building Platform and it announced an initiative for the digitalisation of the construction industry. Indeed, BIM will be applied to all new projects from 2020 onwards. In addition, the French Ministry of Territorial Equality and Housing is promoting the modernisation and innovation within the construction sector and a BIM Task Group has been established in 2015. Moreover, in the same year, the Spanish Ministry of Public Works has established a national BIM strategy and it is working to include BIM as a mandatory requirement on public projects. In addition, Scandinavian Countries, such as Finland and Norway, have developed national BIM Guidelines to support the use of BIM in public works.

These initiatives demonstrate that the Construction Industry is increasingly competing on new principles, implementing a digital approach. More and more the client plays a key role in defining digital requirements and controlling the entire supply chain in order to achieve an effective process. Indeed, first, an ‘Intelligent’ built environment needs an ‘Intelligent’ driver. However, the current implementation and understanding on this new attitude is not very clear and few published data is available in literature. Thus, the aim of the paper is to show the client’s attitude towards the quasi-automation of the procurement processes in the backdrop of a digital environment in some European Countries. Nowadays, it is not possible to fully automate the procurement process, especially the creation of digital requirements and the evaluation of offers (e.g. due to the presence of subjective requirements that cannot be translated into machine-readable rules) (Ciribini et al., 2015). Thus, expression ‘quasi-automation’ is used in the paper.

1.1 Overview of the digitalisation of the Procurement process

The digitalisation of the procurement process is not a new concept and in literature there are several publications on the use of e-Procurement and e-Business indicating the state of art, benefits and barriers both in the public and private sectors (Chaffey, 2009; Eadie et al., 2010; Ronchi et al., 2010; Costa et al., 2013). As showed by Eadie et al. (2010) the principal drivers deal with reduction of costs and time together with improvement of quality. On the other hand, the principal barriers are related to cultural, infrastructure, security, legal and compatibility limitations (Eadie et al., 2010).

In the public sector, the European Commission has promoted several initiatives. In 2010 the European Commission delivered a document to define objectives of the European Digital Agenda. The principal aim is to promote ‘sustainable economic and social benefits from a digital single market based on fast and ultra fast internet and interoperable applications’. One of the key elements deals with the digitalisation of public services for citizen and business (e-Government) (European Commission, 2010a). In the same year, several documents have been published such as the ‘The European eGovernment Action Plan 2011-2015. Harnessing ICT to promote smart, sustainable & innovative Government’ (2010b). Today the EU is working on a new e-Government Action Plan 2016-2020 to complete the Digital Single Market (European Commission, 2015b). Moreover, the Green paper on expanding the use of e-Procurement in the EU (European Commission, 2010c) explained the importance of e-Procurement, the current state of art, challenges and actions to be taken. The principal challenges deal with the overcoming inertia and fears on the part of contracting authorities and suppliers, lack of standards, absence of means to facilitate mutual recognition of national electronic solutions, onerous technical requirements and the management of multi-speed transition to e-Procurement (European Commission, 2010c). The last topic has been clearly described also in the IDC report (2013). The new Directive on public procurement (European Parliament, 2014) makes the use of e-Procurement progressively mandatory and by October 2018 Member States are required to use e-Submission. Despite several initiatives to promote e-Procurement in EU, such as the PEPPOL project, there are still several barriers (2012, 2015).

It is important to underline that usually e-Procurement is associated with the use of electronic processes to procure supplies and services (European Commission, 2010c). Instead, e-Procurement is often used to procure works due to its greater complexity (Bolgagni, 2013).

As previously discussed, Building Information Modelling is more and more becoming a key element of the digitalisation of the construction sector. However, there is not a large number of e-Procurement platforms able to manage a BIM-based process. In Portugal, several research activities have been developed to integrate BIM within e-Procurement platforms during the PLAGE project (Jardim-Goncalves and Grilo 2010a, 2010b; Grilo and Jardim-Goncalves 2011, 2013; Costa and Grilo, 2015). However, a functional platform is not yet available. Moreover, Costa and Grilo’s approach (2015) is focused on e-tendering using a Building Information Model to purchase a specific product for a building, but it does not discuss procurement processes where a Building Information Model is not yet available in tendering.

Some platforms (e.g. Viewpoint For Projects™, Asite™, Aconex® and Conject®) are emerging in the market in order to manage a collaborative BIM-based process and some procurement tools are available. For example, Viewpoint For Projects™ allows setting an invitation to tender attaching a Building Information Model. However, effective data analytics tools are not available and e-Procurement platforms cannot fully take advantage from a BIM-based approach.

2. Methodology

A deductive approach based on an online questionnaire has been used. The empirical data was gathered via an online SurveyMonkey® questionnaire. SurveyMonkey® is an online survey programme that allows the user to create and manage the survey from a web-interface. A sample of leading European clients has been chosen to investigate the state of the art on the digitalisation of the procurement process. Three European Countries, the UK, Finland and Germany, have been selected. The clients were chosen for their active participation in national working groups for the innovation of the AEC sector. In the paper, they are both defined as 'clients' or 'European clients' due to their belonging to Countries where European directives on Procurement are adopted, especially for the public sector. Initially, 46 clients were selected and each of them was contacted by email, telephone or direct contact. A presentation was sent to all contacts by email to get an introduction of the research topic and to better explain the purpose of the survey. Moreover, the same email included a web link to access the online survey.

The survey was a structured questionnaire where questions were listed in a pre-arranged order and all questions required answers. The survey contained 19 questions: 14 closed-ended and 5 open. The survey was divided in three parts: a) general questions to investigate the type of clients b) questions related to the management of tendering and c) questions related to the use of a digital procurement process. The survey covered the following main topics:

- use of information requirements
- evaluation of the entire supply chain in tendering
- digital requirement in tendering
- use of e-Procurement platforms
- benefits and limitation of a quasi-automated procurement process

The online questionnaire has been accessible for three weeks starting from January 2015 and responses were received from 14 contacts, all of them were fully completed. First, results were analysed using SurveyMonkey®. The tool provides an automatic visualisation of results in graphics as well as in tables. Later, data were exported in Excel in order to create different graphs. In addition, the free tool Wordle™ was used to create word clouds to analyse results coming from open questions. Finally, results were shared among interviewees and a workshop was organised to present findings. It is important to underline that the number of received responses is very limited; thus, findings cannot be generalised to the entire construction industry. Moreover, interviewees were selected from groups that are actively engaged in digitalisation processes of their respective countries. Therefore, findings are especially addressed to the leading edge of the industry.

3. Survey Findings

The paragraph reports findings of the survey divided in three consecutive sections: general questions, management of tendering and the use of a digital procurement process. Later, results will be discussed in paragraph four.

3.1 General questions

The first part of the survey investigates client's general information to better understand if they work in the public or private sector and which is their type of business.

The interviewees are mainly public clients (64,29%) followed by developer private clients. Most of them are involved in infrastructure works (42,86%), some only in vertical assets (35,71%) and only few have a mixed portfolio (21,43%). As clients, most of them usually buy capital projects (64,29%) and only few both capital and operational expenditure (35,71%).

3.2 Management of tendering

The second part of the survey explores if clients usually provide information requirements in tendering. In the UK, such requirements have been defined as Employers Information Requirements (EIRs) (The British Standards Institution, 2013). EIRs are pre-tender documentation *'setting out the information to be delivered, and the standards and processes to be adopted by the supplier as part of the project delivery process'* (The British Standards Institution, 2013). The use of client's information requirements in an early phase of the process, forces clients to reason about their needs and provide more information to bidders. The survey investigates also if clients have standard organisational and asset requirements. In addition, other questions explore how clients usually evaluate the supply chain, especially on BIM capabilities. Indeed, BIM is more and more mandatory in tendering, but in literature there are not standard evaluation criteria and it is not clear if and how clients evaluate this requirement.

Most of interviewees (78,57%) affirmed that they determine and issue client's information requirements as part of the tender process. Most of interviewees do not have standard set of organisational and asset requirements (42,86%), others develop them uniquely for each project (35,71%) and only few have such requirements (21,43%). Moreover, the survey reveals that most of the interviews evaluate only the tier 1 design team and main contractor (78,57%) on BIM capabilities. On the other hand, only few (21,43%) evaluate the tier 1 plus their proposed supply chain. In addition, interviewees were asked to express how they usually assess capabilities of the supply chain ticking all options that applied. A large number of clients use BIM pre-qualification questionnaires (92,86%) followed by pre-contract BIM Execution Plans (BEP) (64,29%), interviews (42,86%) and capabilities assessments tools (35,71%). Finally, most of clients use standard criteria to measure capabilities of the supply chain (50,00%), others apply tailored project specific criteria (35,71%) and only few do not measure them (14,29%).

3.3 The use of a digital procurement process

The third part of the survey shows client's feedback on the adoption of a digital approach for the procurement process. Questions examine client's use of digital deliverables as well as electronic procurement (e-Procurement) platforms. Moreover, interviewees express their opinion on the main benefits, risks and cultural barriers related to the implementation of a quasi-automated procurement process, especially in tendering and awarding phases. The survey also investigates potentialities of gamification in procurement. It is a quite new concept and it deals with the paradigm of anticipation. For example, during the tender phase a gamified approach could force the main contractor to simulate its relations with perspective suppliers in front of a specific situation. Finally, interviewees were asked to evaluate clients' and supply chain's current level of competence on the digitalisation of the procurement process.

Most of clients (50,00%) usually include digital deliverables such as 3D parametric domain models plus federated models as part of the contract. Other clients ask also for non-graphical data exchanges such as Construction Operations Building Information Exchange (COBie) (35,71%) and only few do not include any digital deliverables (14,29%). Moreover, the survey reveals that still a large number of clients do not use e-Procurement Platforms as part of their business process (57,14%). Most of interviewees (85,71%) perceive benefits from the quasi-automation of the procurement process and a large number (71,43%) believe that a quasi-automated approach can favour risk mitigation for banks and insurances through the validation process. In addition, interviewees were asked to express how ready are clients in their Country to deploy a computer-readable bidding process through an open question. Most of them said that by now clients are not ready and they are only at the starting point. Furthermore, most of clients answered that they will be ready to automatically generate client's information requirements from a digital brief within one year.

The survey shows that the main risks related to the quasi-automation of the bidding process are the loss of control, poor client's requirements, poor supply chain's skills, technology limitations, the structure of the public sector procurement itself and poor briefing culture change. As previously said, the gamification applied in the procurement process is a quite new concept. Most of clients think that the gamification could not help the awarding stage of a contract. Others believe that it will add costs for clients or interviewees do not have a precise opinion on this topic. On the other hand, other clients think it will be helpful to better understand the scenarios and to promote a dynamic intelligent evaluation of offers. Thus, it will support a more transparent process. Moreover, results on supply chain's readiness for a quasi-automated procurement process are included in Table 1. Tier 1 project managers and technical adviser and main contractors are mainly self-confident; designers, tier 2 specialist sub-contractors and tier 3 product manufacturers, instead, are mainly beginners in managing a quasi-automated process. On the other hand, most of interviewees believe that tier 1 facility managers have less experience.

Table 1: Supply Chain's readiness for a Quasi-Automated Process

<i>Evaluation scale</i>	<i>No experience</i>	<i>Beginner</i>	<i>Self-confident</i>	<i>Expert</i>
<i>Tier</i>				
<i>Tier 1 Project Managers and Technical Advisers</i>	14.29%	14.29%	57.14%	14.29%
<i>Tier 1 Designers</i>	35.71%	50.00%	14.29%	0.00%
<i>Tier 1 Main Contractors</i>	0.00%	21.43%	57.14%	21.43%
<i>Tier 1 Facilities Managers</i>	42.86%	42.86%	14.29%	0.00%
<i>Tier 2 Specialist Sub-Contractors</i>	21.43%	57.14%	21.43%	0.00%
<i>Tier 3 Product Manufacturers</i>	7.14%	57.14%	28.57%	7.14%

Finally, clients were asked which cultural barriers need to be overcome to move towards an automated bidding and awarding process using computer-readable data through an open question. Most of clients believe that trust is the biggest barrier followed by collaboration, inertia to change, security, confidence in data, quality assurance of information, share of risks and rewards and understand of benefits of such approach.

4. Discussion

This paragraph presents the principal implications of findings, taking into account the limited number of responses received.

The survey shows that only few interviewees have a standard set of organisational and asset requirement as well as standard benchmarks to evaluate offers. Such a trend could slow down the potentialities of a quasi-automated procurement process because, without clear standards, clients would have to spend more time in creating digital requirements and evaluation criteria. Moreover, it will be more difficult to compare results of different projects in order to create updated benchmarks. Thus, in order to promote an effective digital process, clients should establish clear standards.

In a digital procurement process, client's information requirements play an important role. Indeed, they can promote more transparent offers because bidders have a better comprehension of client's needs (The British Standards Institution, 2013). On the other hand, thanks to them, clients can speed the evaluation of offers checking the compliance between bids and initial requirements in a quasi-automated way. The UK has been the first Country to develop a digital tool, the NBS BIM toolkit, to set and manage digital client's information requirements (EIRs). Such requirements should be included in each UK public tender by 2016. The research findings reveal that several interviewees understand the importance of client's information requirements and include them as part of the tender process. However, most of interviewees are not ready to manage a computer-readable bidding process using clients' information requirements; even if they are working on this direction to be ready within one year. The results mirror the situation in Countries, such as the UK, when this practice will soon be mandatory. Different results could be identified in other European Countries without similar compulsory requirements. In addition, it is interesting to notice that interviewees believe that project managers, technical advisers and main contractors are self-confident in managing a quasi-automated procurement process. On the

other hand, designers, tiers 2 and 3 should improve their skills, together with facility managers who received the lowest score. For this reason, an appropriate training and support should be provided to improve the overall process.

Recently, the use of Building Information Modelling has been increased and it is used in several phases of the overall process (Dodge Data & Analytics, 2015). Thus, more and more it has been used as selection criteria in tendering, especially in complex projects. Indeed, clients have to evaluate BIM capabilities in order to select tenders able to manage a BIM-based contract. Still a small number of interviewees evaluate the tier 1 players (design team and main contractor) together with their perspective supply chain. Such results could be due to the complexity in defining members of the supply chain in the very early phase of the process. However, the evaluation of the entire supply chain in tendering could be beneficial to better understand if all parties are capable to manage a collaborative BIM-based process. For this reason, the survey includes a question related to the use of gamification. Even if the gamification applied to tendering and awarding phases is a quite new concept, some clients believe that it could create a dynamic intelligent evaluation of offers. Indeed, the involvement of key players of the perspective supply chain in tendering could improve the reliability of bids, moving from evaluation of written promises to the evaluation of real capabilities. For example, a simulated and gamified approach could support the assessment of the supply chain's attitudes towards working in a collaborative environment. Such approach is being used in innovative procurement methods, such as Integrated Project Delivery (IPD) and Project Alliancing (PA), where, before the awarding phase, clients organise workshops and interviews with a selected number of bidders to assess their capabilities, attitudes and behaviours. After the awarding phase, contracts should ensure that the selected team will remain the same in order to take advantage of the gamified approach.

Moreover, a large number of interviewees do not use e-Procurement platforms as part of their business process, even if the European Commission is strongly encouraging them as previously discussed in paragraph 1.1. This result confirms results of other published studies and could be linked to presence of several barriers (Chaffey, 2009; Eadie et al., 2010; Ronchi et al., 2010; Costa et al., 2013) and to the absence of mandatory requirements at national level (IDC, 2013).

It is interesting to notice that a large number of interviewees see benefits from the automation of the procurement process such as risk mitigation for banks and insurance companies. Thus, the digitalisation of the procurement process could be beneficial to better monitor, track and check data reducing possible claims and associated risks, as also discussed by Chaffey (2009). However, in order to reach this goal, an electronic platform is needed.

Finally, interviewees highlighted some risks related to technology limitations as well as others due to the structure of the current procurement process. There are still legal issues related to the implementation of BIM in the procurement process (Eadie et al, 2015) and it is difficult to change people's attitude. Such risks can be correlated to cultural barriers needed to be overcome, such as the lack of collaboration and trust among parties. For this reason, a change in the management of procurement process is needed, introducing innovative procurement

processes that favour a collaborative approach (Bolpagni, 2013). Results are in line with cultural and legal barriers against the implementation of e-Business and e-Procurement identified in literature, as discussed in paragraph 1.1.

5. Conclusions and Future Works

The paper shows the attitude towards the quasi-automation of the procurement processes in the backdrop of a digital environment of a limited number of European Clients that are actively engaged in digitalisation processes of their respective Countries. Results indicate that a large number of interviewees use digital tools to set digital requirements and include digital deliverables in the contract (such as Building Information Models). However, the adoption of e-Procurement platforms and the evaluation of the entire supply chain during tendering and awarding stages are still limited. Moreover, today not all members of the supply chain are ready to manage a quasi-automated procurement process. On the other hand, most of interviewees perceive that such approach can generate benefits and favour risk mitigation for banks and insurances. The results can be used to get a better understanding of the current situation and to define fields where a digital approach can be further implemented, such as the integration between e-Procurement and BIM, as well as the definition of client's standard set of organisational and asset requirements. However, due to the low response rate, results cannot be generalised to the entire construction industry, but only for the leading edge of the industry.

For this reason, in the future, the same survey could be submitted to other European Countries to get more data, especially from Countries with a specific governmental digital construction strategy. Moreover, it could be useful to interview the same group after one year and compare results to monitor client's attitude.

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Steel Framing Construction with Augmented Reality Onsite

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Abstract

New approaches to prefabricated steel framing are proving popular in both first world and third world countries. A container can be packed with a steel section fabricator and all materials required to construct the steel framing for a range of client specified building designs. Such a container can be delivered to a building site in even the most extreme and isolated locations to enable a building to be erected. However, especially in third world environments with a poorly trained workforce, it is possible to assemble the framing incorrectly (e.g., back to front sections) which can have negative consequences on the building's ability to withstand design loads. Steel section fabrication machines have the ability to print onto the steel sections that they roll, which provides a potential for more sophisticated handling of the framing construction process. In this project the use of fiducial markers on the steel framing is investigated as a means of serving the construction process as well as for quality assurance processes. Fiducial markers allow a virtual connection to be established between the BIM design model and the rolled element such that an Augmented Reality (AR) application can be used onsite to support both the construction, and quality assurance, processes. Low cost tablets were investigated as the AR environment to support visualization of framing design on top of the steel framing and to develop a quality assurance application. The impact of accuracy of marker placement, types of fiducial marker, rendering accuracy, field of view of cameras in different tablets, and ease of use were explored for the developed application.

Keywords: Steel framing, augmented reality, quality control

1. Introduction

Mobile devices such as smartphones and tablets are becoming more and more prevalent and have ever increasing processing power as well as various different kinds of location sensors. With these new capabilities, there is an opportunity for these mobile devices to be used on construction sites. By making a connection between the real world and a virtual model of the building, useful real time information can be made available during the construction phase (Koch et al. 2007; Webster et al. 1996). In particular this information could relate to whether the building has been constructed correctly, i.e. provide quality control. This project investigates what problems could be solved in a steel framing application domain by such a mobile application and develops a prototype to demonstrate the feasibility of the solution.

1.1 Steel Framing

Mobile rollforming technology has increased in popularity in recent years with innovative approaches to delivering steel trusses to a building site. In particular, a number of companies manufacture mobile rollforming machinery which can be packed in a container, along with steel coils, and delivered to site for use in remote site construction projects, or in particular for third world settings where the transport infrastructure is not reliable or efficient. In New Zealand the National Association of Steel-framed Housing (NASH) identifies three companies who provide containerised rollforming solutions driven by virtual models developed in BIM-like design tools (i.e., FrameCAD Ltd, Howick Ltd, and Scottsdale Construction Systems Ltd).

While the rollforming machinery is capable of delivering perfectly sized steel framing with highly accurately placed dimples and notches, there is still a manual assembly process for frames and trusses which introduces the potential for human error. This is of greater concern in markets where there is a paucity of a trained workforce and the steel framed construction will be performed by low-skilled workers. This concern is exacerbated by steel frames and trusses appearing quite symmetrical, but in reality having a required installation alignment to ensure that design loads can be withstood.

To help address the assembly concerns the use of information technology to aid in correct assembly, and in the quality control checking of assemblies, is of interest. A vector of support in the context of this project is the fact that the rollforming machinery can print onto the steel sections as they are rolled, enabling a range of (currently low resolution) text or images to be placed on any section of rolled steel.

1.2 Augmented Reality (AR)

Augmented Reality (AR) has been seen as a promising technology for application in many industries, though not reaching its tipping point to date (Carmigniani et al. 2011; Furht 2011). In A/E/C it is mainly expected to benefit on-site processes where the ability to layer virtual model information (e.g., from a BIM) onto the actual site would augment, improve and speed up many current processes. AR can be delivered through many hardware platforms, from smartphones,

through tablets, to specialised glasses and helmets. Providing a plethora of platforms upon which an AR platform can be developed. One of the major issues with AR, and of particular concern in A/E/C, is that of alignment between the virtual and real world (Azuma 1993). To support many processes the AR system needs to accurately locate the user of the system and to paint the virtual model accurately into the real world. Accurate location on site is an ongoing research issue with GPS approaches unsatisfactorily inaccurate in many urban environments and inside buildings, and the alternates of wifi, Bluetooth, inertial sensors, fiducial markers, etc all suffering a range of drawbacks along with their successful use scenarios (Watson et al. 2005; Zandbergen and Barbeau 2011). Establishing and maintaining accurate alignment between real world objects and virtual objects in real time also proves problematic in the majority of A/E/C scenarios, though rapid progress is being made to ameliorate these issues.

2. AR Approach

To develop an AR platform for steel framing erection a range of information inputs are required to feed into the on-site application. Figure 1 provides an overview of the information flows necessary for this type of application. Our solution uses a number of different components to generate an augmented reality view of a particular location at a building site. Using markers printed onto the steel framing, the application is able to precisely determine the position of the device in 3D space, which then enables the application to render an overlay of the building model onto a live feed from the device's camera. This allows the user to verify what has been constructed against the model of the building loaded into the application.

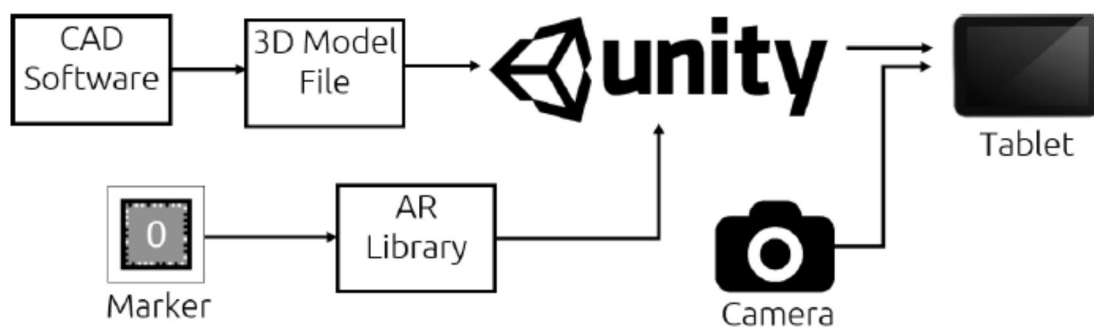


Figure 1: Information flows for an AR application

2.1 Unity

The Unity engine is a cross-platform graphics engine which can be used to visualize models in 3D on both desktop and mobile devices (Unity3D 2014). By using a cross platform engine such as Unity, it is possible to develop an application for both Android and iOS. This will be useful as the application is able to run on whatever type of device is available at the construction site. Unity is able to import 3D models from a range of common building modelling software packages. It also has a scripting engine which was used to develop the interactive components of the application, i.e. the quality assurance process and menu structure.

2.2 Vuforia

Vuforia (2014) is an augmented reality plugin which is compatible with Unity. Using Vuforia, it is possible to define markers and then link them to a position in Unity's 3D model. Through the Vuforia plugin, the application can detect the markers in the physical world using the device's camera, and then adjust the 3D model so it overlays the markers correctly. Vuforia is able to detect the position, rotation and scale of the marker and then adjust the 3D model so that it matches.

2.3 Markers

Developing markers that would be accurately and reliably detected by Vuforia in a range of lighting conditions was one of the major challenges for this project. After trialling a number of different configurations of marker, we found the marker shown in Figure 2 to be most reliable. Because of its large white border and contrasting background, Vuforia is able to detect it reliably at any size greater than 4cm. The black and white binary pattern allows Vuforia to differentiate between 512 different markers, enough for at least a significant portion of a building's framing.

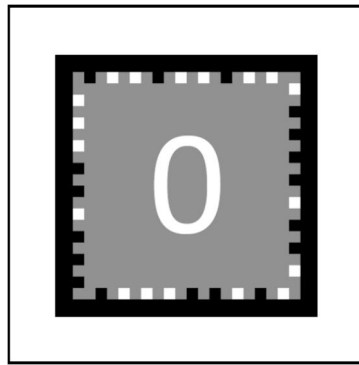


Figure 2: Effective AR marker

Another useful feature of these markers is the central space which is not actually used by the application. This space can be used for human readable text, for instance a joint number. This makes the markers useful even without the AR application.

We carried out an experiment with these markers to determine the relationship between marker size and maximum recognition distance. The larger the recognition distance, the more useful the application, as more of the structure will be visible on the screen.

Our results showed that, as would be expected, the larger the marker size, the better the recognition distance (see Figure 3). In particular, there was a significant jump in detection distance at 4cm, this is the minimum practical limit for marker size. Fortunately, steel framing is typically wide enough to accommodate markers of at least 4cm.

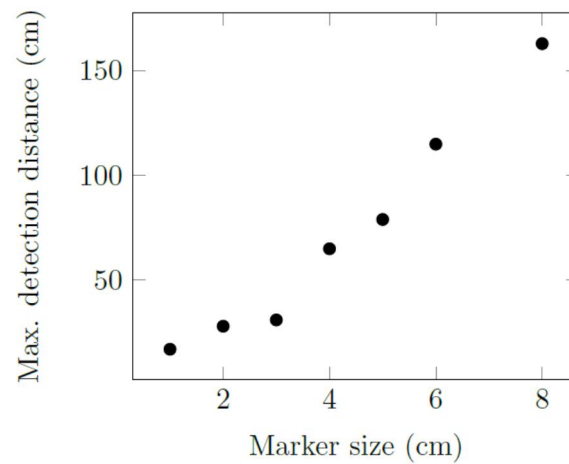


Figure 3: Impact of marker size on detection distance

2.4 Mobile Application

Combining Unity, Vuforia and the markers, we have developed a cohesive mobile application for framing verification. Starting from the home screen the user can select a particular scene they would like to view. Each scene defines a mapping between a set of markers and a 3D model.

Once a scene has been selected, a feed from the device's camera is shown on the screen (Figure 4). When a marker is detected from the camera feed, the corresponding 3D model is overlaid on the screen. The user can then tap on each segment of the model to verify that it is present. In a quality control mode unverified and verified segments are displayed in red and green respectively (see Figure 5). The ID number of the identified marker and the number of unverified segments remaining are displayed in the top left hand corner of the screen.



2.5 Server

To allow an off-site inspector to remotely verify the status of a structure, we have introduced a server component which communicates with the mobile application. The server component tracks the status of each piece of a truss, so that a mobile application can save the status (verified or unverified) of every object to the server. This status can also be loaded from the server by a mobile application, so that multiple devices can be used to verify the same building at the same time.

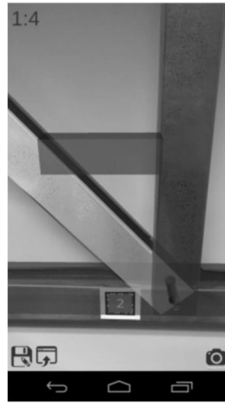


Figure 5: Truss with verified and unverified steel sections

In addition, the camera button in the application allows the user to upload screenshots (as seen in Figure 5) directly to the server. Each screenshot is associated with the marker currently in view. This allows a remotely-based inspector to view photos of each point of interest on the structure and manually verify that it is correct.

To allow information about the current status of the structure to be viewed remotely, there is also a web interface. This allows an expert at a remote location to login, view the overall progress of a building as well as details of every component tracked by the system.

2.6 Limitations

While this project demonstrates the potential usefulness of augmented reality in steel framing quality control, it is very much a proof of concept application. As such, there are a number of limitations in our implementation which would have to be addressed before this project could become practically useful.

Firstly, it would be difficult to print the markers with sufficient clarity for use in this project onto steel framing. Currently, the steel printers are only able to print black ink onto the framing (for labelling different sections), whereas our markers require three high contrast colours (black, white and blue) to be reliably detected. This could be addressed by improving the printing technology, or improving the marker recognition system.

Another interesting problem we encountered was the differing field of view (FoV) of different devices' cameras. When testing on a Nexus 5, for instance, the virtual model and the camera feed lined up perfectly. However, on an ASUS tablet the model did not line up well at all, as shown in Figure 6. This could be fixed by changing Unity's rendering settings depending on the device being used.

A side effect of the intensive image processing performed by the augmented reality engine is the high battery consumption when using the application. A typical mobile device depletes its battery after approximately one or two hours of running the application continuously. This is difficult to mitigate and could become a problem when checking a large building.



Figure 6: Truss with incorrect AR alignment

3. Evaluation

3.1 Quality Control

The main purpose of this application is to streamline the quality control process. We considered the different ways framing could be incorrectly assembled and evaluated how well the mobile application would detect these faults.

Component missing: If there is a component which is in the 3D model but not present at the building site, it would immediately be apparent to the user - when the user comes to check on that particular component, it will not match with any component in the physical world.

Extra component: If there is a component which should not be present, it should be obvious that it does not line up with any part of the 3D model. However this case is not as straightforward as the case of the missing component as the application cannot automatically identify and track these extra components.

Component in incorrect location: One of the specific problems tackled was symmetrical looking pieces of framing being inserted the wrong way around. If there are unique markers at each end of such a piece, it would be obvious when using the application that the framing has been assembled opposite to the expected model.

Component misaligned: Our application is also able to make small errors in alignment obvious to the user. In our testing we found that if a joint was as little as 5° different to the 3D model, it was very apparent that something was misaligned.

3.2 User Testing

To evaluate the ease-of-use of our application, we carried out user tests on Software Engineering students who had never used the application before. The testers were given a simple explanation of what the application does and then were asked to verify our example truss, upload the data to the server and then view their progress on the server. They were encouraged to think out loud and were asked for feedback after the task was completed.

Overall the feedback was positive, with users easily able to determine how the application worked, the meaning of the green and red components and the actions of the various buttons. The testers were all able to identify all the correctly assembled joints as well as a joint with a missing cross-section. However, the testers did highlight some interface issues in the menu system of the application, poor scrolling and confusing menus (which have since been addressed).

All of the testers agreed that this system would be helpful for verifying the correct construction of a building. While this feedback was helpful, more realistic user testing at a real building site with construction workers is needed to determine how useful the application would be in a practical context.

4. Conclusions

Combining architectural visualisation and augmented reality is a powerful way of addressing some of the real world problems experienced in the construction industry. While there are a number of limitations of our implementation, the prototype does demonstrate the feasibility of performing quality control of framing and truss assemblies using augmented reality. The markers developed, in combination with the mobile application, provide easy access to the building model. The checking-off process in the mobile application allows for effective quality control, and the server allows the verification process to be overseen remotely.

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Automated Extraction of Construction Collocations for Knowledge Discovery Based on Text Mining

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Abstract

Text data plays a critical role in construction project management and covers an overall project lifecycle from its beginning to completion. To be specific, project decision makers can take advantage of text data generated from previous projects, in order to solve similar project-related risks occurred while executing different projects. However, text data has usually been in an unstructured form and it was hard to utilize; tacit knowledge presented in documents turned out to be difficult to collect, analyze, evaluate and manage systematically throughout the project lifecycle. Thus, it is important to develop a text data management system not only to discover knowledge but also to keep abreast of accumulated data for a project team. This research developed a prototype system of UNI-Tacit and its modules for preliminary implementation. The primary objective of this study is to investigate text-specific characteristics of the construction industry, such as peculiar term usages or structures of phrases/documents, which can support the extraction of knowledge from text data. The research methodology to support automated knowledge discovery in UNI-Tacit, included (1) data pre-processing and (2) collocation analysis. The research analyzed approximately 30,000 documents on the web such as editorial articles, interviews, official correspondences, and journal papers to demonstrate the usefulness and practicality of the proposed system. Specifically, collocation techniques were uncovered and the most applicable method to overcome technical difficulties, mainly caused by the construction industry's distinct features during collocations, was determined. UNI-Tacit presents two main contributions. One is the automated keywords extraction, which can summarize original documents, and the other is multi-document summary visualization to provide meaningful insights for decision support relevant to keywords.

Keywords: Construction text data, text mining, collocation, knowledge discovery, UNI-Tacit

1. Introduction

A significant amount of text data has been accumulated over time in the construction industry (Hjelt and Björk, 2006; Zhu et al., 2007; Ma et al., 2011). It is so, because construction projects are unique, complex, and of long duration, and the stakeholders face numerous issues from the beginning until the conclusion of the project (e.g. Figure 1). Any problems that arise during the project lifecycle are commonly written in documents as text, which is the most natural form of storing information (Tan, 1999). Construction sites generate documents such as specifications, quality and safety reports, design change documents, and claim documents, as well as construction-related text data on the web such as news, editorials, reports, and journal articles (Rubin et al., 1999; Chun, 2001).

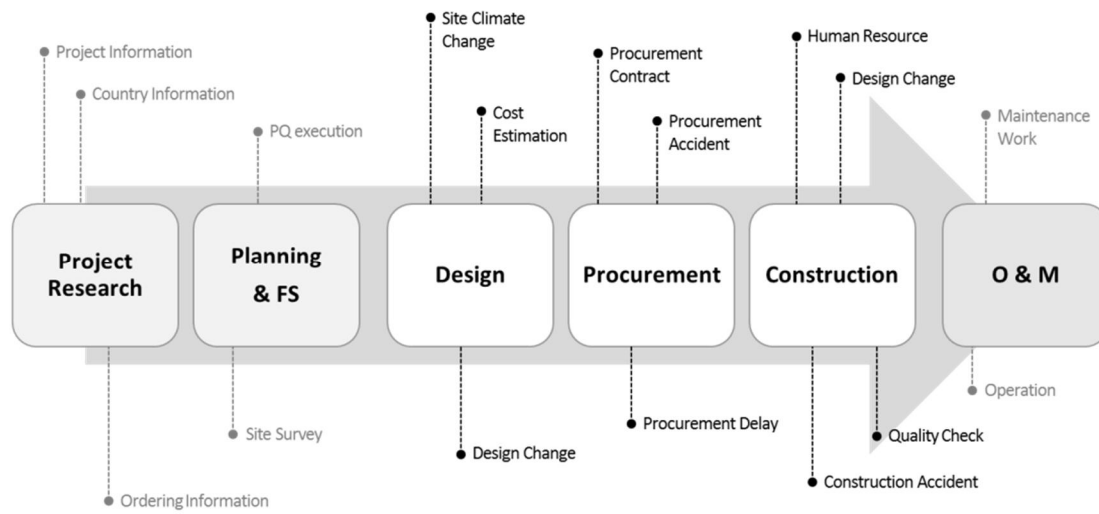


Figure 1: Various issues in a construction project

Text data is very useful to the construction industry, regarding project-related decision making. Nearly 80% of the information generated by companies is in document form (Cleveland, 1995; Gantz and Reinsel, 2012). Furthermore, important information collected from previous projects as experience, is mainly presented through documents (Pathirage et al., 2007; Soibelman et al., 2008). Such information can be reused in upcoming projects, delivering lessons learned for better risk management and project control. Thus, text-based information can play an important role in business strategy development in the highly competitive construction industry (Song et al., 2009; Qady and Kandil, 2010).

However, there are challenges in utilizing text data. Above all, text data needs to be pre-processed before being able to extract useful information from it, as most text data is unstructured (Akilan, 2015). The characteristics of natural language (e.g., non-standard expressions, segmentation issues, and tricky entity names) need to be investigated during the data processing. Complex and distinctive linguistic terms exist in numerous types and forms, in the construction industry (Soibelman, 2008). Moreover, the text data management system infrastructure is scarce in the construction field (Go, 2013). Such text management environments in the construction business, result in plenty of constraints when applying existing text mining techniques, used in other

industries, to construction and construction-customized text mining techniques need to be developed.

In addition, problems to keep up with daily updated information and manage piled up construction documents, still exist. They are usually time consuming and require specific manual efforts. To deal with these setbacks, researchers have mainly focused on two fields of study: text analytics and information visualization (Liu et al., 2009). However, few researches that maximize the value of text analytics and information visualization for construction application, were studied (Liu et al., 2009).

To tackle these challenges, this research developed UNI(User Needed Information)-Tacit (Figure 2) prototype. The primary objective of this study is to investigate text-specific characteristics of the construction industry, such as peculiar term usages or structures of phrases/documents, which can support the extraction of knowledge from text data. This was achieved by data pre-processing and collocation analysis. These processes support two main contributions. One is the automatic extraction of the appropriate keywords, which leads to a brief summarization of documents, and the other is a practical visualized output, which provides meaningful insights to keywords in the construction industry.

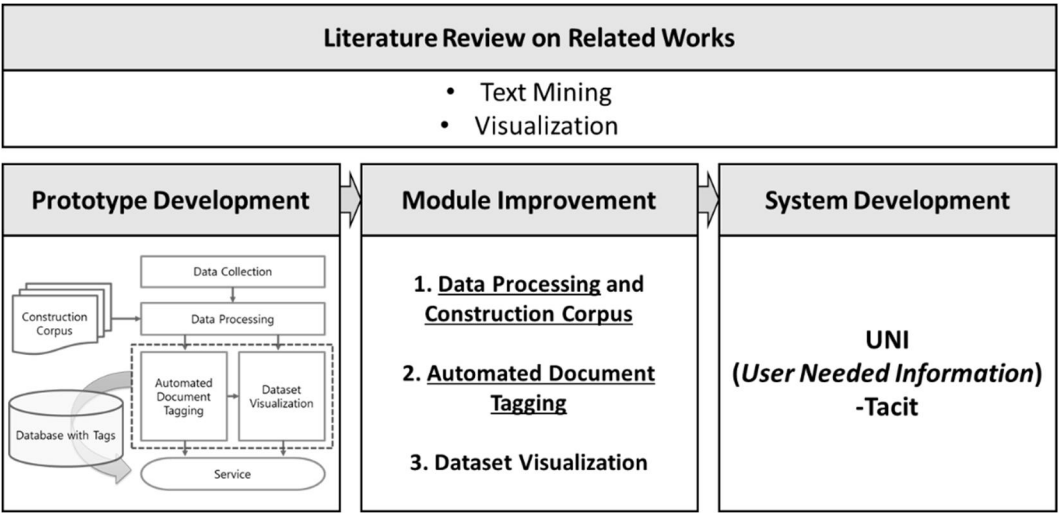


Figure 2: Research framework

In the rest of the paper, UNI-Tacit system framework and user interface are briefly described. Then, the methods of key processes to discover knowledge mechanically are described. The key processes consist of data pre-processing and collocation analysis. The application and discussion of the proposed processes are presented, and the paper concludes with a summary of the research, contributions, and future works.

2. UNI-Tacit System Overview

UNI-Tacit is designed to utilize piled up construction text data effectively and efficiently. With UNI-Tacit, users can view extracted keywords of documents based on automatically processed data and capture essential information easily and quickly through keywords via the visualization function.

2.1 System Framework

UNI-Tacit is constituted by modules, represented by each box (Figure 3). Modules in dashed rectangles are automatic processes (automated document tagging and dataset visualization) and other modules (data collection, data processing, and service) surrounded by a solid line are semi-automatic processes, which include a few manual steps.

The proposed system in this research, mainly focuses on data processing for extracting appropriate keywords from each text data automatically and on dataset visualization for conveying its essential information quickly and efficiently. The construction corpus is used as a data processing module, which reflects the text-related characteristics of the construction industry.

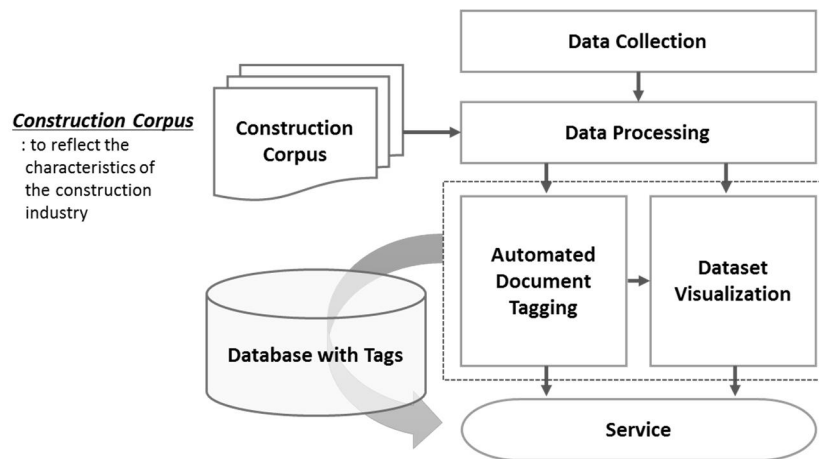


Figure 3: UNI-Tacit system framework

2.2 User Interface

Figure 4 demonstrates the implementation of UNI-Tacit prototype user interface, which employed an opened construction-related online data. The main concept of the user interface is interaction, thus when a user clicks on a tag, the system provides the dataset of documents, including the selected tag, as keywords. To be specific, a global map comes first into view because all countries are tagged, and if a user clicks on a country, a wordcloud is created with the list of the dataset based on its (including the chosen country as a tag) keywords (Figure 4(a), 4(b)). The user can also click on a term he/she is interested in, in the wordcloud and find practical information about

that term (Figure 4(b), 4(c)) and the clicking will result in a new wordcloud and a list of dataset for the newly clicked tag.

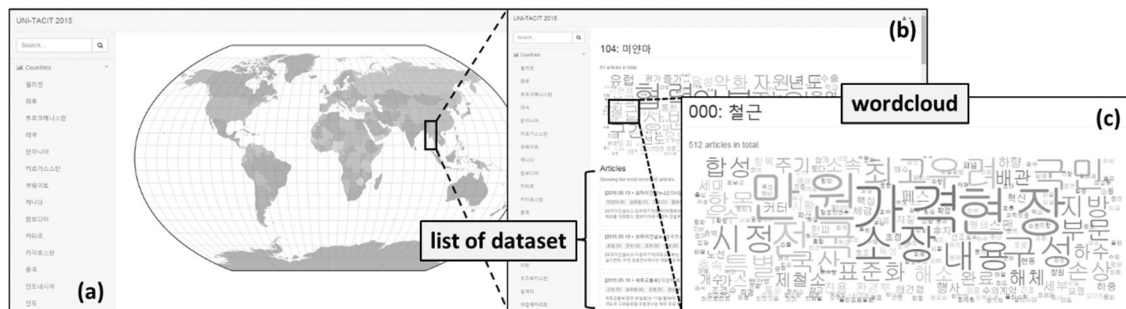


Figure 4: UNI-Tacit user interface

3. Automated Knowledge Discovery

The UNI-Tacit prototype discovered knowledge automatically based on data pre-processing and collocation analysis, which are essential processes to keyword extraction and visualization. The core objective of these processes is to enhance the extraction of exact keywords. To tackle this issue, data pre-processing and collocation analysis methods are proposed.

3.1 Data Pre-processing

Data pre-processing is a necessary step to vectorize text data. Data processing is a semi-automatic process, which includes both automatic and manual steps. Automated steps consist of POS tagging, term frequency calculating, and filtering, and manual steps include dictionary selection, optimum morpheme selection, and filter selection.

In the case of Korean data, the POS tagging process is usually combined with morphological analysis, which identifies the structure of morphemes and other linguistic units in a phrase. Thus, POS tagging is the same as the process of marking-up morphemes in a sentence based on their definitions and context (Park, 2015). Term frequency is calculated based on the POS tagged data, and filtering includes removing unsuitable terms as keywords.

3.2 Collocation Analysis

Collocation is an expression which consists of more than two words that correspond to a customary or habitual manner (Manning and Schutze, 1999). It is common to say ‘strong coffee’, not ‘powerful coffee’. In the same way, one ‘rides a bicycle’, but does not ‘drive a bicycle’. These are collocations in natural language. In this manner, collocations (e.g. strong tea) are more compositional than free constructed phrases (e.g. good boy), but less compositional than idioms (e.g. kick the bucket).

Collocations differ from industry to industry. For instance, tool box meeting(TBM) is a collocation in the construction industry, while it is not a collocation in other industries. To be specific, the phrase *tool box meeting*, in general fields, will be split into *tool*, *box* and *meeting*, and interpreted just as a tool, a box and a meeting. On the other hand, in the construction industry, *tool box meeting* implies several specific meanings, such as assigning the task of the day, conveying the instructions and contact information to the workers at the beginning of the day. Moreover, there are some collocations which are homonyms, meaning that a phrase can be a critical keyword in the construction industry, but not in other fields, and vice versa.

Thus, collocation analysis and determining an appropriate collocation method, enables the system developer to automatically find some conventional construction phrases out of documents, and to reflect peculiar text-specific characteristics of the construction industry. Collocation discovery also aids data processing by replacing words with the wrong tag, with collocations that are correctly composed phrases, in terms of the construction industry.

Three methods for collocation discovery from construction text data, were analyzed in this study. The hypothesis testing included the t test and Pearson's chi-square test, and mutual information methods, which were selected from among many after carrying out a literature review. Each method was evaluated quantitatively and qualitatively, and the most appropriate method was chosen.

The hypothesis testing detected collocations by assessing whether terms occur together by chance or not. Term occurrences were considered to be independent from each other, which meant that $P(w^1 w^2) = P(w^1)P(w^2)$, and the hypothesis was then tested. Thus, the formulated null hypothesis H_0 implied that there was no relation between the two terms (Manning and Schutze, 1999). The t value for the t test was calculated through the following equation:

$$t = \frac{\bar{x} - \mu}{\sqrt{\left(\frac{s^2}{N}\right)}}. \quad (1)$$

The chi square value for the Pearson's chi square test was calculated by the equation below:

$$\chi^2 = \sum_{(i,j)} \frac{(O_{ij} - E_{ij})^2}{E_{ij}}. \quad (2)$$

These values were used to compute the probability p in relation to a significance level (e.g. 0.05, 0.01, etc.).

The mutual information method also assumed that terms were independent from each other, but it was a measure which was theoretically motivated by information. The pointwise mutual information measured the amount of information (reduction of uncertainty) gained by the occurrence of each term (Manning and Schutze, 1999) through the subsequent equation:

$$I(x', y') = \log_2 \left(\frac{P(x' y')}{P(x')P(y')} \right). \quad (3)$$

Both quantitative and qualitative evaluations are required for the appropriate collocation discovery method in the construction industry. Thus, the Jaccard index evaluated the methods quantitatively, as it is commonly used to assess the performance of keywords extraction by the ensuing equation:

$$J(A, B) = \frac{|A \cap B|}{|A \cup B|}. \quad (4)$$

The construction experts' consultations on discovered collocations were taken as qualitative evaluation.

4. Application and Discussion

To demonstrate the performance of the proposed UNI-Tacit prototype system, the system was applied onto a dataset: an opened construction-related online data. In this section, we present the results of the application, followed by a discussion of the results. The application was conducted on a Macbook Pro with Intel Core i7 CPU and 16GB memory on Python programming language.

4.1 Data Overview

The targeted dataset of the proposed system prototype comprised construction-related documents scattered on the Internet. Specifically, construction-related news, editorials, interviews, reports, and official documents on the Internet were deemed to be appropriate for the dataset because these data types are prolific, frequently generated and accumulated in a variety of themes and, above all, treated as being useless at present.

Six construction-oriented websites were selected as the target web pages, which deal mostly with the mentioned data types. Cdaily, Cnews, Fnnews, and Ohmycon sites cover mainly data derived from news, editorials, and interviews. KISCON deals mostly with editorials, reports, and official documents. MOLIT generates primarily official documents and related news. Detailed information on each data sources is ensued in Table 1.

Table 1: Data overview

<i>Korean</i>	<i>English</i>	<i>Number of data</i>	<i>Website address</i>
건설일보	Cdaily	474	https://www.kiscon.net/kcn/list.asp
일간건설	Cnews	4,242	https://www.kiscon.net/kcn/list.asp
파이낸셜	Fnnews	1,561	https://www.kiscon.net/kcn/list.asp
KISCON	KISCON	3,804	https://www.kiscon.net/cks/share_bbs/list.asp
국토교통부	MOLIT	1,492	http://www.molit.go.kr/USR/NEWS/m_71/lst.jsp
	Total	25,143	

The dates of the collected data range from the website's inception date to 21/05/2015. The total number of data files for the pilot study was 25,143, which is approximately 279MB as a memory unit.

4.2 Results and Discussion

Raw data firstly went through the data pre-processing step. In this phase, unstructured crawled data was transformed into a structured form. The Twitter dictionary was selected for POS tagging on the dictionary selection step, because the Twitter dictionary requires a relatively short processing time and displays good POS tagging performance on online data. Only Nouns tagged as words frequency, were calculated, since other morphemes are too obscure to represent documents. Lastly, too frequent and too infrequent terms were removed in the stop words removal step, because those terms just lead to the curse of dimensionality with little merit. The terms were sorted by frequency, and the top 30 frequent terms and terms which occurred only once, were deleted. The average number of words per document was 479.97 and the number of unique nouns, excluding stop words, was 21,668.

The selected methods for collocation discovery (the t test, Pearson’s chi-square test, and mutual information) were applied to the POS tagged data because collocations are meaningful only when they are discovered as consecutive words. A sentence such as “A dog bites a piece of cookie.”, after going through the entire data pre-processing step, would only keep the information of “dog: 1, piece: 1, cookie: 1”, which is useless for finding out collocations.

In this study, the focus was on which collocation discovery method was appropriate for the construction industry, therefore collocations were analyzed, regardless of each term's tag. Also, the bigrams (two consecutive words) which occurred more than 30 times, were taken into consideration, because computing all bigrams would just consume time, without any particular discoveries. The number of bigrams with more than 30 times frequency was 49,194.

[illegible]

Figure 5: Collocations and calculation results (t test, chi-square test, mutual information)

Figure 5 shows the examples of discovered collocations (in dashed rectangles) and calculated values (in grey rectangles) for each method presented on the list of highest-to-lowest values. The differences between each method can be spotted. Thus, the Jaccard index, which focuses on how many common items two groups have, in their union, evaluated which one would be optimal to the construction industry. The higher the Jaccard index is, the bigger the intersection portion is. Thus, from the qualitative standpoint, the mutual information method showed the best performance, in terms of detecting the most collocations among each method's results for all cases of top 1,000, top 5,000 and top 10,000 collocations.

Table 2: Jaccard index

<i>Jaccard Index</i>	<i>J(t, chi-square)</i>	<i>J(chi-square, mi)</i>	<i>J(mi, t)</i>
<i>Top 1,000</i>	0.410	0.493	0.826
<i>Top 5,000</i>	0.494	0.606	0.819
<i>Top 10,000</i>	0.559	0.670	0.840

The construction experts' consultation guaranteed the usefulness and practicality of collocations. Specifically, there have been considerable errors on the POS tagging process as construction documents do not only include many Sino-Korean words but also follow different word spacing rules respectively. Discovered collocations were of high assistance in the solving of this drawback. An example of this is *레포트즈* (*le+ports à leports*) and *최우선적* (*Choi-woo+shipment à the first priority*), which are composed together. There are also collocations, which reflect the characteristics of the construction industry, such as noun phrases, including *Fast Track* and *Life Cycle*, which should be composed together to understand its exact meaning.

The service page of UNI-Tacit prototype system is presented below, in Figure 6. The final output is displayed on the service page, having gone through all modules (data processing, automated document tagging, dataset visualization) in the UNI-Tacit prototype system. When the user clicks on a tag, the keywords of the tag's dataset are drawn in the form of wordcloud, and the dataset list is ensued, below the wordcloud. The extracted keywords are also provided with the document subject and a 100-character preview.

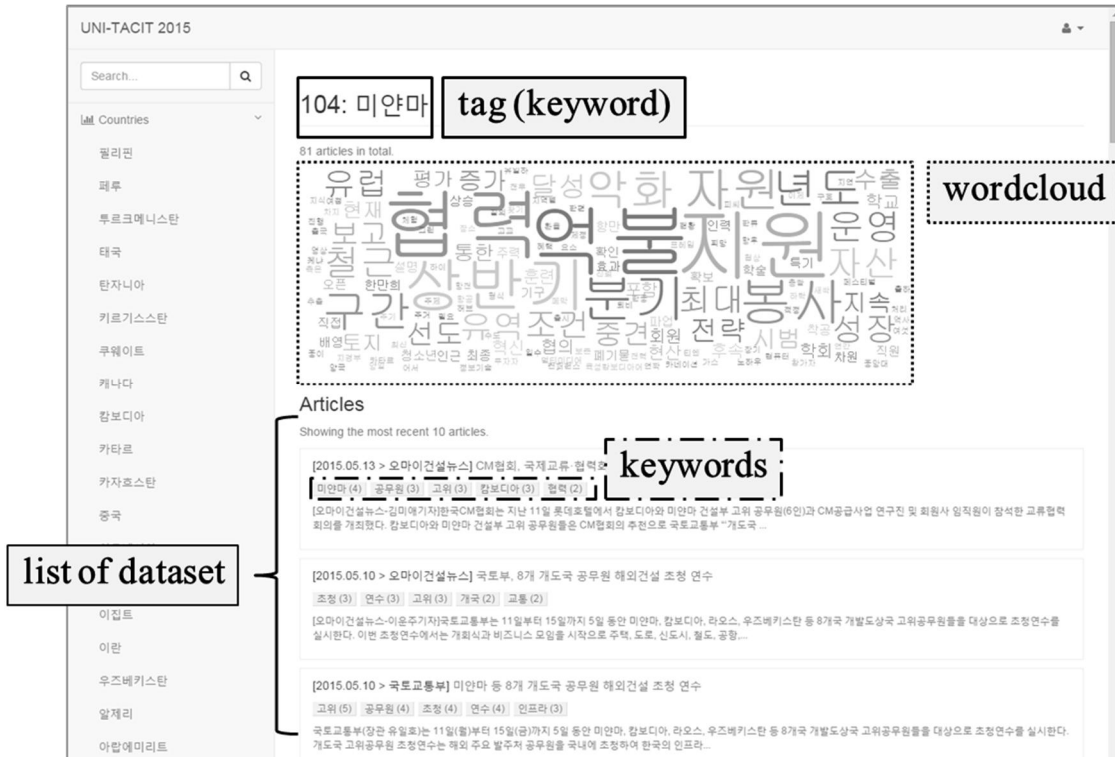


Figure 6: The service page of UNI-Tacit prototype system

5. Conclusion

The UNI-Tacit prototype system extracted correct keywords for a document by data pre-processing and collocation analysis and finally discovered knowledge by document tagging with keywords and dataset visualization based on keywords. Specifically, collocations reflecting the characteristics of the construction industry were discovered and also, the most appropriate method for finding collocations, was determined. Discovered collocations aid text mining in the construction industry overcome technical difficulties, mainly caused by the construction industry's distinct features. From the UNI-Tacit system's point of view, the proposed method of data pre-processing and collocation analysis showed promise, regarding text mining techniques applicable to the construction industry.

In the future, the developed UNI-Tacit prototype system in this study can be improved by developing methods to discover knowledge automatically. Collocation analysis considering trigrams (composed of three consecutive words) would help find more useful collocations. The term-document matrix generated in this study is a base for topic mining, which would lead to better keyword extraction. The dataset visualization improvement is also an attractive subject of research in the construction industry to convey information more effectively and efficiently. The application of the proposed system to English databases is expected to show more novel and promising results, as there are well-developed English text data pre-processing libraries and even more construction related-data in English.

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Virtual Reality Headsets for Immersive 3D Environment: Investigating Applications in Construction Jobsite Organization

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Abstract

Virtual Reality (VR), sometimes referred to as immersive environment, is a computer-generated 3D environment that can simulate the real world environment. A user wearing VR headsets can feel the same experience, as he/she would have in the real world. The aim of this pilot study is to investigate the feasibility of 3D VR Headsets in jobsite planning and management, from educational as well as industry implementation perspectives. The specific objectives consist of: (1) to study the current industry workflows for site logistics, layout and planning; (2) to investigate the feasibility of VR Headsets for jobsite planning simulations; and (3) finding ways on how to enhance the effectiveness of jobsite planning process through the use of VR Headsets. A jobsite model during the structural phase of the buildings construction was created using Unity 3D^(R) software. Oculus Rift VR headset was chosen for its support and integration with the Unity 3D^(R) software. Using the model, three scenarios demonstrating applications of 3D VR Headsets for jobsite management were created. Mixed methods research techniques including a focus group and a questionnaire survey both adopted for feedback and data collection. Presented in this paper are the main findings of this pilot study, which helped us to explore an emerging technology that could be a game changer in the design and construction industry. The results of this research aided in our determination of the best value and applications of VR headsets for jobsite planning and management within design and construction disciplines. We found that VR headsets are indeed very beneficial - allowing the users to immerse into a near-actual environment. The users were able to interact, identify, and gain an in-depth experience pertaining to jobsite management. The application of textures, materials and site development were found to create a life-like feeling. Each participant became physically involved in his/her exploration, exhibiting natural movements outside of the VR environment. This paper also presents some limitations of VR headsets and provides recommendations for future research.

Keywords: Virtual reality headsets, construction, jobsite planning, jobsite management, immersive 3D environment

1. Introduction and Background

1.1 Virtual Reality and Jobsite Organization

Although the term Virtual Reality (VR) has gained popularity recently, its roots can be traced back to the mid-nineteenth century (Wikipedia, 2015). As time evolves, this technology is becoming better, cheaper, and more accessible (Froehlich and Azhar, 2016). The definition of virtual reality is quite straightforward. ‘Virtual’ means ‘near’, so the term ‘Virtual Reality (VR)’ basically implies ‘near-reality’. VR refers to “a computer-simulated reality computer technology that replicates an environment, real or imagined, and simulates a user's physical presence that environment in a way that allows the user to interact with it. Virtual realities artificially create sensory experience, which can include sight, touch, hearing, and smell.(Wikipedia, 2015). The term VR was introduced in the 1860s, when the concept of 360-degree art through panoramic murals began to appear. After spanning a period of more than a hundred years for the framework to form, VR came into the public’s attention, and the first VR headset was created in 1990s. During the past 10 years, VR has seen a tremendous growth in popularity. Nowadays, it is more often used to describe a wide variety of applications associated with immersive, highly visual, three-dimensional (3D) environments. The 3D environment, which appears to be life-sized from the perspective of the user, can be simulated through computer. It can be interacted with, explored and controlled by a person through a head-mounted display (HMD). HMD is “a pair of goggles or helmet with a screen in front which displays three dimensional images or video”. The person who wears a HMD becomes part of this virtual world. With an embedded tracking device, images displayed to the wearer change as he/she moves the head (Wikipedia, 2015).

VR can be extremely useful in the construction industry. Among possible applications, VR technology could significantly aid in jobsite organization, which comprises of a substantial number of tasks spanning from planning to execution stage. Effective jobsite organization is imperative for any construction project as it can provide massive benefits in efficiency that condense the project schedule and productivity that significantly reduces the overall cost of the project (AEC Business, 2015). Yeh (quoted in El-Rayes and Khalafallah, 2005) states that construction jobsite organization during all the construction phases requires the identification of the building footprint, temporary facilities’ location including security fences, access roads, parking area and storage areas, stockpiles of excavation, site trailer, fabrication shops, and batch plants. Short and fast transport routes, explicit material flow, efficient use of technology and a safe work environment ensure the success of a construction project (Astour and Franz, 2014). An optimized jobsite organization plan can lead to: (1) optimum usage of available space, (2) less relocation of materials, (3) minimizing travel times of labor, material, and equipment on site, (4) better accessibility to the jobsite, and (5) a safer work environment (Zolfagharian and Irizarry, 2014). As such, effective jobsite organization is significant and critical during all construction phases and should be properly performed and updated as the project goes on.

However, to develop an effective jobsite organization plan, a wide range of factors need to be taken into account. As with the construction of any project, unforeseen complications most likely exist. While preventing all of these issues may not always be possible, having a clear strategy in

place to resolve a potential problem can lead to significant cost and time savings. According to Voigtmann and Bargstadt (2008), jobsite logistic processes take up to one third of the total execution time on site, and well-planned and executed construction logistics have the potential to reduce the construction time by 10 percent and the cost by 4 percent in outfitting processes.

Due to the complexity and the number of factors involved, jobsite planners have adopted technologies to improve the efficiency of their tasks. The emerging technology of Virtual Reality provides an effective mean of verifying site operations as well as site logistics. According to Kizil and Joy (2001), people gain 70 percent of information by vision, resulting in systems like HMDs that provide the visual component of immersion to develop virtual environments. The use of high quality three-dimensional graphics, sound and dynamic simulation combine to form a uniquely engaging experience (Kizil and Joy, 2001). By placing users in an immersive environment, it enables the visualization of jobsite arrangements in construction projects at different stages, thus providing the users with a more illustrative site plan and letting them visually see the space utilization. Jobsite organization, including traffic routines for equipment, locations for material stack and manpower availability can also be incorporated into the module to be checked visually as part of the logistics plan (Kymmell, 2008).

1.2 The Virtual Reality Head Gear - Oculus Rift®

This research was conducted using the Oculus Rift Development Kit 2 VR Headset as shown in Figure 1. The Oculus Rift was chosen for its support and integration with Unity 3D® software. The Unity 3D® software was an essential tool for digital model development. Among all of the head mounted VR products which are available in the market, the Oculus Rift, a wearable virtual reality headset which has been labelled as one of the top 10 creations in 2013, has a more tremendous impact on the virtual reality market. It delivers a stereoscopic 3D view with smooth frame rates at high resolutions for immersive virtual reality. A gyroscopic sensor is embedded in the headgear, which can track any tiny rotation the user's head makes so the view can change accordingly, while simultaneously a 3D environment image will be generated on the connected computer (Desai *et al.*, 2014). For now, Oculus Rift has not yet been launched in the construction industry as a commercial product. However, it has the potential to revolutionize the industry in several aspects. With time, the VR headsets will evolve, with applications becoming more apparent and widespread.



Figure 1: Oculus Rift Development Kit 2 (Desai *et al.*, 2014)

2. Research Objectives and Key Questions

To test the feasibility of 3D VR headsets in construction education and practice, this pilot study focused on the area of jobsite organization. The following were objectives of this: (1) to study current industry workflows for site logistics, layout and planning; (2) to investigate the feasibility of VR Headsets for jobsite planning simulations; and (3) finding ways on how to enhance the effectiveness of jobsite management through the use of VR Headsets.

Key questions we seek to answer included the following: (1) Can VR Headsets offer any advantages in jobsite organization as compared to traditional methods?; (2) Should VR Headsets be used alone or in conjunction with the traditional methods?; (3) Are VR Headsets economically viable for commercial usage?; (4) What are the potential benefits and drawbacks of VR Headsets for jobsite organization?; and (5) Are there any potential barriers to widespread adoption within the construction industry?

3. Methodology

The study was conducted utilizing mixed methods research using both qualitative and quantitative research instruments. The study was divided into three phases as shown in Figure 2.

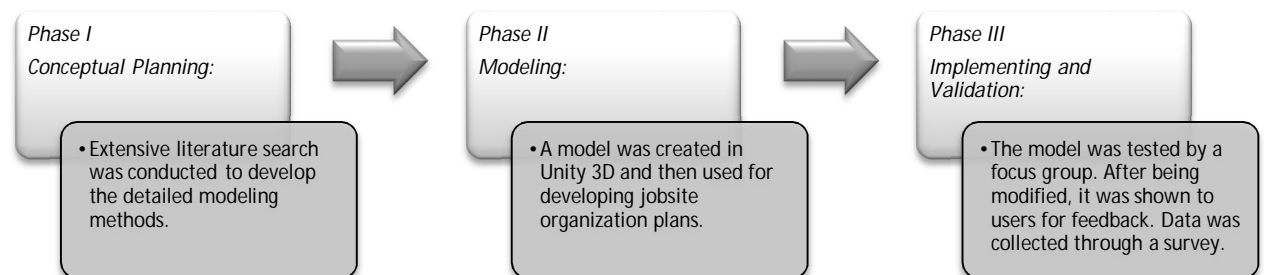


Figure 2: The Research Process

The following sections explain each phase of the research.

3.1 Phase I: Conceptual Planning

The purpose of the conceptual planning phase was to explore existing uses of VR Headsets in construction industry and to develop a detailed plan for creating the jobsite organization models. During an extensive literature review, the following referenced areas of application in construction were identified: (1) Site layout and planning; (2) Rehearsing erection sequences; (3) Progress and monitoring of construction processes; (4) Evaluation of construction scenarios; (5) Inspection and maintenance; and (6) Healthy and safety training. Next step was to review all available hardware (i.e. VR headsets). A number of VR headsets were identified and reviewed such as Oculus Rift DK2, Sony Project Morpheus, Samsung Gear VR, Google Cardboard VR, and LG G3. Among all of the head mounted VR products which are available in the market,

Oculus Rift® is found as the best choice. The reason of this has been mentioned in section 1.2. More details of this analysis can be found in Froehlich and Azhar (2016).

3.2 Phase II: Modelling

A model simulating a jobsite was created in this phase. The following software were selected: (1) Autodesk Revit® for creating the 3-story structure, (2) SketchUp® for editing and exporting all the material stack, equipment, characters and related families needed onsite, (3) Unity 3D® for rendering the model, (4) MonoDevelop® for creating the script; and (5) Camtasia Recorder® and Camtasia Studio® for producing the end product videos. Oculus Rift® headset was used to view the model in Unity 3D®. The terrain texture mapping was first created in Unity 3D® software. Unity® is a cross-platform game engine developed by Unity Technologies and is used to develop video games for PC, consoles, mobile devices and websites. A 3-story steel framing structure was created in Autodesk Revit® and then imported into Unity 3D®. All the material, equipment and characters were imported from the SketchUp® warehouse to make the simulated jobsite looks real. Figure 3 shows a screenshot of the model.



Figure 3: The Jobsite Organization Test Model

After rendering the above model, three scenarios were created, stressing how variation in jobsite organization plans can affect the effectiveness of site utilization. Scenario 1 and 2 were created based on the specific location of this project. Differences of site orientation, site access, crane placement, equipment path, material storage and waste access between these two scenarios. Scenario 3 was created as a vacant jobsite and its purpose was to allow users to create an ideal jobsite. All the material and equipment were placed off-site. By dragging and placing the material and equipment onsite, the end users were able to create their own jobsite layout. The following deliverables were produced: (1) 2D site plan captured from Unity 3D®; (2) 3D site plan (i.e. the 3D rendered model); and (3) 3D site plan with immersive environment using Oculus Rift; and (4) Narrated videos for presentation purposes.

3.3 Phase III: Implementing and Validation

For model testing and relevant data collection the following steps were performed: (1) Opinions were collected from a focus group consisting of eight BIM professionals; (2) After considering the opinions recorded in step 1, modifications were made to the model. Fourteen construction students were then invited to test the model. They were shown how Oculus Rift works in the above-mentioned scenarios. Afterwards, a questionnaire was used to gather their opinions as how they think of trying on Oculus Rift compare to the traditional methods; (3) Responses were analysed using descriptive statistics. Based upon these responses the advantages and disadvantages of Oculus Rift and its use in the construction industry were identified.

4. Model Development, Implementation, and Validation

4.1 Model Development and Implementation

A two-dimensional (2D) site plan is an effective method for implementing a jobsite organizational plan. Providing a simple and concise overview of the jobsite easily communicated to construction personnel. Due to the complexity of the construction projects, the way we organize jobsites is always challenging. Rationalization of the jobsite organization method is essential in catering all the different needs of the personnel as the construction goes on. The M. Miller Gorrie Center, a 3-story steel-framed, brick-clad building, during the structural phase of construction was chose to simulate jobsite organization. Figure 4a and 4b captured from the Unity 3D® model and marked with different colours are the 2D site plans for scenario 1 and 2.

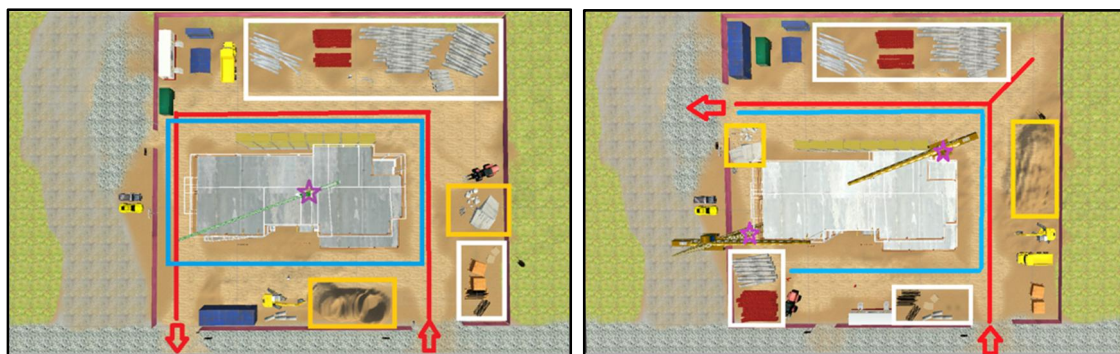


Figure 4: 2D Site Plans (a) for Scenario 1(Left) and (b) Scenario 2 (Right)

Differences can be seen from the following aspects: (1) Site access is marked in red colour. Placement of an entrance and an exit for vehicles in scenario 1 and scenario 2 are next to the jobsite trailer; (2) Crane placement is shown as purple stars. The type of crane, size of the load, crane efficiency, constraints and the associated costs were considered but not shown. In scenario 1 one tower crane was used, while in scenario 2 two tower cranes were employed; (3) Material storage is marked in white colour. Material was staged onsite at each phase of construction. In scenario 1 it was staged on the backside, while in scenario 2 it was staged separately but within the accessible range of the crane and located on the main delivery route; (4) Trash and waste access are marked in orange colour. In scenarios' 1 and 2, trash and waste stacks were located

along the main equipment path; (5) Equipment path is marked in blue colour. Trucks are used and shown on site plans for material delivery and waste removal.

Compared to the 2D site plan, a 3D site plan is a more powerful visual tool providing the viewer a life-like experience. It can show a detailed rendering of every component present at the site, including the equipment, materials as well as the site topography. Compared to the 2D plan, the 3D one illustrates how a jobsite may look like in reality, which makes it easier to understand. In addition, a 3D plan could let one see the volume and amount of spaces on site thereby making jobsite layout easier. Figures 5 and 6 depict the 3D site plans for scenario 1 and 2.

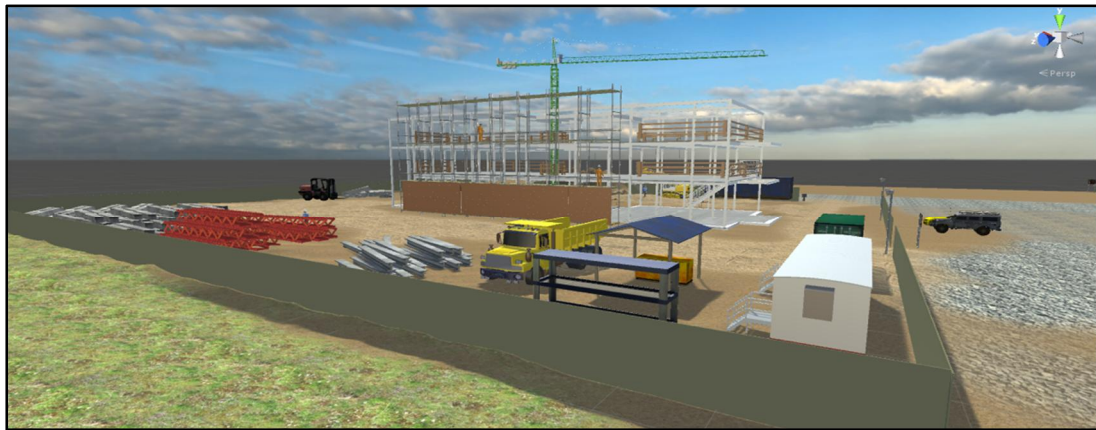


Figure 5: 3D Site for Scenario 1



Figure 6: 3D Site for Scenario 2

For both scenarios, immersive environments of the 3D site plans were also developed providing a full VR experience to the users. Utilizing the Oculus Rift®, a 360-degree virtual view could be experienced by the user, sparking his/her early engagement in jobsite organization. Figure 7 shows a user's view through Oculus Rift® headset. The whole walk-through process via Oculus Rift® was recorded and shown to focus group participants for discussion.

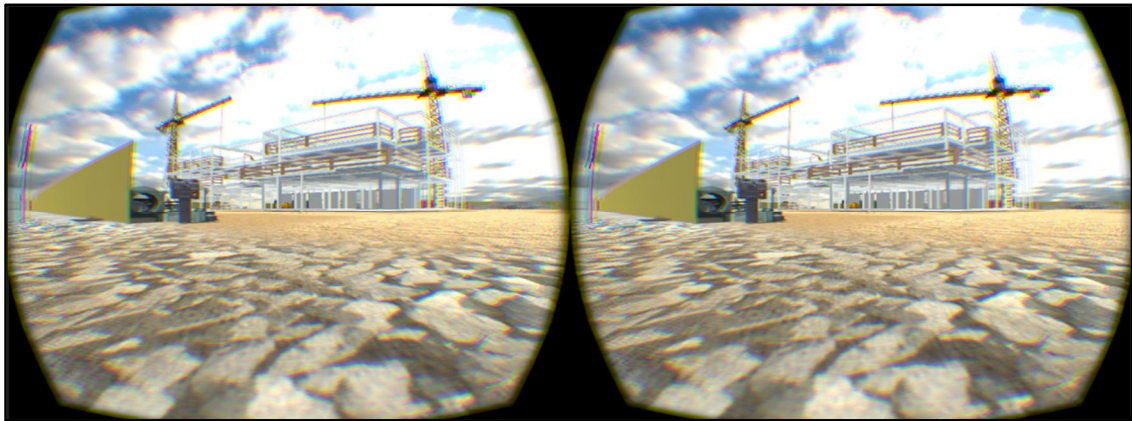


Figure 7: Users View through Oculus Rift® Headset (for Scenario 2)

Scenario 3 was developed assuming a vacant jobsite. All the material and equipment were placed off-site. The embedded script allowed users to interact with the 3D environment by dragging and placing materials and equipment on the site, thus creating their own ideal jobsite layout. Figure 8 shows the equipment and material available to the users in front of the jobsite.



Figure 8: 3D View of Scenario 3

4.2 Validation: Analysis of Responses of the Focus Group

A focus group of eight BIM professionals was formed. The three scenarios and accompanying narrated videos were shown to them and their opinions were recorded. The participants were first shown the 2D site plan, then the traditional 3D site plans, and finally the 3D site plans in immersive environment. They were asked to identify strengths and weaknesses in all the models. They were also asked to identify any advantages of utilizing the Oculus Rift®. Participants considered ‘Jobsite Virtual Tour’ as best candidate for VR applications. Some specific comments were as follow: (1) “Very promising way to assess potential danger without being put in the actual situation.” (2) “It reminds me of a game. It’s very interactive and effective. I think it’s an interactive idea for safety training and the immersive environment is definitely useful.” (3) “It shows actual situation, real life experience rather than Revit model”.

The following comments were collected for the application of VR in jobsite management: (1) “Crane placement has a great deal to gain from a VR interface. This would allow workers to see where a jobsite is in relation to the crane. The improved awareness would be beneficial for jobsite safety and planning.”; (2) “Was a good tool for identification and orientation of the jobsite, which provided a better understanding of what to expect on the site.”; (3) “Slower assessment but you get a real life hands on idea of the site layout.”; and (4) “Very beneficial when determining jobsite area and organization as well as safety.”

At the end of the focus group session, the participants were asked ‘Is your company currently using or plan to use the Oculus Rift®?’ Among the eight BIM professionals, five said ‘No’, two of them were ‘in testing and researching stage’, and one company currently utilizing it. One BIM professional revealed potential barriers for the headgear to be accepted by the construction industry: “It’s hard for the construction industry to accept technology that is unproven or still doesn’t work well. It will be a very long time before VR is accepted.” In addition, cost, inability to adapt to the quick changes and motion sickness were some other concerns expressed by the focus group members.

4.3 Validation: Analysis of Responses of the Questionnaire Survey

Fourteen graduate students with some construction experience were invited to participate in the testing process. Each participant was given 30 minutes to test all models (i.e. the 2D site plan, the 3D site plans and 3D walk-through model using Oculus Rift®) and then asked to complete a short questionnaire. Key words identified from the focus group discussion were used for opinions’ measurements in the questionnaire.

In question 1, respondents were asked to rate the effectiveness level of each of the three site plans on a 1 to 5 scale. Table 1 shows the results.

Table 1: Effectiveness of the 3 Site Plans

<i>Measure</i>	<i>Mean</i>	<i>Median</i>	<i>Mode</i>	<i>S.D.</i>
<i>2D site plan</i>	<i>1.23</i>	<i>1</i>	<i>1</i>	<i>0.58</i>
<i>3D site plans</i>	<i>1.62</i>	<i>2</i>	<i>2</i>	<i>0.62</i>
<i>3D site plan with immersive environment</i>	<i>1.85</i>	<i>2</i>	<i>2</i>	<i>0.36</i>

2: Highly effective; 1: Moderately effective; 0: No differences; -1: Moderately ineffective; -2: Highly ineffective

The 3D site plan with an immersive environment had the highest mean value with the lowest Standard Deviation (SD). The mean value of 1.85 indicates a moderately to highly effectiveness in jobsite organization. The traditional 3D site plans have the second highest mean value, but a SD of 0.62 indicates some mixed responses. By looking at the median scores, it is apparent that a considerable amount of respondents think that a traditional 3D site plan is as effective as the one with immersive environment. One respondent indicated that both the 3D plan and the 3D plan with immersive environment result in a ‘slower observation process than a 2D drawing’. Some respondents indicated that the amount of effort needed in developing 3D site plans outweighs their benefits over the 2D plans.

Next respondents were asked to indicate the level of possible advantages that Oculus Rift® offers in jobsite organization. Results are shown in Table 2 and Figure 9.

Table 2: Level of Possible Advantages that Oculus Rift® offers in Jobsite Organization

<i>Measure</i>	<i>Cumulative Mean</i>	<i>S.D.</i>
<i>Site orientation</i>	1.62	0.62
<i>Site access</i>	1.23	0.89
<i>Crane placement</i>	1.08	1.00
<i>Equipment location/path</i>	1.46	0.84
<i>Material storage</i>	1.46	0.84

Degree of certainty: 2: Definitely; 1: Probably; 0: Neutral; -1: Probably not; -2: Definitely not

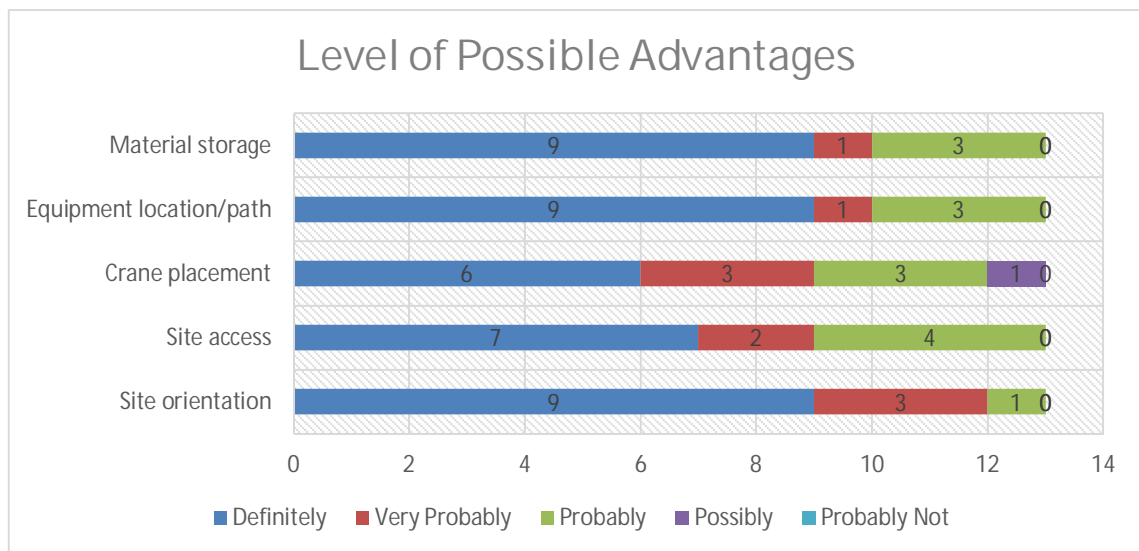


Figure 9: Distribution of the Responses

Of the five measurements indicated that Oculus Rift® offers ‘Definitely Probable’ to ‘Very Probable’ offer advantages in jobsite organization. Following are some specific comments from the survey respondents:

- ‘Crane placement has a great deal to gain from a VR interface. This would allow workers to see where a jobsite is in relation to the crane. The improved awareness would be beneficial for jobsite safety and planning.’
- ‘Was a good tool for identification and orientation of the jobsite, which provided a better understanding of what to expect on the site.’
- ‘Slower assessment but you get a real life hands on idea of the site layout.’
- ‘Very beneficial when determining jobsite organization.’

The following are some of the respondents’ overall impressions either toward the VR headsets or the 3D immersive models:

- ‘Proven VR system. Certainly some possible applications but cost/benefit may not be sufficient to justify purchase of the system for some companies.’
- ‘Very good organizational tool to use. However, I felt sort of lightheaded afterwards.’
- ‘Very neat concept that can certainly benefit the industry.’
- ‘It’s a neat, interesting software but I mainly see it used for visual presentations of spaces compared to organizations of spaces.’
- The immersive is beneficial. However only if the frame rate and motion can be calibrated.
- ‘Wearing it for an extended period of time gave me motion sick.’

Some users complained about motion sickness, which could be directly related to the amount of time spent in the VR environment. Participants stated, “using the Xbox game controller instead of the built-in head tracking eased the blurring associated with the movement”. Collective feedback from participants indicated there is a strong interest in learning more about VR headsets in the construction industry. The participants interacting with the built scenarios and being able to identify key aspects as well as conflicts confirms VR as a viable option for jobsite management. Many participants wanted to explore beyond the built scenarios such as visiting the surrounding site and testing various site logistics options to obtain the best combinations (e.g. best location for tower crane placement).

5. Concluding Remarks and Recommendations

This pilot study aimed to test the feasibility of 3D VR headset applications in construction practice and education with focus on jobsite management. The results showed positive responses from both industry professionals and students. VR headsets and their applications in the construction industry have endless potential. Overall, we found that VR headsets are indeed very beneficial - allowing the users to immerse into a near-actual environment. The users were able to interact, identify, and gain an in-depth experience pertaining to jobsite management. The application of textures, materials and site development were found to create a life-like feeling. Each participant became physically involved in his/her exploration, exhibiting natural movements outside of the VR environment. This observation confirms the immersive viability of the VR environment, creating a lifelike reality. The workflow outlined in this paper allows for gaming like scenarios to be developed. There are many other options for creating a VRE, depending on the amount of control and detail. Some simple click and go options are, *insiteVR*, *irisVR*, and *Revizto*. The respondents made some recommendations during the data collection stage. One was the use of mobile controller. As the respondent sometimes needed to turn around in the model and it was inconvenient to use the keyboard to navigate, a mobile controller would allow for easier movement in the environment, i.e. Xbox controller. Another one was to provide more background information and instructions. The VR headset cuts off the user from the outside world. The end users focused more on what they can see instead of what they can hear. Adequate interpretation on what they will experience in the VR environment and what you expect them to see will enhance a better understanding among the end users. From this research, we have also uncovered a number of limitations concerning the effective use of the VR Headset such as: (1) Single user limitation. While conducting focus group, other people have no visibility of what the tester could see in the

virtual world. To enhance communication and interactivity, a projector connected to that computer could be used to show the inherent movement of the user to other participants; and (2) Improvement in model quality. Some further improvements to the 3D immersive model could be made. Specifically reducing the size of the model to eliminate the lag while moving in the model and using more real information to rationalize the model.

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Improved Construction Safety: An Analysis of Real-Time Physiological Data through Innovative 'Smart' Safety Vests

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Abstract

The development of systems to monitor the physiological parameters of construction workers to generate early warnings has the potential to improve health and safety significantly in the globally dangerous construction industry. The aims of the recently-formed CIB task group on wearable sensor technology evidence the need for research and innovation in wearable technologies in construction, which lags in technology adoption compared to other industries.

An innovative approach using wearable technology and e-textiles to monitor the physiological parameters of construction workers in real time is proposed to improve health and safety. The technological feasibility of the proposed system was validated using a system implementation.

This paper reports the fully functioning system and its components. The proposed systematic mechanism to validate the usability of the system on a real construction site is also discussed. It reports the planned process to test the smart vest system on a construction site and to capture real-time physiological parameters.

An anticipated outcome of the research project is a significant contribution to the use of wearable sensor technology in the inherently dangerous construction industry to achieve improved safety performance.

Keywords: Construction safety, smart technologies, smart vest, wearable, real-time data

1. Introduction

1.1 Construction industry's poor safety record

Globally, the construction industry is one of the poorest performing industries in terms of its safety record. In the USA, out of 4,251 worker fatalities in private industry in calendar year 2014, 874 or 20.5% were in construction: that is, one in five worker deaths in 2014 were in construction (OSHA, 2015). In the UK the construction industry is the second-worst industry in terms of worker fatalities (HSE, 2015).

In Australia in 2014, the mining sector, the fourth worst performing industry, recorded 13 fatalities, whereas the construction industry, the third worst performing industry recorded 29 fatalities. Due to industry's poor safety record, the Australian Work Health and Safety Strategy 2012-2022 identified the construction industry as a priority industry for work health and safety improvement (Safe Work Australia 2012).

1.2 Health risks due to heat-related illness

Workers exposed to extreme temperature conditions are at risk of heat-related illness (also termed heat stress). Heat-related illness covers a spectrum of disorders (Lugo-Amador et al, 2004) such as heat stroke, heat exhaustion and heat rash. Heat stroke occurs when the core body temperature rises above 40.5°C. It can cause liver, kidney, heart and muscle damage. Often, the nervous system is affected, resulting in delirium, coma, and seizures. Permanent disability, even death, can result. It is evident that workers are unable to recognise early warning symptoms of heat-related illness. Construction fatalities from heat stroke have been reported globally.

Accident statistics report fatalities and serious injuries due to exposure to extreme temperatures. For example, in 2006, 3,100 U.S. workers had a heat-related illness that caused them to miss work (Office of Compliance, 2009). According to recent statistics from Occupational Safety and Health Administration (OSHA), construction worker fatalities were reported in occupation categories such as concreters, carpenters and construction labourers. In Australia, worker fatalities, lost time injuries and serious compensation claims were recorded due to heat stress (Government of Western Australia Department of Commerce, 2014), including in the construction industry (Mining Australia, 2013). From 2001 to 2010, relatively high incidence rates (6.8%) and compensation claims (4.6%) were reported in the construction industry in South Australia (Xiang et al., 2015). This study investigated the association between ambient temperature and occupational heat illnesses, and estimated that claims are associated with the 35.5°C threshold, above which claims increase.

Indoor and outdoor environmental factors or job-specific factors can expose construction workers to health risks due to heat stress. Outdoor environmental factors include high/extreme temperatures and/or humidity, radiant heat from direct sunlight, and areas with limited air movement (no wind or ventilation). Indoors, hot air conditions can be caused by nearby radiant

heat sources such as boilers, steam pipes, ovens and heated tanks. Job-specific factors such as physical exertion and the use of bulky or non-breathable protective clothing and equipment can also contribute to the problem (US Department of Labour, 2015). Workers in operations involving high air temperatures, radiant heat sources (such as arc welding), heat-treatment operations, plating, and those working in confined spaces are also vulnerable to risks.

2. Background and Related Work

Regulatory bodies such as SafeWork in Australia, Occupational Safety and Health Administration (OSHA) in the USA and the Health and Safety Executive (HSE) in the UK are increasingly recognising heat stress hazards.

For example, in the USA, OSHA has introduced a practical guide to workers and employers in the form of a tool called the heat index. The heat index indicates the risk level associated with a range of temperatures and suggests protective measures against each risk level. In the UK, the HSE recommends carrying out a heat stress risk assessment in the workplace and a heat stress check list is provided to control the risks.

Researchers predict productivity decreases in other regions of 11–27% by 2080 in hot regions such as Asia and the Caribbean (Kjellstrom et al., 2009), and globally up to 20% in hot months by 2050 (Dunne et al., 2013).

In Australia, heat stress has been recognised as an occupational risk by many state level regulatory bodies. WorkSafe Victoria (2012) and SafeWork South Australia (2012) have developed practical guidance notes that advise how to prevent heat illness from working outdoors in hot weather or where heat is generated as part of work. WorkCover Queensland (2015) outlines a preventive strategy for heat-related health problems at work. However, a recent study in Hong Kong on the institutional analysis of construction accident causality based on the investigation of heat illness cases on construction sites recommends revisiting the guidelines, in recognition of the existence of the system and the institutional environment associated with it (Rowlinson, et al. 2015).

A recent Australian study reports that heat stress in the workplace is not only an occupational health hazard but also significantly reduces labour productivity, based on the self-reported estimates of work absenteeism and reductions in work performance caused by heat during 2013–2014 (Zander et al., 2015). These researchers reported an annual cost of US\$655 per person across a representative sample of 1,726 employed Australians. This represents an annual economic burden of around US\$6.2 billion for the Australian workforce. This amounts to 0.33 to 0.47% of Australia's GDP. Similarly, a study done in Australia which included the construction industry on heat-related occupational illness reports that excessive heat exposure presents a significant challenge for the industry or activity (Singh et al., 2015). This study also reports that heat exposure during Australian summers commonly results in adverse health effects and productivity losses.

Edirisinghe and Blismas (2015) propose a technological solution to the problem based on the innovative approach of using wearable technology and e-textile to monitor the physiological parameters of construction workers in real time and to generate early warnings of hazardous conditions for improved health and safety. The technological feasibility of the proposed system has been validated through a prototype system (Edirisinghe and Blismas, 2015). This paper reports the further development of the system and the plan for usability validation of the technology in the construction industry.

2.1 Wearable technologies

Next-generation wearable technologies and e-textiles to monitor physiological conditions have been successfully used in industry sectors such as therapy and rehabilitation (Dunne, 2010), health and fitness (Coyle et al., 2009; Senol et al., 2011) and healthcare & tele-medicine (Lee and Chung, 2009; Pandian et al., 2008). For example, Lee and Chung (2009) developed a wireless sensor network-based wearable smart shirt for health and activity monitoring. In this smart shirt, ECG and acceleration data are transmitted via Zigbee. Another example is the wearable physiological remote monitoring system developed by Pandian et al. (2008). It is a washable shirt, which uses an array of sensors connected to a central processing unit with firmware for continuously monitoring physiological signals. The sensors measure electrocardiogram (ECG), photoplethysmogram (PPG), body temperature, blood pressure, galvanic skin response (GSR) and heart rate.

However, little research has been done on safety, particularly in the construction industry, where technology adoption is slow compared to other industries (Hosseini et al. 2012), with the exception of work on nano-material-based anti-heat stress uniforms (Chan et al., 2012; PolyU, 2014). However, this uniform is not capable of monitoring the parameters and providing real-time feedback/warnings.

The International Council for Building (CIB) formed a task group on wearable sensor technology (TG 92) to encourage research and innovation in wearable technologies in construction in 2015. The smart safety vest system (Edirisinghe and Blismas, 2015), while addressing a significant health problem in the industry, also strategically aligns with the research and innovation requirements in the building and construction industry.

3. Smart Safety Vest

The smart vest measures the body temperature and heart rate of construction workers using the LilyPad Arduino embedded platform, which is a micro-controller board designed for wearables and e-textiles. The data is transmitted to a mobile phone in real time. The system has an alerting mechanism to alert about unacceptable variations of measured parameters. For example, warnings for extreme temperature ranges are generated by flashing LED lights in the vest or by playing audio/video on the smart phone/device. Given the increasing popularity of smart phones, visualisation and alert generation is facilitated through a smart phone. In situations where the national and/or

organisational policy does not encourage a smart phone on site (for example, anecdotal evidence suggests that in the UK construction industry the use of mobile phones on site is discouraged) the same functionality will be provided at the central computer.

Figure 1 illustrates the smart safety vest system. The system is composed of three components: smart safety vest, mobile app and smart safety glasses. The functionality of each of the components is described below.



Figure 1: Smart Safety Vest System

- **Smart safety vest**
The vest has temperature and pulse sensors sewn into the vest. These sensors monitor the body temperature and heart rate of the wearer. The vest has flashing LEDs to facilitate the alert mechanism.
- **Mobile app**
The sensor data is sent to the mobile app via Bluetooth connectivity. The mobile app visualises the data graphically. The mobile app has two functional components to visualise the temperature data and the heart rate data separately. As described above, the mobile app facilitates the alert by generating audio/visual warnings.

- Smart safety glasses

Smart safety glass is included in the system to demonstrate the feasibility of projecting the sensor in smart glasses. This is particularly useful if the workers are not allowed a mobile phone on-site for them to self-assess their own health conditions.

Figure 2 illustrates the graphical use interface of the mobile app which visualises the temperature data. The current temperature values and the variation of temperature values over the period are displayed.

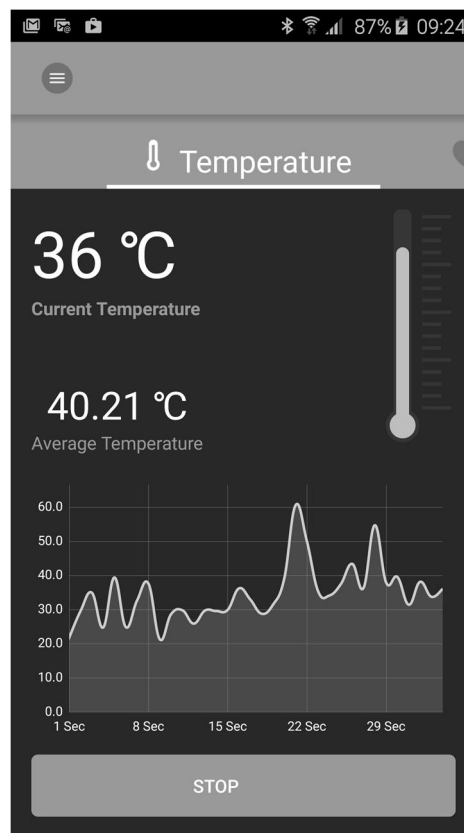


Figure 2: Data visualisation on the mobile app

4. Technology Usability and Extendibility

4.1 Technology Usability Validation

As the technological feasibility of the system has been validated, the next step is to validate the usability of the technology in industry. With recent funding support from an industry award, the system will be tested in the construction industry. Calibrating the sensors to various climates,

seasons, and organisational and work procedures will be done during site testing. Workers from a range of work groups at multiple sites including concreters, brick-layers, plasters and carpenters will trial wearing the smart vest during normal duties. The workers will be provided with the mobile app subject to organisational policy. Management personnel will be given access to a central computer to monitor the worker data.

The technology evaluation together with the users' perceptions of using the technology will be evaluated after the trial period. The smart vest usability for the workers will be tested using the widely used system usability scale (SUS) developed by Brooke (1996) and validated by Bangor et al. (2008 & 2009). The widely-used SUS is an inexpensive, yet effective, tool for assessing the usability of a system. The effectiveness, efficiency and user satisfaction of the smart vest system will be evaluated using SUS by surveying the workers at the end of the trial period. Management feedback will also be sought at the end of the trial period to evaluate the usability of the system for organizational needs.

Management feedback will also be sought at the end of the trial period to evaluate the usability of the technology for organizational needs. In-depth interviews will be conducted to understand management perceptions of using the technology. Interviews will be designed based on the Technology Acceptance Model (TAM) by Davis (1989). TAM is widely accepted, used and tested in research to help understand management behaviours in technology acceptance. The interviews will cover the participants' perceptions of using the technology in terms of benefits/advantages, ease of use, trialability, result demonstrability, compatibility of the technology, motivators for using the system (change of image and relative advantage due to technology use), challenges experienced, and willingness to use the technology in future.

4.2 Extendibility

The smart safety vest system has potential for extension into two areas in future. Figure 3 illustrates the future smart safety vest system.

Firstly, the sensors are extendable beyond the temperature and pulse sensors. Depending on the physiological parameters to be monitored, the vest can be extended. For example, muscle sensors can be included to monitor ergonomic hazards. Motion sensors can be included as proximity detectors of exposure to hazardous environments/equipment. ECGs or other biomedical sensors/pads can be included to monitor other health conditions.

Secondly, the alerting mechanism can be linked with healthcare support systems such as emergency services. The alerting mechanism can also be included in a web application for remote telemedicine support systems. These are essential and integral parts of future mHealth applications.

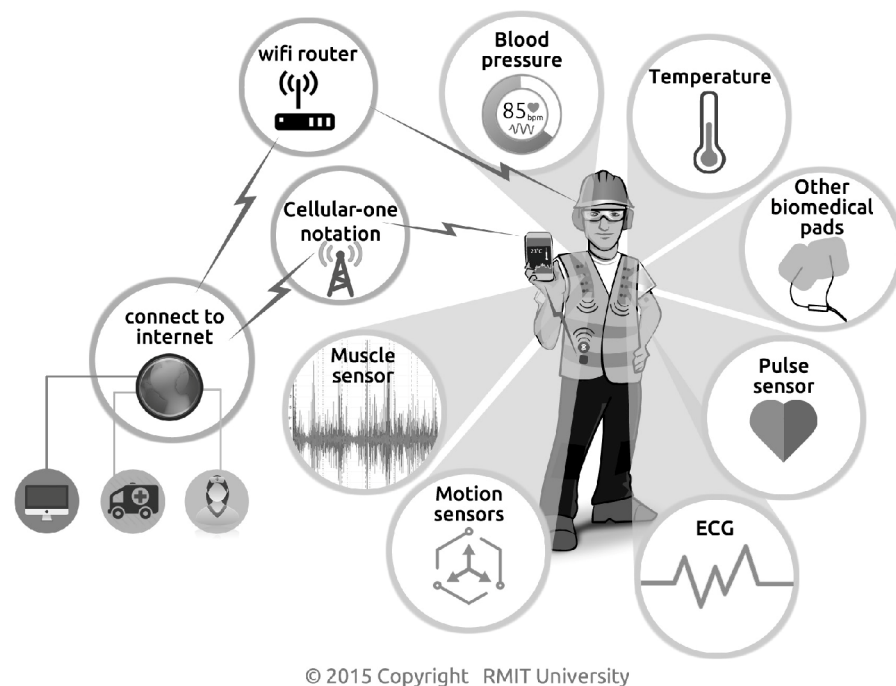


Figure 3: Extendibility of the system

5. Conclusions

This paper presents the innovative smart vest system developed to improve safety related to heat stress conditions in the construction industry. The safety vest system captures real-time physiological conditions of the workers and communicates the data with a mobile app and/or a central computer for management personnel to review. The data in these systems will be visualised in graphical format and early warnings will be generated if abnormalities occur. The plan to validate the technology's usability in industry was discussed.

The feasibility for the workers to use the mobile phones on site can be influenced by the organisational and/or national regulations and policies. For example, anecdotal evidence suggests that the use of mobile phones on construction sites is becoming restricted in the UK. In future the system will provide a central application for the site management to visualise the risk profiles of workers to overcome this limitation. The future work also includes extending the system to other physiological parameters and to link with remote health care systems.

It is expected that the proposed technology addresses a significant problem in the industry and contributes to the zero harm vision in the industry. At the same time, the smart vest system

contributes strategically and in a timely fashion to the research needs of the building and construction industry and is expected to enable step change in industry practice in technology adoption.

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“Next Step”: A New Systematic Approach to Plan and Execute AEC Projects

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Abstract

Planning and control of project execution is the core of project management. One key success factor is an adequate implementation strategy. The Architecture, Engineering and Construction industry (AEC) is portrayed as an industry with serious challenges ahead. Among observed problems that often happen in AEC project are the decisions, which are made in wrong time or at the wrong level of organization, as well as solutions executed in the project without being aligned with corporate strategies. This conceptual paper presents a new systematic approach introduced in Norway to fight the many difficult challenges in the AEC industry. The systematic approach is called “Next Step” and is a framework inspired by the RIBA plan of Work. The new framework presented in this paper identifies the key steps and tasks in a project lifecycle from the definition to the termination of the building. The framework focuses on project execution as well on the critical decisions on a corporate level, involvement of the proper stakeholder perspective, and a sustainable development of the AEC industry. The main purpose is to help the actors of the AEC industry. The intention is not to define a constraining recipe, but to give the industry a common language and collective reference for AEC projects. The framework also highlights important issues in the front end of projects concerning strategic alignment and project planning. This paper also reports on the adaptability of the new framework with different procurement forms. The new framework suggests examining the different phases in this systematic approach through different perspectives: by introducing the perspective of the owner, user, supplier and public, the project is driven to achieve strategic goals and leads to a more efficient process and sustainable outcome.

Keywords: Project execution framework, perspectives, stage gates, project delivery methods, contracts

1. Introduction

Planning and control of project execution is the core of project management. One key success factor is an adequate implementation strategy. This is specifically true in the architecture, engineering and construction (AEC) industry. Implementation strategies refer to the systematic approach to planning and execution of a specific project within a corporation. Reasons for wanting systematic approaches are obviously the constant need for continuous improvement and learning from past experiences. These are difficult challenges, and given the wide array of different contexts (national-, financial-, industry etc.) and individual strategies of corporations (business models, markets, growth etc.) and technical solutions (elements, products, materials etc.) it is no surprise the approaches vary a lot. Focusing the AEC industry, the specific challenges are often identified as being increasingly fragmented and complex on one side (Pennanen et al., 2010) and reluctant to change and innovate on the other (Dale, 2007). These characteristics combined portray an industry with serious challenges ahead.

To summarize some observed problems that frequently occur in construction projects: strategic decision-making often rely on documents (Business Case, Project Plans etc.) that are incomplete, inconsistent and in some cases simply wrong by purpose or incident (Flyvbjerg et al., 2002). Decisions are not made in time, sometimes made on the wrong level of the organization (Berg, 1999) or by the wrong individuals. This may be indication of unclear roles in connection to the decision-making process, or ineffective organizations. It may also indicate errors and flaws in decision making on individual or group level as pointed out by many authors (e.g. (Kahneman, 2011; Lovallo & Kahneman, 2003; Raiffa et al., 2006). Another recurring problem is solutions planned and executed in projects, without being aligned with corporate strategies. Projects are often viewed as pure execution without responsibility for delivering the right product, the right result for users and owners. This is evident in the traditional definition of a project as a unique task (PMBOK, 2004). It is also well known that construction projects are tormented with errors and mistakes in planning, design and execution, costing unnecessary money and reputation (Love et al., 2003).

In sum all these challenges form a problem-complex that is too much to handle for each individual project owner, project sponsor or project manager. Allowing completely individual implementation strategies to be developed for each single project will not only be costly in terms of making the same development many times, but will also miss out the opportunity to improve and learn. This conceptual paper presents a new systematic approach introduced in Norway to fight the many difficult challenges identified above. The framework is presented in chapter 3. The main issues in this paper are addressed through three axes, each represented in a research question:

- How can the framework help to achieve the right result for owners and users?
- How can the framework help to secure that the right perspectives are considered?
- How can the framework deal with different procurement forms?

2. Theoretical Framework

2.1 Success and stakeholders

In project management literature there are many definitions of success, yet Oxford dictionary of English simply states, “Success is the accomplishment of an aim or purpose” and failure as “lack of success”. Samset (2010) states “Projects are initiated to solve problems or satisfy needs”. Thus, we can assume that a project success is actually connected to its ability to solve those problems or needs.

The identification of problems and needs and the process of solving them is an important step to be able to define the project, and to define the aim or purposes in order to achieve success. Samset (2010) also argues to look at AEC projects in a larger context than only to solve the immediate problem. He claims that monitoring of a project should be both on tactical and strategic level. The tactical level deal with what most regards as the important success indicators in a project; cost, time and quality. Tactical success in projects is associated with the term “project management success” (Cooke-Davies, 2002). The strategic level looks at indicators as effect, relevance and sustainability. Strategic success is associated with “project success” (Cooke-Davies, 2002).

The AEC industry is a fragmented industry and relies on many different stakeholders to complete a project (Kerosuo, 2015). Each stakeholder have a different perception of the aim and the success of the project and these stakeholders will most certainly try to optimize their own operation (Aapaoja et al., 2012). This leads to sub-optimization of projects (Zidane et al., 2015). The right stakeholder involvement is important to create value in projects. By displaying key stakeholders and together aligning their aims, can help to conquer some of the differences (Yang et al., 2009). Keeping the most important stakeholders in mind, it is important to look at the three major groups of stakeholders and their views. Samset (2010) refers to this as perspectives and list them as the owner perspective, the user perspective and the executing perspective.

The owner is the initiating and financing party, the one who normally has a long-term interest in the investment that the project represents. The user is the party who is going to utilize the result of the project for operating their business. The executing party (-parties) is the architects, engineers and contractors who are executing the project on behalf of the owner – the project organization. The owner typically has, or at least should have, interest in the strategically performance of the project, while the executing parties typically limit their interest to the tactical performance (Slevin & Pinto, 1987). Bertelsen and Emmitt (2005) identify the owner, user and society as important groups that a “client” should represent: “These three groups of interest each value different things at different times in the life of the building.” Identifying the perspectives early might help to change and understand the focus of the stakeholders.

2.2 Project delivery methods

Project Delivery Method (PDM) - a system for organizing and financing design, construction, operations and maintenance activities that facilitates the delivery of a goods or service (Miller et al., 2000). Choosing different PDM will affect the project cost, schedule, success and influence the efficiency of running the project. This makes it a challenging issue for stakeholders and decision makers (Al Khalil, 2002; Chan et al., 2001; Kumaraswamy & Dissanayaka, 2001). The suitability of the selected PDM can improve the project performance to a great extent (Al Khalil, 2002; Han & Kuk et al., 2008; Kumaraswamy & Dissanayaka, 2001; Oyetunji & Anderson, 2006; Udechukwu et al., 2008).

There are large numbers of different PDMs available in AEC industry to overcome the shortcomings of traditional procurement (Alhazmi & McCaffer, 2000). Numerous authors have categorized the range of procurements forms in the literature. However, in this paper we try a new classification of procurement forms, to make it more practical for alignment with the framework. This classification is inspired by a very recent PMI book (Walker & Lloyd-Walker, 2015). The procurement forms could be fitted in three groups:

Segregated procurement forms: A key feature of procurement forms in this group is a trend to separate design and construction/delivery. Segregated forms include well-known traditional approaches. The dominant segregated form of procurement, which is operating in most countries, is Design Bid Build (DBB). In DBB the owner will receive the bid and award construction contract based on the finished designer's construction document. In this procurement approach, it is assumed that the project design is complete enough to enable a bidding process to establish the cheapest and/or the quickest tender cost. It also assumes that the price of design variations encountered throughout the delivery process will not be excessive (Masterman, 1992; T. Rizk & Fouad, 2007; Sanvido & Konchar, 1998).

The advantage of segregated forms, which is the key cause to select this procurement form in many organizations, theoretically lies with market contestability for the lowest cost (bid) in combination with shortest time. Other example of forms in this group is Cost reimbursement (Cost-Plus).

Integrated procurement forms: Integrated procurement forms are to some extent either physically or contractually integrated design and delivery process. A key character of this collection of procurement forms is that there is a planning and control logic driving the project and a confidence that integration is mainly accomplished through planning and control systems. Some of the procurement forms in this group are: Design and Construct (D&C), Management contracting (MC/CM), Joint venture consortia, and BOOT family procurement approaches (PFI, PPP). The most recognized procurement form in this cluster is Design and Construct (D&C) where one entity is contractually responsible to produce design and perform the construction service, typically called design-builder. It integrates the design and delivery functions either through an integrated firm mechanism, which has an in-house design team, as well as a delivery team or by the delivery organization outsourcing the design to another team that becomes its design services provider (Molenaar & Songer, 1998; Molenaar et al., 1999; T. F. Rizk, Nancy, 2007).

In all integrated procurement forms the main focus is on integrating design and delivery processes by emphasizing on planning and control, however, this does not eradicate the importance of collaboration aspect and the people management but it indicates the weight on systems integration through planning and control.

Collective procurement forms: In this cluster the focus is on integrating the project design and delivery teams rather than the process by highlighting collaboration and coordination. Some might claim that this group of procurement forms could be the most mature forms for best outcome and value for money. Collaborative procurement forms like *Partnering*, *Integrated Project Delivery (IPD)*, *Delivery Consortia/Partner (DC/P)*, *Competitive Dialogue (CD)* and *Alliancing* are fitted in this collection. However, the authors believe that some of the forms in this cluster (partnering, competitive dialog, etc.) are naturally represented as a cultural state or formal/informal contract arrangements rather than procurement choice. They have characteristics, features, and cultural elements that can be applied to other forms.

Collective procurement forms provide a framework for establishing mutual objectives among all parties involved. This normally also lead to developing an agreed dispute resolution system. Collective forms need strong team building skills among participant. Compared to other traditional forms it also needs a different paradigm from highly commercial winner-gets-all and adversarial relation between parties involved. In collective forms, the project owner does not only engage/collaborate with the designers but also collaborate from the very initiate stage of the project with contractors and possibly with significant subcontractors. Collective forms mainly characterized by covering collaboration, transparency, innovation and accountability.

2.3 Phases and decision gates

The governing of projects is a major challenge for project management. With the increased focus on governance over the last decade, phases and decision gates became more in focus and hence have received increasing attention (O.J. Klakegg et al., 2009; Müller, 2009). A fundamental logic in this perspective is that for each step of the development, one should stop and check the status before moving on, that is; one should proceed only if everything is in order. This approach is maybe best summarized in the concept of gateways: a formal control of documents and assumptions before making a decision to accept a project, or to close one phase and enter into the next. The source of this thinking seems to stem back to the term “stage gate” introduced by Cooper (1993). We choose to use the term “decision gate” as a reminder that in a governance perspective, we hold the decision to be the main issue connected with these gates.

The gateway is a key element in an adequate implementation strategy: Seen from an owner’s perspective a decision point (a point for looking forward), whereas seen from the constructor’s perspective it may be a milestone (a point for celebration, following accumulated results), as pointed out by Lereim (2009). The purpose of a decision gate, as seen from a project owner’s perspective, is to make sure the formal decision-making is successful in supporting the success of the organization, business-corporation or public entity. Broadly speaking, this depends on making the right decisions. The logical way of making sure the right decisions may be achieved

is to choose the right people to make the decisions, and make sure they have the best possible basis for making the decisions.

Having the best possible basis for making key decisions is a question of extracting the right information. The right information is a question of what is available (known at the time of decision) balanced against the cost of obtaining more/better information and the risk associated with making the decision on less than perfect basis. Decision gates are often characterized by having defined procedures for assessments/control and decision making, defined roles and responsibilities, criteria for acceptance, and a gatekeeper (owner of the gateway process) who decides whether the project is allowed to enter the gateway or not.

The cost of attaining perfect information means it is rational to divide the development in steps and not produce more than needed at each step. Making sure the relevant information is available at the right time and in adequate detail is paramount. Consequently, phases and decision gates are key elements of an information flow framework. Examples from phases given below are meant to illustrate some selected decisive moments in this development:

The first phase is the initial process where the problem or need is acknowledged. This could be due to an owner having a site he wants to realize, or a company looking for other facilities to do their business. This indicates a reason to invest and is often referred to as the business case. Acknowledging that a reason to invest exists is a decisive moment because it drives the decision-making and planning process forward and raises expectations among users.

The next logic step is to view the feasibility of the business case; can it be developed, what are the best alternative concepts, what should the project include. This should now end up in a brief, specifying the contents of a project. Particularly the brief is viewed as a crucial document to achieve a successful project (El. Reifi et al., 2013). The brief is the foundation for a good design and production process. Approving the brief is another decisive moment because this is the point in time where you decide what the users are going to get in the end.

Another key milestone is the handover from the contractors to the owner. This decisive moment represents responsibility shifting from executing party to owner. At this point it is crucial to compare the actual delivery against what was decided in the final brief. For some projects this is when the owners and users for the first time are able to consider to what degree the project fits his or her needs. Traditionally this was where the focus of the project organization ended, but today there is strong focus in the use of the project, looking at how the users of the project succeed in their business and in the management of the facility.

Having a long-term perspective that includes sustainability of the investment is today required, even expected for all parties, despite traditional short-sighted execution perspective. Sustainability has to be considered in terms of the investment's economical-, social- and environmental consequences. Only when the truth is known about the investment's long-term consequences can its true value be assessed. This makes the decision to terminate,

decommission or sell the facility into another decisive moment. This is where the initial intention meets the hard reality of the end and the circle is completed.

3. Result

In January 2015 Bygg21 and The Norwegian Property Federation took an initiative to make a common phase model for the Norwegian AEC industry. The project was undertaken by a research group from the Norwegian University of Technology and Science (Ole Jonny Klakegg et al., 2015). Figure 1 presents an outline of the resulting framework, which was released in December 2015 (www.bygg21.no).

Step	1 Strategic definition	2 Brief development	3 Concept development	4 Detailed designing	5 Production	6 Handover	7 In use	8 Termination
Core process	Owner perspective							
	User perspective							
	Supplier perspective							
	Public perspective							
Management process	Planning							
	Procurement							
	Communication							
	Sustainability - economics							
	Sustainability - environment							
	Sustainability - scocial							

Figure 1: Outline of the framework called "Neste Steg" (Next Step)

The framework “Next Step” is generic and based on a similar set-up as the RIBA Plan of Work (RIBA, 2013). The AEC industry can use the framework with any form of contracts and is open for future development of new PDMs as well. The main purpose is to help the actors of the AEC industry with defining key tasks that need to be fulfilled in the different stages of a project, and to help coordinate their involvement. The intention with this framework is not to define a recipe that needs to be followed to the letter, but to give the industry a common language and collective reference to execute projects.

The different steps of the project are indicated on the top of Figure 1. Each step has a clear purpose and together they all the different phases of a project. In this framework there are 8 steps, including the last important step of termination. Termination can refer to the termination of ownership; i.e. the owner sells the property or the demolition of the building in order to utilize the site in a different way. The logic of the steps is based on a systems thinking approach with input, process, and output logic, creating decisions gates after each step. The output can be input to the next step or leading to a termination of the project. The process is the actual tasks that need to be completed in order advance the project (Ole Jonny Klakegg et al., 2010).

Inspired by Eikeland (2001) the framework divides the processes into two major categories: Core processes and Management processes. Core processes are main tasks and supporting tasks that develop the professional contents of the project. Management processes are planning, coordination and control tasks that need to be performed professionally to make the core processes work well.

In the core processes, the activities are separated into four different perspectives, allowing the stakeholders to easier identify their major activities and tasks and understand the purpose of the tasks at hand. The fundamental perspectives are described by Samset (2010), consisting of owner- user- and executing perspectives. In addition, the new framework includes a public perspective to put focus on how projects need to work actively with their context. The core processes are described with recommended activities that needs to be addressed, in what perspective they need to be performed, and summarizes necessary start-up conditions (input) and deliveries (output) from each step. The idea is that all parties in the project need to know that these are the main activities and issues to be addressed. The framework does not prescribe who should address each task – it is up to the project management to organize the project. The framework prescribes what perspective, or mindset, each task should be performed in.

The management processes includes several categories of tasks that are of the utmost importance for the project process. Planning, procurement and communication are three vital examples. These processes run continuously over time across all steps, but also include separate tasks for each step. Another category of management processes deals with the sustainability of the projects. To secure a wide perspective all three dimensions of the triple bottom line is explicitly addressed. To secure a long time perspective the 8th step focus termination of the project result (the infrastructure, building etc.). There shall be no excuse for not making sustainability considerations in construction projects.

The planning tasks are linked to making plans for the execution of the tasks, adding details to the plan through each step. Examples of important planning tasks include planning the handover strategies from the contractor to the owner and for the user. The procurement tasks will vary along the steps and have to be adjusted to the execution strategies of the project. A typical question is at what step you procure consultants and contractors: This can vary from step three to step five depending on how early involvement is optimal for the development of the project. Some execution strategies require involvement of all parties on an early stage; other strategies develop a detailed design before procuring the construction companies and suppliers. The framework holds that it is important not only to plan but also to control that the plans are followed. The framework is a powerful tool for project management.

Communication in a project is important and challenging; given that the construction industry tends to be fragmented with many different parties specialized in different areas. The framework explicitly addresses the digitalization of the project process, especially the use of integrated communication tools, such as building information models (BIM) as a communication platform. Developing digital project execution strategies early in the project is important to make sure the parties are all “on the same page”.

Sustainability is necessary for future projects – both in execution and with regards to the result. The AEC industry will not be allowed to continue using energy and producing waste like they used to. The framework differentiates the sustainability in three dimensions: economic, environmental and social. The economic sustainability includes securing the right choices in investment and for the full lifecycle cost of the project result. The environmental sustainability is regarding the use of materials, emission, heating, cooling etc. – both the climate effect and the energy use. The social sustainability is how the project affects the life of the team members, users of the result and people around the project, including ethical dimensions and fairness in distribution of effects.

4. Discussion

Planning and control of project activities is still a challenge in the AEC-industry. As seen in the introduction, this is a serious threat to tactical or project management success (doing it right). However, as argued in the introduction, there is a bigger issue – the strategic or project success (doing the right thing). More systematic planning and execution in every step of the development, from problem to solution to effect to termination, can improve both. Doing this one by one (each company by themselves) will necessarily create non-conformance and miscommunication. It will also require a lot of unnecessary effort in repeatedly inventing the wheel. It will waste time and resources and at the same time create limited results.

Trying to change this situation require major steps. Designing a new framework like described above is only a first step. Whether it is good or bad, suggesting it as a general standard will inevitably spark resistance in a traditional industry. To have effect many actors will have to adapt their systems and management practice to the new framework.

First of all, the time is right. There is a growing attention to the importance of good governance in solving major challenges in the industry, companies and projects. All leading actors in the industry accept sustainability as the standard – at least on paper and in speeches. There is a highly developed understanding that projects are about value creation and that everything that represents wasting time and money or “gold plating” is improper. This is helped by the current slow-down in the economy due to reduced activity in the oil and gas sector. Finally there is a wide range of different new standards being developed for PDMs and information exchange that paves the way for integrated delivery strategies. These strategies obviously need some sort of common framework.

The new framework itself is made as flexible and future oriented as possible. The generic framework is valid for different projects delivery methods (PDM) including future innovations. The framework is scalable in the sense that roles and activities can be adapted to small and big, simple and complex projects. Finally the framework is not a strait jacket that requires everyone to become the same or use the same words. On the contrary, it is designed acknowledging the need for companies to be able to develop their profile and competitive edge. The framework is supposed to be a common reference and “language” that all parties refer to in order to clarify concepts and better coordination. In order to achieve this, the framework should highlight the

most important issues in each step, and help to create a platform for timing the right decisions and securing relevant basis for these decisions.

The framework is constructed from well-known principles and international best practice. It has a solid basis. For most actors the changes needed to implement it will be small to moderate. A comparison between the project-models of major companies in the industry reveals that most of the major decision making points are identified in most models(Ole Jonny Klakegg et al., 2015). The level of detail in models varies and the choice of words and graphic presentation is different, but the fundamental structures are remarkably compatible.

Leading organizations in the Norwegian AEC-industry are behind the new framework, including major public clients. The response from the industry has been positive. Other major actors are ready to start using it, and this is the main force that will be able to influence the industry. By January 2016 it is already clear that three different committees in Standards Norway are using Next step as a part of their working basis in developing new standards for the AEC industry. When major clients require it used as a reference, and major executing parties also say they will comply, this has the potential to grow into a strong wave with the force to change a conservative industry. In the long run, the observed improvements will be the best selling points for the model. This of course still remains to be seen.

5. Conclusions

This paper presents a new Norwegian framework for the AEC industry. The framework is not a detailed recipe for project execution, but tries to define the key tasks and steps in a project from the definition to the termination of a building. To sum up we conclude the proposed research questions:

How can the framework help to achieve the right result for owners and users? By defining the decisive moments and the necessary steps on the way from problem to solution until the investment is terminated. By forcing the parties to consider the long-term issues, and assess holistically the relevance and sustainability of alternative concepts, the right choice comes forward and becomes the natural decision.

How can the framework help to secure that the right perspectives are considered? A key feature of this framework is the focus on the key stakeholders and their perspectives. To help the owner make good business decisions, the actors need to think like an owner when they perform their tasks in planning and execution. To create the right solution for the users, the actors need to think like a user and consider how the project can best support the user's business and facility management. To perform an efficient execution process the actors need to think about project delivery models early and make conscious choices about constructability. To secure that society's perspective is considered, the model puts emphasis on requirements, approvals and other aspects of context that the project has to work with.

How can the framework deal with different procurement forms? One challenge in delivering a project is at what stage you procure consultants and contractors. The framework helps to deal with this challenge by explicitly state on what stages different procurement strategies has to be considered to be valid alternatives. Collective and integrated procurement forms needs to be considered early – from step three to five – depending on how early involvement of parties is optimal for the development of the project. Segregated procurement forms could be fitted in step five. A typical problem today is that some strategies are constantly considered too late in the process and thus remain unexploited. Other actors choose strategy from tradition and lack of awareness more than a conscious choice. If they are confronted with the new framework there will be no room for such neglect anymore.

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Towards Quantification of the Economic Efficiency Advantage of Alliancing in Complex Infrastructure Projects

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Abstract

Project Alliance is a construction project delivery system where the owner and service providers form a joint organisation as well as share project risks. Challenging projects are expected to benefit from alliancing although existing proof is somewhat ambiguous. Thus, the study aimed to improve the understanding of whether project alliancing can be used to implement a challenging construction project economically compared to traditional delivery systems such as Design-Bid-Build, Design-Build and Construction Management at Fee.

The subjects of study were ideas born in the development phase of an actual alliance project and their refinement into innovations that bring cost savings and added value as data on related savings and other impacts were available. The comparison of the alliance contract and traditional delivery systems was based on expert assessments. Experts assessed first and foremost the capacity of traditional delivery systems to promote the creation, demonstration and introduction of new ideas, and the beneficial effects they can have at best. That allowed comparing the relative performance of different delivery systems.

The alliance model seems to have several features that stimulate birth of ideas and innovations, such as multidisciplinary expertise, contract and risk sharing procedures that motivate innovation, as well as a fairly long development phase that allows developing innovations and putting them into practice. On the other hand, traditional delivery systems feature many identifiable factors that cause fewer ideas to be born, demonstrated and introduced than the alliance model. Moreover, introduction may be delayed due to factors like contract negotiations which often reduce the benefits derived from innovations in the case of traditional systems. Alternative delivery systems are not expected to result in similar cost savings as alliancing, but in a price level clearly above that attainable by alliancing without any actual value creation benefit.

Keywords: Alliancing, project delivery systems, comparison, economic efficiency, transport infrastructure

1. Introduction

Demanding road and rail projects, their conditions and input data are fraught with great uncertainty. The numerous designers and implementers, many interest groups and linkages to existing infrastructure increase the complexity of the projects. Traditional project delivery methods based on a certain distribution of responsibilities have been found to be poorly suited for projects of this type. The uncertainty is reflected in large risk contingencies while the primary interest of the parties is to safeguard their own interests.

In Project Alliance (alliance contracting) designers, contractors and the project owner form a joint project organisation and work in open collaboration. All benefit from the success of the project entity and there is neither need nor opportunity for company-specific sub-optimisation. Moreover, alliance contracting makes good use of the early cooperation of the actors. Thereby it is believed to enable better innovative development and more effective project implementation than traditional delivery methods. Yet, systematic comparison data are scarce.

The aim of this study was to increase understanding of the ability to implement construction projects at a lower cost than normally through alliancing. Its economic efficiency is compared to results achievable by alternative delivery methods. The work concretises in the development possibilities of a project solution, and other possible factors causing differences in relative economic efficiency are not analysed meaning that e.g. possible differences in transaction costs and pricing are excluded. The study was also limited to the alliance's development phase, i.e. the planning period between the selection of the alliance consortium and agreement on the project's commercial terms when conditions for launching construction exist.

2. Compared delivery methods

The most common delivery methods used to implement infrastructure projects in Finland, limited to the investment phase, are Design-Bid-Build, Design-Build, and Construction Management at Fee. Thus, they are also the logical benchmarks of comparison for the economic efficiency of Project Alliance. The project is generally organised as follows when using them:

- *Design-Build* (DB), where a contractor under contract to the owner is responsible for the project's design and construction as an entity.
- *Design-Bid-Build* (DBB), where the owner assumes responsibility for design and the project is constructed on the basis of a separate contract.
- *Construction Management* (CM), where a separate organisation manages the overall project and implementation is realised through numerous partial contracts.

In alliancing, the traditional roles are abandoned on the contract level, and in its purest form all the key parties – owner(s), designer(s) and contractor(s) – form an alliance through which they assume joint responsibility for the project's design and implementation. The alliance organisation comprises people from all partner organisations, including the owner's. Decisions on project implementation are made jointly and unanimously by the parties. Alliance partners

also share the risk of project implementation. Thus, the reward of service providers is based on the success of overall project implementation, not on their performance of their individual tasks (Lahdenperä, 2009, DTF, 2006, DIT, 2011).

In alliancing, the key actors are brought together and the alliance is typically formed at an early phase with respect to design. Service providers are often selected as a consortium with an emphasis on competence. Then, actual collaboration begins with a development phase during which the project solution is developed and the project's target cost is set and other central goals are concretised. The implementation phase starts only after agreement is reached between the parties on the above. The case study project also followed the presented procedures (Alliance Executive Team, 2014) although the alliance contract can be applied in many different ways.

3. Present knowledge

The alliance contract has been the subject of active research since the first projects that used it (e.g. Ross, 2003; Walker & Hampson, 2003; Hauck et al., 2004). These and many later project-specific case studies (e.g. Jefferies et al., 2014; Walker & Jacobsson, 2014; Morwood et al., 2008) focus on principles of operation while also trying to assess the results achievable by alliancing. Belief in the excellence of the model is strong in general. However, also as concerns assessment of performance, the study is mainly qualitative with the exception of occasional cost savings estimates. Walker et al. (2015) and Sweeney (2009) are among the rare studies based on a broad stock of projects and exact data. The results speak for the excellence of alliancing as earlier studies. DTF (2009) also examines project outcome data but mars the otherwise positive picture by questioning alliancing based on non-price selection. The significance of project-specific challenges and conditions, however, remains unclear (cf. Rooney, 2009).

Despite their merits, quantitative studies (Sweeney, 2009; DTF, 2009; Walker et al., 2015) are also deficient due to the lack of an unambiguous benchmark. For instance, actual cost is compared to the previously agreed contract price, the target cost or the owner's budget estimate since genuine comparison of projects in a world of individual projects is nearly impossible. This raises many questions because the contract price level is determined differently in different delivery methods, and the owner's budget is a highly unreliable and most often too optimistic standard of comparison (e.g. Flyvbjerg et al., 2002; Cantarelli et al., 2012; Andersen et al., 2016). Thus, it is clear that assessment of alliancing requires further study, especially in terms of quantification of the economic efficiency of alliancing in relation to other delivery methods.

4. Study method

Comparison of the economic efficiency of different delivery methods is not very simple. Statistical comparison of large amounts of data produces exact results, but in the case of individual projects it is problematic since different projects use different delivery methods, and all influencing factors cannot be taken into consideration explicitly. On the other hand, that would not even have been possible in Finland in the case of alliancing since there is only little

experience of its use. Therefore, it is best to use the case study method with alliancing whereby in-depth focus on the performance of the model and the ensuing understanding achieved facilitate implementation of the comparison (cf. Yin, 2014; Eisenhardt, 1989).

As to alternative delivery methods, the study uses expert opinions which allows closing the gap between evaluation of the different operational preconditions and impacts of alliancing and other delivery methods. The case study generates data on the new procedure – alliancing – and it is the task of experts to use that data to evaluate the capacity of so-called traditional delivery methods to meet the challenge of alliancing. There is a lot of experience from so-called alternative delivery methods. Consequently, if the experts first familiarise themselves with the results of the case study on alliancing, their evaluations become more reliable.

The starting point of the case study were the innovations of an alliance project, of which the five most significant were selected for examination. First the birth mechanisms of innovations were investigated including influencing factors and boundary conditions. These were then presented to infrastructure experts participating in a focus group workshop: the 17 persons represented owners (7), designers (4), contractors (4) and construction management consultants (2). Then the experts of the workshop divided into five groups. An attempt was made to include members of all actor types in each group. Each group also included a case study project participant to specify knowledge about innovations and their backgrounds.

Each team concentrated on assessing one of the five major innovations. Guided by a list of questions, they were to consider the possibility of the innovation becoming reality if one of the alternative delivery methods had been used to implement the project. Each team also reported the results of its work to the entire group of participants and time was reserved for discussion afterwards. The reporting at this phase formed the framework for the qualitative analysis of the study (Ch. 6.1). After discussion, workshop participants were asked to complete a personal questionnaire, the results of which were used as input data for the quantitative part of the study (Ch. 6.2). The focus group was used to get expert views as well as to give the participants an opportunity to exchange information and views with each other before presenting their evaluations in order to ensure transfer of sufficient background information and comprehensive understanding as a basis of assessments concerning a complex issue (cf. Morgan, 1996; Cyr, 2015). Personal questionnaires were, again, used to avoid the dynamics of randomness related to team work and the related possible bias in results. They also enable more detailed analysis.

In the questionnaire respondents were asked to estimate the *probability* of a certain innovation of the case study project being adopted by alternative delivery methods and what the *benefit/cost saving* compared to alliancing would have been if adopted. The response alternatives (see Fig. 1 below) cover all possible paths forward meaning that the sum of their probabilities would always be 100 per cent by delivery method. The savings in euros achieved by alliancing were made known at the workshop in relation to all innovations dealt with, but in the questionnaire it was 100 per cent for the sake of simplicity. The net gain to the owner was the primary target of estimation when all possible other additional costs or, for instance, the

share of the implementer are considered besides savings. In order that the formulation of the question would not lead people to regard the gain from alliancing as the absolute maximum, it was stressed to respondents that the gain could well exceed 100 per cent. Responses to all questions were otherwise complete except that four respondents did not evaluate the expected innovation benefit of Construction Management at Fee. The procedures are explained as to calculation of comparative prices in the results section (Ch.6.2). They are based on the results of the questionnaire as well as the costs of the case project (Ch. 5).

5. The case project

The case project of the study was the Tampere Road Tunnel to be implemented by an alliance. As the project proceeds, Highway 12 (which presently runs along the shore of Lake Näsijärvi above ground) will be put in a tunnel in the centre of Tampere [Alliance Executive Team, 2013]. The tunnel section is 2.3 km long. Moreover, the road and street arrangements, the relocation of utilities/services networks, and the interchanges at both ends of the tunnel are part of the project. Both directions of travel have their separate tunnels with three lanes including a safety lane. Several passageways with fire and smoke compartmentation will be built between the tunnels, and traffic control and guidance systems will play a significant role in the project. All in all, we are speaking of a demanding project fraught with much uncertainty.

Alliance procurement started in December 2011, and the parties signed the development agreement in July 2012. Development-phase planning led to the alliance implementation contract which was signed in October 2013. The road section is expected to be ready for use in late spring 2017 and the finishing work will end about a year later. This is the third alliance project launched in Finland (cf. Amaral Fernandes et al., 2014); the owner had experience from one rail project launched a year earlier (Lielähti–Kokemäki allianssihanke, 2015).

A total of 76 recorded development ideas were born during the alliance's development phase (Alliance Executive Team, 2013), about half of which (39) were accepted for use while a quarter (20) were relegated for assessment at the alliance project implementation phase. The cost-benefit impacts of 28 adopted ideas were reported in the project's first value-for-money report (Alliance Executive Team, 2014) while the other innovations were implemented mainly due to their positive value effects. The total saving was reported to be about M€17.0. The share of the five most significant innovations was M€9.2, and the combined benefit of the achieved shorter schedule M€2.5. According to the owners, the building plans including the innovations are in all respects such that the quality level of the road plan will be met: quality or life-cycle requirements have not been sacrificed to achieve savings.

The target cost based on the alliance implementation agreement is M€180.3 (at May 2013 cost level) which puts the logical estimate of the so-called baseline price at M€197.3 (i.e. 180.3 + 17.0). On the other hand, the road-plan phase cost estimate (ELY, 2011; March 2011 price level), corrected to the index value of the target cost (OSF, 2013), is M€203.6 when the cost items (ab. M€4) missing from the (original) estimate but included in the project are considered.

6. The results

6.1 Factors affecting economic efficiency

With regard to alliancing, experts emphasised its great ability to generate innovations which was the key to high economic efficiency. The joint interest of alliance members is to implement the project in an overall efficient fashion which eliminates obstacles to the expression of ideas as the participants have no need to sub-optimize their performance. Should the implementation of an idea require re-design, the designer is compensated for it. Since the owner is also part of the alliance, alteration of earlier designs is easier when it is also in the interest of the owner. Confrontation does not occur and distrust and risk avoidance do not guide decision making.

Ideas are born mainly during development-phase planning when conservative application of competition regulations no longer prevents new alternatives from emerging. Multidisciplinary expertise becomes integrated in planning and creates good conditions for development. Since ample time can be reserved for the development-phase, ideation, development of ideas, dealing with permits and re-design are possible. All in all, the assessments of the performance of alliancing correspond to those of a parallel survey related to the project, but implemented from a different perspective and using different experts (Lahdenperä, 2015).

Project development is more difficult when using the alternative delivery methods instead of alliancing. In delivery methods based on apportioned responsibility and risks, the actors lack the motive and overall competence required to improve economic efficiency. Even the business logic does not support the presentation of ideas. The distribution of the risks, responsibilities and benefits related to new solutions is unclear without negotiations. Thus, even good ideas are not always brought forward since it does not benefit the inventor of the idea – even the opposite may happen. If a suggestion for improvement is made, however, the other parties may try to prevent its introduction. The parties optimize first and foremost their own share and the best of the project is not the driver of development.

The possibilities and problems of different delivery methods are naturally slightly different. As it is not possible here to delve into these details, reported in Koski and Lahdenperä (2015), a joint summary is presented only. Accordingly, obstacles to birth and presenting of ideas in traditional delivery methods, in accordance with the sequential phases used in the survey (i.e. A–C in Figs. 1–3), are the following:

A. Before contractor selection during design

- The designer does not present an improvement idea as it may involve extra work or re-design. The party fears that the owner considers the idea part of the already purchased expert service package. Thus, the idea should be made part of the design solution without extra compensation which is not reasonable from the designer's viewpoint. Alternatively, the presented idea does not move forward should the owner have to

commission re-design by separate parallel orders. Another obstacle can be if the designer has to obtain permits related to the idea.

- Design commissions are generally lump-sum and put out to competitive tender. Therefore, there is no time for ideation and alternatives are rarely analysed. The main aim of design is to produce the necessary design documents. Constructability and cost awareness is also poor, and lack of overall competence minimises improvement ideas especially in DBB where design and construction are differentiated. To be sure, in DB the competence of designers and contractors is utilised synergistically already at the tender phase, but the preconditions for promoting ideas remain inadequate especially due to the challenges posed by public procurement.

B. At competition phase of contractor selection

- Requests for proposal plans can be too detailed and the owner may limit the contractors' alternative proposals. The primary reason is that degrees of freedom and alternatives leave too much room for interpretation which may lead to Market Court appeals and subsequent project delays and extra costs in case of public procurements. Should the owner nevertheless accept an idea suggested by tenderers, the needed requirement changes or even the idea itself, should be made known to all to ensure fair competition. That would eliminate the competitive advantage offered by the idea and only make competition more complicated which prevents effectively the publication of improvement ideas.
- Often the owner also has quite limited resources for processing proposed changes. There is no time to determine the compliance of alternatives with requirements and regulations. That is necessary especially since there can be fear that the presenter of an idea tries to reap all the benefits from it, and the idea does not necessarily benefit the owner, or may even be harmful. The attitude is the result of the experiences from confrontation and sub-optimisation in traditional projects. A short competition phase is also a hindrance since new solutions require redesign or decisions by authorities and affect the tasks of other parties which can be critical especially when using parallel agreements.

C. After contractor selection during implementation

- A proposal for improvement made during the construction phase requires agreeing separately about who pays for design, who assumes responsibility for the design solution's functionality, and how the benefits are shared since lump-sum contracts do not deal with these issues. On the other hand, the negotiations are expected to be so cumbersome and long that people do not wish to go to that trouble, especially if the preconditions for profitable introduction of the ideas have already weakened crucially at the implementation phase. The project has advanced so far that there is no time to introduce the idea, or it will no longer bring sufficient benefits.

- The activity takes place in a climate of general lack of confidence. The parties to the project suspect that anyone who presents any idea only seeks to benefit from it himself, and therefore do not support or approve its introduction. An individual party can also prevent the introduction of an idea in the parallel agreement model if only seeking its own advantage. Agreeing about changes is impossible in the shared responsibilities model. The parties want to save their labour and avoid taking risks by sticking to previously used solutions and operational models and existing building and implementation plans.

6.2 Comparison of economic efficiency

The respondents to an expert survey estimated first the probabilities of the occurrence of the ideas behind the alliance's innovations in alternate delivery methods (Fig. 1). The responses indicated that the failure of innovations to materialise is most probable in DBB (alternatives D–E), but there is not much difference between DB and CM-at-Fee. Often the idea would have been assessed (D) by the actors also in the case of the alternative delivery methods, but it would not have put into practice. Yet, it is clearly more probable that the idea would not even have been presented to other project partners (E) as was stressed especially by contractors.

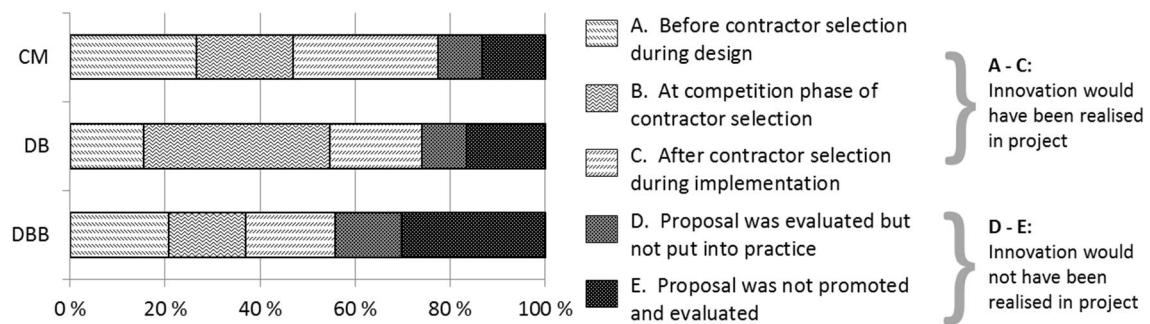


Figure 1: Estimated probabilities of occurrence alternatives (average values).

Yet, the introduction of the idea is not the only crucial factor since its net benefit may differ between delivery methods. Figure 2 shows the probabilities of the described phases combined with estimated net benefits (response averages). Accordingly, the strength of DB is the competitive tendering phase (B) where high probability of occurrence and owner benefit are combined. There DB beats clearly the other methods, but in design prior to competition (A), it fares worse than the alternatives because it involves mainly definition of requirements. After selection of contractor(s) (C), innovation expectancy is generally lower than at earlier phases. This is shown best by Figure 3 where the impact of the estimated probability and net benefit are combined (by multiplication), and the estimated savings potential is described as accumulating in phases. At the same time, the final situation of Figure 3 (C) shows the relative total development potential of different delivery methods. According to the results, DB would be the best alternative for an alliance although CM-at-Fee is nearly as good. Yet, it is estimated that these methods only provide about half of the development benefits of an alliance while DBB's share was only a good third.

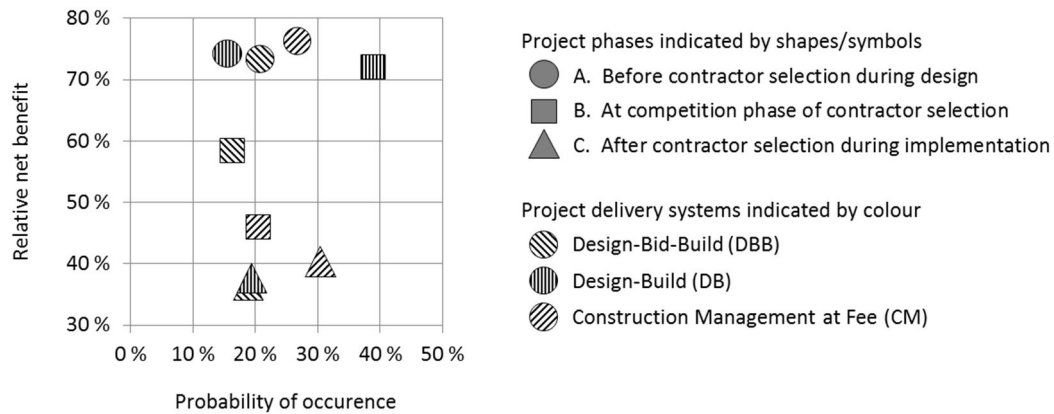


Figure 2: Probability and relative net benefit of occurrence alternatives.

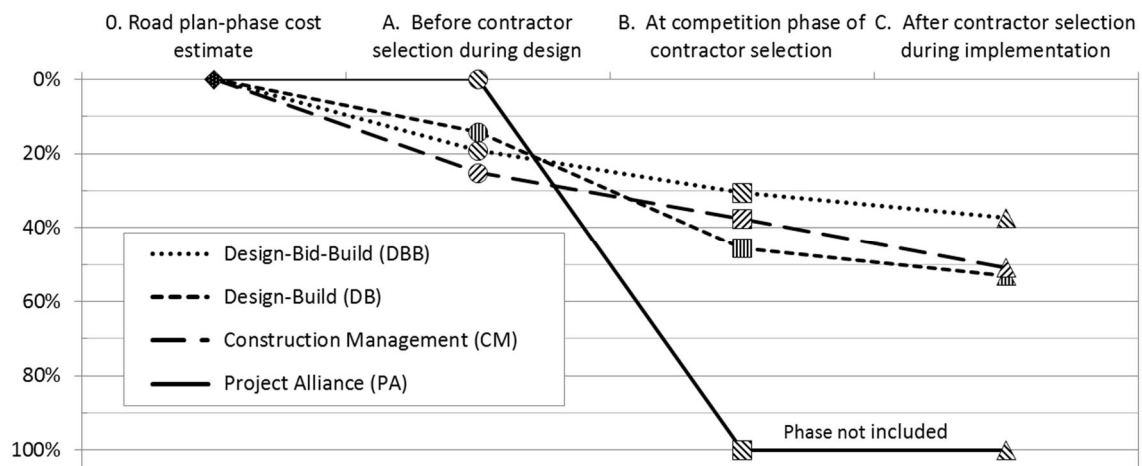


Figure 3: Estimated relative reduction of cost level by phases.

Figure 4, again, presents the comparison costs of delivery methods when this relative total development potential is applied to the cost data of the case study (see Chs. 3 and 5). Calculations were made for the part of owners and other respondents separately although Figure 3 shows their joint estimates only. The comparison cost of a delivery method is the so-called baseline price minus related cost improvement. Two alternative baseline prices are used in calculations. In *Calculation I* (solid colouring) the baseline price is the target cost of the alliance implementation agreement plus the cost savings from innovations (taking into account the 100% saving gives the alliance a comparison price in line with its actual target cost, i.e. $180.3 + 17.0 - 100\% \times 17.0$, etc.). The development potentials of other delivery methods are smaller and the comparison costs correspondingly higher. In *Calculation II* (non-solid colouring) the baseline price is the cost level of the owner's estimate composed before the launching of the project, but index-adjusted for the time the target cost was set (including missing items; 100% development potential equals the difference between the owner's cost estimate and agreed target cost, i.e. $203.6 - 180.3$). Baseline cost II is higher than cost I which means that the comparison costs of alternative delivery methods are also higher, respectively.

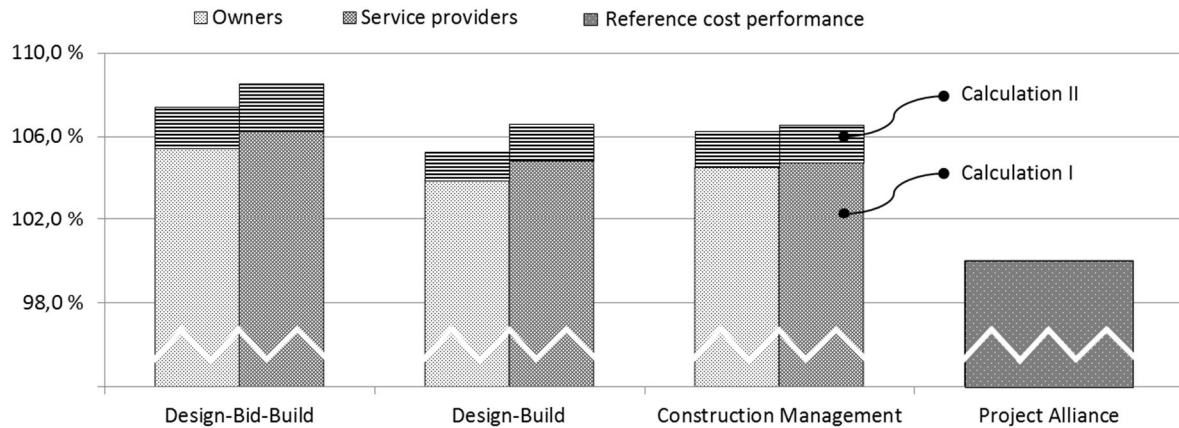


Figure 4: Relative comparison prices of different delivery methods.

Owners assessed the development potential in alternative delivery methods slightly better than other respondents. Yet, the views were quite similar since the differences in overall costs between owners and other respondents were at the most one percentage unit while the difference is mostly smaller than the difference between delivery methods. The difference with the alliance is in any case fully clear in every respect. Thus, it can be said that the use of alternative delivery methods is not expected to provide cost efficiency corresponding to that of an alliance contract, but that they would lead to a price level typically 4–6 per cent higher than that achievable by alliancing (I). An alternative survey (II) indicated even bigger differences (5–8%).

7. Discussion

The study aimed to increase understanding of the value creation capacity of project alliance compared to so-called traditional delivery methods. As to the alliance, the study was, however, limited to development phase innovations while the implementation phase was left out of the comparison. Alliancing can, yet, be assumed to be at least as capable of effective implementation as the other methods. Functioning cooperation boosts effectiveness, and the alliance already had a stock of development ideas to be evaluated only at the development phase while the owner also had the possibility of benefiting from implementation phase improvements due to the target cost procedure. On account of the incompleteness of the case study project, the implementation phase of the alliance was, however, not examined in the study.

As a result of the multidimensional nature of value creation, the cost side received emphasis in this study aiming at quantitative assessment. Yet, the owner did consider that value creation was not sacrificed to reduce costs. Instead, part of the innovations were introduced precisely because they generated added value. Thus, all improvements were not aimed at cutting costs. Inclusion of many qualitative key result areas as payment bases should also enhance value creation. Traditional delivery methods have not incorporated corresponding systems. Moreover, the fast implementation of an alliance project can have positive societal impacts that were not dealt with in the comparison. Thus, alliancing would appear to be even more advantageous than indicated by the calculations.

Although the result suggests that alliancing is superior, its generalisability can be questioned. After all, we are only dealing with a single project. Moreover, the development was also strongly driven by the uncertainty of project implementation as a low target cost was an apparent precondition for a favourable political decision to implement the project since the entire project was questioned anew on the political level while the development phase was underway (cf. Vainio, 2015). On the other hand, the uncertainty has also reduced potential subcontractors' willingness to submit serious tenders which has weakened the ability of the alliance to improve economic efficiency. Assessment of the influence of these factors is naturally impossible.

Determination of the innovation potential and cost savings of alternative delivery methods was based on expert opinions. They were experienced infrastructure construction professionals who were familiarised with the case study project and the innovations to be evaluated in advance. Part of the experts knew the project very well beforehand. The reliability of the responses is also increased by the fact that the experts did not assess alliancing, but specifically its alternative delivery methods, of which they had years of practical experience. Their views on the functioning of alliancing were also quite similar, and no special bias was identified in the responses. On the part of the alliance, again, the data are based on actual performance.

A key point is also that the study not only sought out differences between the economic efficiency of delivery methods, but also focused strongly on determining what is required to come up with and implement improvement ideas. As a result, several factors were found in the processes of traditional delivery methods that hindered introduction of proposed improvements. The emphasis on these hindrances is also fully in line with the estimates of economic efficiency which supports the perceived correctness of the quantitative overall assessment. Moreover, the overall view seems to be in line with literature (cf. Ch. 3) while also providing wider understanding.

8. Conclusions

The study assessed the economic efficiency of different delivery methods – Project Alliance, Design-Bid-Build, Design-Build and Construction Management at Fee – in transport infrastructure construction. The result was that an alliance creates the preconditions for achieving the highest economic efficiency particularly in demanding projects. The indicative comparison suggested at least 5 per cent higher costs for alternative delivery methods than alliancing without any added value. It is obvious, of course, that the relative performance of alternative delivery methods improves in the case of simpler projects, and that mere formal use of alliance contracting does not always guarantee a good result either. Yet, alliancing creates excellent conditions for benefiting from the integration of different competencies. Development in traditional delivery methods, on the other hand, is hindered by inadequate incentives, stringent boundary conditions for designs, tight schedules, rigid attitudes and many challenges related to the functioning of competition.

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The Development of UK PFI from an Organisational Economics Perspective

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Abstract

The increased use of integrated forms of procurement, specifically PFI, for provision of new UK public service assets is a defining feature of tax funded fixed capital investment since 1992. The value for money proposition of PFI relies on the notion that through integrating construction and operations via a single contract, whole life cost efficiency gains are made possible, indeed incentivised. Discussion focuses on improvements in our understanding of PFI, whole life cost and value for money issues over recent years, through reference to key literature including academic papers, empirical analyses, audit reports and industry publications. A range of organisational economic concepts is applied in reflection of recent policy developments, with an underlying theme of potential for *investment in operations*. Review of the healthcare sector's outsourcing practises, as well as the scope and scale of PFI healthcare investment in recent years allows for in depth discussion on issues of asset ownership and control, as fundamental concepts in procurement theory. To conclude, findings of recent studies are considered in light of reforms to the standard PFI model, including the insistence that future PF2 contracts should exclude soft FM services from their scope, as well as increase equity investment in the SPV. The need for greater transparency on the cost and performance of public service assets is posited to support better comparison of the efficacy of alternative procurements methods.

Keywords: PPP, public investment, value for money, whole-life costing, healthcare

1. Introduction – a brief PFI history

1992 saw a fundamental change in UK public procurement. This change would spread to become a feature of many developed nations publicly funded long-term investment. This change concerns the approval to use private financial capital in the delivery of public service assets (Norman Lamont, 1992). When in 1997, New Labour came to power, despite what might have been expected (though their abandonment of Clause 4 may have indicated their accommodation of the private finance initiative (PFI) in principle), they greatly expanded the policies' use with the vast bulk of all projects today reaching financial close under their reigns (2002-2008). In the year New Labour came to power, the first of the Bates Reviews of PFI reported advising government should establish an internal unit to co-ordinate its use (Bates, 1997). This led to the creation of the Treasury Taskforce within HM Treasury. The second Bates review (Bates, 1999) encouraged a more outward facing centralised unit (a proxy regulator) that could engage with the private sector more effectively. The incorporation of Partnerships UK (P UK) aimed to fulfil this ambition. This unit was also intended to better support local public clients of the growing number of PFI projects in the pipeline.

PFI was radically different forms of procurement than most public sector estate management functions had ever been required to use. One complexity of early PFI was a lack of standardized contracts. Local clients and private sector bidders duplicated much of the work to establish similar output based service contracts, these being a defining feature of PFI. This problem led to P UK's development of the Standardisation of Procurement Contracts (SOPC), with the fourth and final iteration in 2007. P UK also published guidance notes and provided assistance to local, decentralised procurement teams. One emerging issue was the lack of public procurement skill in terms of negotiating with an often more informed private sector team (Armstrong, 2005).

P UK facilitated government direct investment in PFI projects via equity stakes. Typically, this included a *pinpoint* equity stake of 1% (one tenth of issued equity given typical gearing at 90%). Shareholdings in special purpose vehicles (SPVs) often took the form of mezzanine type shareholder loans, a hybrid between debt and equity. Public sector investment was intended as a means of monitoring these projects allowing access to useful information as shareholders. New Labour's commitment to private involvement in public services was in no doubt and the establishment of large programmes of capital investment ensued post 2000. Building Schools for the Future (BSF) was the most significant. A part PFI, part conventional procurement programme set to renew all secondary comprehensive schools in England (budgeted at \$45bn).

In the aftermath of the GFC, the incoming coalition government stopped the pipeline of PFI projects in 2010 to conduct a review of the policy, as well as scrapping BSF. P UK was brought back into HM Treasury, transferred under the remit of the larger-scoped unit of Infrastructure UK (I UK), itself only recently merging with the Major Projects Authority to form the Infrastructure and Projects Authority going into 2016. The 2010 review finally led to the announcement of PF2 in late 2012 as an adapted form of PFI. Given on-going fiscal austerities, government also took the decision to sell off many of the equity stakes in operational projects. August 2011 saw the sale of BSF Investments to the equity fund International Public Partnerships Ltd. Ironically there is a return by government to consider investing directly into PF2 projects. PF2's application looks likely to pick up to re-establish the longer-term use of private capital in the procurement of public service assets.

PFI is presently being used to deliver over 720 contracts. These have already delivered projects with combined capital values around £54bn (un-indexed, HM T, 2013). The weighted average contract length by capital value is 27.8 years. The longer-term liabilities on the public purse in PV terms for this portfolio of projects is approximately £177bn (discounted at 2.5% RPIX). The following paper attempts to consider the impact of the above developments in the PFI policy from an organisational economics point of view (Coase, 1937). Considerations of the implications for risk transfer, financial and value for money aspects are critiqued.

2. Value for money and whole life cost

One underlying principle of PFI is its incentivisation of investment in operations (Hart and Moore, 1990). The SPV is the legal entity contractually liable to deliver PFI serviced assets. The use of a SPV is crucial in providing off-balance treatment and limited recourse to sponsor corporate assets should the contract go badly. The construction and operational costs are at the

discretion of a single agent, the SPV. They are thus, in theory, able to internalise the interdependencies between construction and operations via one contract (Hart et al., 1997; Iossa and Martimort, 2008). The incentivisation comes in the form of higher residual profits on the unitary charge payments (UCPs) revenue if they are able to reduce whole life cost (WLC). The UCP is the predetermined price for the contract paid in periodic instalments subject to adequate service provision. A key feature of the UCP in UK PFI is that a *significant* proportion of the payment must be *at risk* subject to provision of predefined serviced assets. This feature is important given that this allowed PFI's classification as *operational leases* (in the early days), rather than *financial leases*, the latter prohibited by public procurement rules (ONS, 2006).

The value for money achieved on the contract in excess of alternative procurement options will depend on the extent to which *investment in operations* is pursued, how well competitive procurement processes did in capturing these returns for clients, as well as the cost of capital used to deliver projects. There will be other project performance and time value of money considerations that will impact on the value for money (VfM) achieved through the project life cycle (Nasir, 2007). These will include the actual level of risk transfer achieved in light of some high profile failed contracts (NAO, 2009a, 2003a, Whitfield, 2012).

In light of incentives for investment in operations, its expected SPVs to pursue design and build solutions that seek to minimise WLC. This is especially the case for soft FM services¹, where the alternative is to pursue profitable contracts that may fail benchmarking and market testing (BM&MT, NAO, 2007a). Any gain in equity returns resulting from inflated operational contract prices from the client will only partly benefit the equity-owning sponsor, being shared with other equity owners in the SPV. An equity owning delivery contractor will wholly appropriate any gains in terms of higher revenues for operational contracts. This creates a moral hazard for the contractor to extract profits from operational contracts, rather than wait for future financial return on equity. The relevance of this point is limited by the extent to which equity-owning sponsors deliver these services. These are often sub-contracted to other providers, bringing with it further complexity in co-ordinating optimal service delivery (Rintala, 2005).

The higher cost of private capital used to deliver PFI projects is a major impediment for the net value of these returns from *investment in operations* (Public Accounts Committee, 2011), which could be achieved in publicly financed projects if adequate incentivisation of their delivery could be instilled (Mumford, 1998; Palmer, 2000). The nominal values of capital expenses over the project's life (put, arguably too simply, as a function of discounted factor price (r) and quantity (C_i)) will be subject to far less discounting, given the bulk are incurred at the front-end during construction. Their present value thus will be markedly greater, compared to future operational expenses (function of discounted factor price (w) and quantity (O_i)). This limits the extent to which present value reductions of WLC can be achieved via investment in operations. That is, the future potential savings from investment in operations translated into present value

¹ Soft FM services are services, usually labour intensive, which operate within the facility to support front line service delivery e.g. cleaning, catering, laundry, portering, security etc. They typically account for around 25% of the UCP in a full scope hospital PFI contract, but this will vary between projects. Consider one type of project that has proved popular in recent years, that of public street lighting, which will involve little or no soft FM services.

will have been subject to considerable discounting. This issue is compounded by the higher discount rate applied resulting from recourse to private capital. Here, w is used to convey the higher proportion of future operational expenses incurred on labour intensive (waged) factors of production in the form of cleaning, catering, security and other operational service staff. These estimated costs are at risk with potential increases in labour cost, the impending introduction of a UK living wage serves as a case in point. Operational costs are commonly indexed against RPIX variable or fixed 2.5% to account for these anticipated cost increases. Considering the long-term nature of these contracts, it is likely they may witness periods of above long-term average inflation cost increases, though not in recent years in the UK following the GFC.

The downward constraint to this minimisation of WLC is the provision required under the contract (P_i)², and the ability of capital and operational resources to deliver these (Murray, A. et al., 2013). Another constraint on PFI's ability to achieve returns from investment in operations, at least in a healthcare context, concerns the labour intensity of required services. While there may be instances of innovations in the way operational services are delivered under PFI, the prevalence is for services that closely resemble forms of delivery seen in non-integrated outsourcing contracts. This suggests a lack of major innovations in operational service delivery resulting from investment in operations. A further finding on the novelty of innovations in pursuit of lower WLCs concerns the risk aversion of debt providers to back new, untested, perceivably risky design solutions (Ive, 2004; National Audit Office, 2010; Rintala, 2005).

The constrained optimisation of whole life asset provision (Murray et al, 2013)

$$\text{Min WLC:} \quad r_i C_i + w_i O_i$$

$$\text{Subject to:} \quad f(C_i, O_i) = P_i$$

The ability of the operator to reduce WLC is arguably higher concerning elements of hard FM, given the functional on-going fixed cost of building performance is determined to a much greater extent during construction. This may be, in part, why these services are not subject to such strict tests of continuing competitive provision. Nevertheless, there will be knowledge held by any incumbent soft FM provider about the interaction of the specific asset's characteristics and optimal service delivery and management. An example of this may include the benefits of site planning design in reducing the need for security personnel.

3. Healthcare sector insight

For a sectorial insight into the diverse PFI programme, we focus on contracts procured by the Department for Health (DoH) in England. To place healthcare PFI into context, the analysis below (Fig. 1) presents two concepts plotted over time. These include the capital values of projects agreed at financial close (left hand axis) and the UCPs liable to pay for the contracts (right hand axis). It includes all UK PFI contracts and those pertaining to DoH and local

² In reality it may prove more profitable for an SPV to run riskier lower cost asset management regimes, that incur infrequent penalties and do not meet P_i completely (sweating the asset and holding back *some* life cycle funds).

authority Trusts³. As is evident, healthcare contracts represent between 20 - 30% of both capital values and of the on-going UCPs. The present view that seemingly all UCPs liable beyond approximately 2041 are liable against healthcare contracts suggest they represent the entirety of longer-term contracts procured most recently.

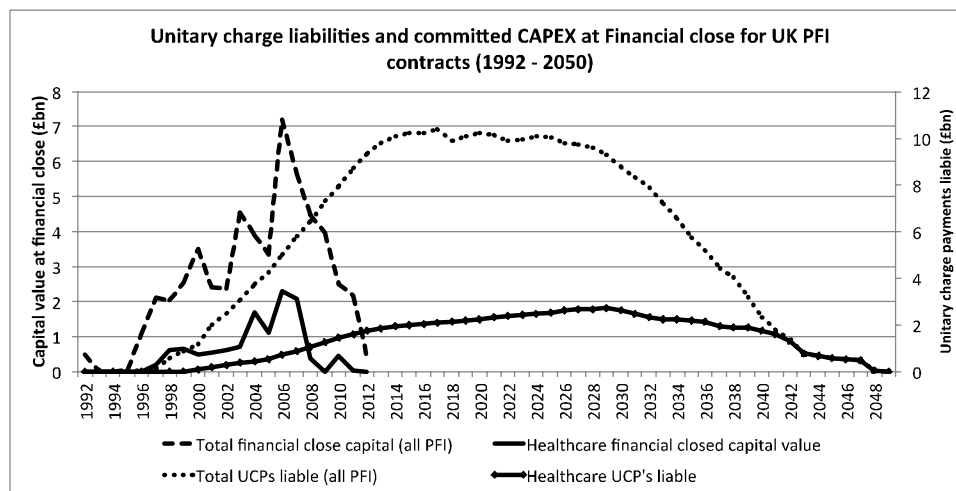


Figure 1. PFI programme and healthcare sector: capital values and unitary charge payments (1992 – 2050, nominal) Source: PFI signed projects list March 2013, HM Treasury

3.1 Contract scope

The scope of operational services in PFI contracts is important in defining the SPV's exposure to potential for investment in operations, as well as the inherent risks attached to levels of service. There is significant variance in the scope of PFI contracts, especially with regard to Soft FM services. A survey of hospital contracts undertaken by the NAO (2010) found that around one third of hospital contracts did not include core Soft FM services such as cleaning and catering. With reduced scope of Soft FM services, the contracts resemble more DBFM (maintenance) rather than DBFO (operation) status. The negative impact on value for money from the higher cost of capital of PFI projects arguably increases here by reducing scope of operations. The higher cost of capital incurred must be at least compensated for by future returns from investments in operations and reduced WC, if VfM is to be more favourable to conventional D&B and separate O contracts. In the DBFM case, the client will fund relatively expensive private finance for a facility in which a separately outsourced operational contractor (for catering say) has not been given the opportunity, or incentive, to *invest in operations*.

3.2 Non-PFI outsourcing

The contract period will of course be important, in part determining the incentive for investment in operations. If the contract is short (say 2 – 5 years) there will be limited scope for the contractor to realise returns from investments in the asset to be operated, hence one of the

³ A small numbers of additional healthcare projects will have been commissioned by devolved administrations in Wales, Scotland and Northern Ireland. These are not included here due to the devolved and variable coverage of data.

fundamental reasons why PFI contracts are of such considerable length. Considering some specific potential scenarios of asset ownership, the provision of catering serves as a case in which there is variability, in both form of provision and extent of asset ownership. These two aspects will have bearing upon one another in line with transaction cost economics (TCE) theory (Mumford, 1998; Williamson, 1981), in the sense that asset ownership frames the potential risk transfer as asset owners are the bearers of residual risks (beyond those specifiable within the contract). The provision of pre-prepared catering services lends itself to outsourcing as an activity considered less and less as a core (in-house) function of public clients. Insight on the extent of in-house catering within the NHS is covered in data from Patient Environment Action Teams, compiled previously by the then National Patient Safety Agency (disbanded in the 2010 *'bonfire of the QUANGOs'*). Using 2010 data, of the 1232 facilities surveyed approximately 57% of facilities recorded catering as provided in-house (Table 1 below). This vastly underestimates the extent of private catering in the NHS as many of the newest PFI facilities are very large General Acute hospitals with many times more beds than other smaller facilities. Using another dataset from 2008⁴, and just looking at NHS hospitals that are completely new as of 1995 (Table 2 below), we see that where as there are over twice as many new non-PFI hospitals, (95 to 37), the combined gross internal floor area of these PFI facilities is over 4 times that of non-PFI conventionally procured facilities.

Table 1. Reported status of catering service provision for English Hospitals, 2010. Source: NPSA PEAT data 2010

	Catering service				
Catering provision	Cook-Serve	Delivered Meals	On-Site Central Production	(blank)	Grand Total
Contracted ⁵	185	225	70		480
In-House	292	213	198	1	704
Mixed	18	22	7		47
(blank)				11	11
Grand Total	495	460	275	12	1242

Table 2. The type, size and application of PFI for new hospitals from 1995 to 2008. Source: NHS Information Centre, Estates Returns & Information Collection data, 2008

Type of hospital	PFI			Non-PFI		
	Number	Size		Number	Size	
		Average GIFA (m ²)	Std. dev		Average GIFA (m ²)	Std. dev
Community	7	4,696	2,168	16	3,728	2,008
General acute	8	51,777	39,410	5	6,509	4,481
Long stay	6	8,018	5519	20	3,982	3,919
Multi-service	3	26,081	38,402	4	3,003	269
Short term non-acute	11	6,600	5654	33	3,463	3,632

⁴ Hospital Estate Facility Statistics (HEFS), as collated via the Estate Return and Information Collection (ERIC) by the NHS Information Centre, Leeds. Available from hefs.hscic.gov.uk.

⁵ Includes PFI facilities where catering is provided within the scope of the contract, besides traditional outsourcing.

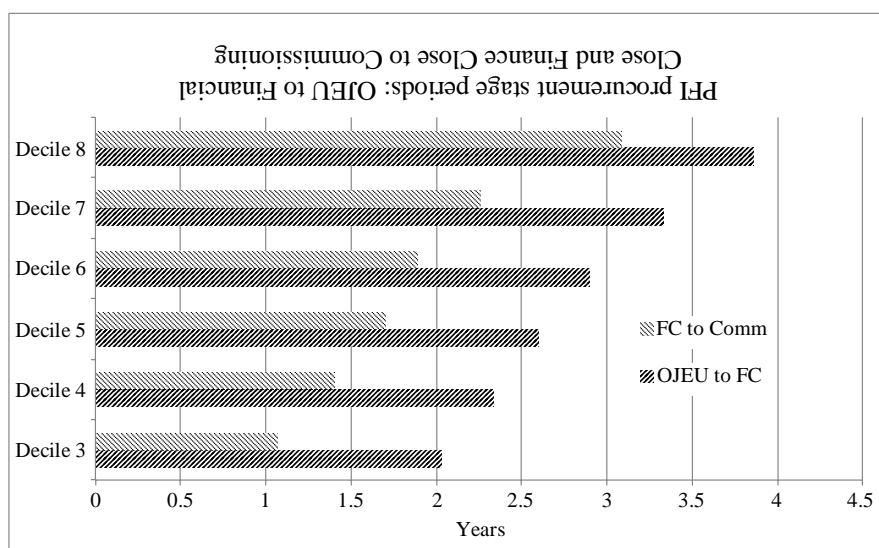
Specialist	2	8,733	7,869	17	5,440	7,166
TOTAL	37	17,933	27,459	95	4,112	4,323

Source: (Ive et al., 2010, Table 9)

One can also see from the Table 1 above, there is a higher prevalence of the catering services being provided as *delivered meals* when it is contracted (47%) compared to when it is in-house (30%). This might imply the quality of contracted catering services is inferior, though recent analysis suggests catering is an area where private provision is able to reduce costs considerably, without anticipated lower indicators of service quality (Mohammadi et al., 2013).

3.3 Procurement lead times

One on-going criticism of PFI concerns the long procurement periods witnessed securing preferred bidders, and further towards financial close of the contracts. The typical period between OJEU and financial close, where data is available is between 2.25 and 3.25 years (n=372, Fig. 2, HM Treasury, 2013). This is a considerable period of time incurring comparatively larger transaction costs than other public procurement options. One of the factors here concerns the due diligence processes required by lenders before approving debt finance pre financial close. Another major source of transaction costs come from the prescriptive output specifications of contracts. These costs, at least in the UK, will have benefitted from the introduction and development of SoPC. One constraint on reducing procurement costs for other types of projects, especially Schools and Hospitals, will have been the decentralized nature of these clients, where an NHS Trust will commonly only procure one PFI hospital. This limits the potential for learning and efficiency in future procurements using such new forms of procurement. Considering the period between financial close and commissioning is typically between 1.25 to 2.25 years (50% - 70% of the period from OJEU to FC, and of course including the construction period), it would seem the main impediment to more prompt delivery of these projects is the competitive processes required to secure a preferred bidder. The lack of clients having properly thought through project requirements before commencing procurement is cited as a major cause of delayed procurements (NAO, 2003b).



*Figure 2. Procurement lead times for PFI projects.
Source: PFI signed projects list March 2013, HM Treasury*

3.4 Competition during procurement

Depending on the specific project, typically 7-9 consortiums will respond to the invite to tender, reducing to 3-5 for the actual fully developed bid. Actual competition is limited somewhat given the considerable bid costs involved in PFI (Construction Industry Council, 2000, 1998), leading to the common strategy that any repeat bidder needs to win at least 1 in 4 projects to cover the considerable sunk cost, as a form of transaction cost, of failed bids. Social infrastructure projects (specifically schools and hospitals) have witnessed considerable price creep during preferred bidder stage (Armstrong, 2005). This is not surprising given the prevalence of decentralised public clients, a factor in determining the commercial expertise of clients, and thus their ability to negotiate with consortium bidders (Assenova et al., 2002). Relatively few Local Authorities will have experience with more than one PFI schools project. Contrast this with, for example, the Highways Agency (now Highways England, a more devolved agent of government) who would have been able to build experience and develop expertise in managing the procurement process of a clear project pipeline. That will have contributed to maintaining competitive tension through to financial close.

3.5 Balance sheet treatment

Another source for early scepticism about PFI concerned its treatment of the facility asset with regard to who is acknowledging the future financial liabilities. Under public procurement rules, liability for the asset should be determined by who owns the *operational risk* for the service, and as such can be considered an *operational lease*, rather than a *financial lease* (ONS, 2006). Pure finance leases are not available as a form of capital investment for UK public clients. The acceptance of PFI in the 1990s relied on the assurance there was significant operational risk transfer to justify operational lease status (HM Treasury, 1997). This operational risk comes in many forms, dependent on the terms of contracts. It was required to be *significant*, represented by a minimum 20% of the UCP that must have some deductible element based on contractual performance. This risk transfer allowed government to classify liabilities on such contracts not as determined financial risks but rather contingent on contractual performance, avoiding the requirement to place significant sums of *committed* liabilities on the government's balance sheet. In more recent years, criticism of this approach has led government to acknowledge the significant liabilities under PFI contracts (House of Commons Treasury Committee, 2011). Now, of the near whole portfolio of projects (n=696, HM Treasury, 2013) 95% are recorded as on *balance sheet* under International Financial reporting Standards (IFRS).

3.6 Life cycle allocations

Lifecycle allocations exist to provide for on-going capital replacement and maintenance. They are built into UCPs the SPV receives for the contract. The relative size of life cycle allocations will be of considerable importance to lower WLC. A more intensively used facility, say a waste to energy disposal plant (in more recent PFIs) undergoing significant wear and tear, might

reasonably require a higher proportion of WLC allocated to the life cycle fund. This will ensure the asset is maintained adequately and does not lead to increased risk of unavailability due to asset failure. Specifically when those life cycle expenditures are intended to be incurred will bear on the project's NPV as the anticipated return to the SPV investing in the asset. Further, when in reality those expenditures are incurred will bear on the on-going profitability of the SPV. If the SPV wants to take the risk of not expending life cycle funds, and accept the resulting chance of non-availability if the asset deteriorates and becomes unavailable (incurring financial deductions from the UCP), they may make additional returns. There is increasing pressure for public clients to share in these savings, as many early projects were considered to have over allocated resources to these life cycle funds (HM Treasury, 2012). Analyses comparing the annual comparative total cost of a wide range of FM expenditures seem to suggest there is little difference between PFI and non-PFI renewed schools (Edkins et al., 2011). Further, this study highlighted the vast differences in specifically hard FM expenditures between conventionally procured (and operated) schools and PFI schools. PFI schools were shown to incur typical life cycle expenditure profiles compared with flat line expenditures in non-PFI schools up to 9 years into operation. This raises concerns about the accumulation of backlog maintenance in non-PFI schools, an issue that PFI was designed to resolve.

3.7 Financing PF2

Following the latest review of PFI (2010-2012) and announcement of the PF2 reformed policy, there is now a requirement for larger allocations of shareholder finance within future projects (increased to 15% from 10%). There are many relevant implications of this. One might be to reduce the likelihood that sponsors will *walk-away* from contracts⁶ given the higher sums of their own money⁷ tied up in the SPV. Another implication is the strengthening of the incentive for investment in operations. Mandating that more SPV capital is equity increases the proportion on which the financial returns from investment in operations can be earned.

An undesirable implication of increasing proportions of equity will be a positive pressure on the weighted average cost of capital, a core concern for PFI projects generally. Theory (Grout, 1997) and practice (NAO, 2012; Vecchi et al., 2013) tells us that as PFI resorts to privately sourced finance (as opposed to the government raising public debt via gilts), it will incur a higher overall WACC. The highly geared nature of PFI Co's helps reduce this differential. The cost of debt and equity do relate to the proportions of each capital source applied, with higher gearing typically increasing the cost of debt as anticipated interest cover ratios tighten⁸. Further, it is reasonable to expect the returns of PFI equities to reduce in time given the established nature of this procurement route, as well as the increasingly active secondary market for PFI

⁶ The incidence of this is quite rare in UK PFI by any reasonable benchmarks. Considered from an option theory perspective, discounting the significant sunk costs incurred by the SPV in building the facility, the present value of expected future losses would assumingly have to be *significant* to absorb the reputational cost of walking away. Additionally, the expected loss would have to counter front loaded procurement costs and potential refinancing gains.

⁷ The vast majority of initial sponsor equity stakes in PFI Co's is typically held by the main build and/or operational contractor involved in delivering the project, though there is frequent subcontracting of services.

⁸ The extent of this is tempered by the low levels of client and market (demand) risk in availability assessed PFIs.

equities (De Biasio and Murray, 2015). This is an area the government could help assist, promoting transparency in this unlisted market (Whitfield, 2014), if they intend to continue the use of private capital in this way.

Following the GFC, the debt margins on project finance (inc. PFI) increased significantly, if only temporarily. With debt's larger proportion in the SPV's financial capital employed, this will have increased the WACC of SPVs established during those periods' higher debt costs, as well as some of those that had little choice but to refinance in that period. It seems reasonable to assume a minority of PFI Co's operating in 2016 will not have had, or chosen, to go through a refinancing following the GFC, given initial debt tenors are typically around 7 years. Quantitative easing no doubt helped SPVs access cheaper debt finance in the GFC aftermath. There will have been instances of SPVs who had neared construction completion during the GFC that will have required refinancing (e.g. a bridge loan). This will have led to at least a temporary and significant increase in the SPV's WACC.

For those sponsors that have sold off their equity stakes in recent years, they cease to be incentivised in minimising WLCs in future operations. Their remaining revenue stream from the project will be the payment for any on-going operational services, and not the residual financial returns above on-going cost of service provision. This issue could also cause conflict with the wider SPV shareholder, as the contractor is left chasing higher margins on delivery of operational services, rather than waiting for equity returns via the SPV. This may lead to SPVs seeking to replace incumbent providers, if they believe new providers can provide better value services. Whether they would offer equity to incentivise this new supplier is unlikely given the standard model for commercial service outsourcing. If not, the new supplier would do well to encourage spending of unspent life cycle funds to renew the asset they are responsible for future maintenance and/or operation of. Observing these actualities through PFI Co's life cycles is an imperative to develop evidence based, incentivised forms of private finance procurement.

3.8 Soft FM services in PF2

The decision of the coalition government to remove soft FM services in PF2 is questionable, given the emphasis placed on operational innovations PFI projects are supposed to deliver. This is in spite of evidence to suggest the performance of such services within operational PFI contracts are at least as good, often better, than those seen in conventionally procured facilities (Edkins et al., 2011; NAO, 2010). The reduction in the operational scope of future PF2 projects will mean that the potential returns from *investment in operations* are materially reduced, given the sizable proportion of the UCP payment that go to pay for soft FM services in present contracts (NAO, 2007b, pg 5). This will have a negative effect on the potential for, and pursuit of, whole life cost reducing innovations. Presumably, these services will now be kept in-house or separately outsourced, incurring separate and additional procurement transaction costs.

4. Conclusions

The development of PFI in the UK has been something of a learning curve, especially in aspects of their procurement. The typically much lower period from financial close to commissioning

suggests projects are reaching operations promptly, as acknowledged by the NAO in numerous studies (NAO, 2009b, 2003b). Key issues such as balance sheet treatment, as well as fairer distribution of considerable re-financing savings via gain share mechanisms serve as good examples of how this policy has adapted to be more acceptable for continued use.

The considerable proportion, and variety, of PFI projects in the Healthcare sector demonstrates its ability to deliver medium to large projects, some very complex, that may have not been deliverable under alternative procurement methods without cost overruns and a lack of integration between build and operations. One finding concerns the observation that the entirety of recent longer-term PFI contracts is solely within the healthcare sector (Fig. 1). Given the continued high profile nature of NHS reforms, especially the role of community based primary care, it is hard to conceive private finance will not have a role in many of these future projects.

Equity incentives within SPVs will impact on the pursuit of investment in operations. The requirement for increased equity investment in future PF2 projects should serve to increase these incentives and strengthen the case for using such forms of procurement. Procuring authorities might benefit in future by appreciating this, especially if they intend to consider the pursuit of WLC savings as a viable defence against the higher costs of capital involved.

Further research should focus on developing fair benchmarks of both build and operational cost and performance if government is to support the use of this controversial policy. One area for work concerns the collation and analysis of SPV accounting data that should give insights into the levels of risk transfer against the UCP liable on the government. Greater transparency is needed to compare the efficacy of alternative procurement routes, an area where government as the client could do more, as consistently reiterated by the NAO.

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Model of Public and Private Partnership Project Development: Lithuanian Case

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Abstract

Public-private partnership is one of the recent co-operation models, which has been widely and successfully applied in Western Europe and over the world. PPP programming is boosting in Lithuania recently: 22 new PPP projects are on the way at the different preparation and development stages. There is a need for the system of PPP project prioritization from the public sector perspective. In order to make PPP projects successful, the appropriate evaluation procedures have to be applied and adequate criteria used for the project assessment.

The objective of this research paper is to analyse the model of PPP project development in Lithuania and to suggest the new criteria for the certain stage of the PPP project assessment procedure which would help to justify distribution of limited public sector financial resources for the most sustainable projects within the area of any specific sector. In order to achieve the objective, the legal basis for the implementation of the partnership between the public and private sectors as well as the PPP project development methodology in Lithuania was analysed. The criteria set for PPP projects evaluation was developed by the authors and according to results of the expert evaluation survey their relative weights were established. The new approach was applied in the case study for PPP projects evaluation by using SAW, COPRAS and TOPSIS multi-criteria assessment methods. All three selected methods revealed the same effectiveness priority results of the considered PPP projects.

Keywords: Public and private partnership, project, multi-criteria evaluation

1. Introduction

Lithuania, like many other Eastern European countries is searching for the new ways to improve the existing public infrastructure and services as well as to create the new ones. Public-private partnership is one of the recent co-operation models, which has been widely and successfully applied in Western Europe and over the world to stimulate the economy and attract the investments into the local infrastructure development.

According to the European PPP Expertise centre (EPEC) Review of the European PPP Market in 2014, 82 contracts with the total budget of 18,7 billion EUR were signed in Europe and in Turkey in 2014 (EPEC, 2015). “In countries which are commonly considered to have a mature PPP environment and favourable conditions for project implementation (e.g. United Kingdom, France), investment projects implemented under the PPP model amount to 10%–15% of the annual state investment programme” (Aleška, 2013).

Statistical data provided by Ministry of Finance of the Republic of Lithuania proves that implementation of PPP model and its impact on the economic development of the country has been growing in Lithuania. 34 PPP contracts have been implemented in 2014, of which 32 were concessions contracts, and only 2 Private Finance Initiative (PFI) projects: Vilnius Balsiai school construction project was finished in 2011 and Palanga seaside resort bypass construction in 2015. In total 47 PPP contracts were concluded and 139 million EUR were invested until January 1, 2015. Most of the PPP contracts were implemented in utilisation, recycling and waste management sector (10 cases), in the area of culture, sports, leisure facilities, equipment and other infrastructure (9 agreements) and energy sector, including heat and electricity, petroleum and natural gas (8 contracts). According to PPP accounting data investment reached 15,84 million EUR in 2014, payments for private entities amounted to 10,72 million EUR, and public sector entities received income of 4,34 million EUR.

PPP programming is boosting in Lithuania recently and becomes a part of EU SF programming for 2014-2020, which also promotes the partnerships between the public sector and business. 22 new PPP projects are on the way at the different preparation and development stages. In order to make PPP projects successful, the appropriate evaluation procedures have to be applied and adequate criteria used for the project assessment from the private as well as public partner perspective.

The objective of this research paper is to analyse the model of PPP project development in Lithuania and to suggest the new criteria for the certain stage of the PPP project assessment procedure which would help to justify distribution of limited public sector financial resources for the most sustainable projects within the area of any specific sector.

2. Lithuanian Model of Public and Private Partnership project development

“Public-private partnerships” means the ways of co-operation between a state or municipal authority and a private entity as specified by laws, whereby the state or municipal authority transfers to the private entity the activity assigned to its functions, while the private entity invests into this activity and the assets required for carrying it out and receives a remuneration therefore as specified by the laws. The forms of partnerships between the public and private sectors shall be specified by this Law, the Law of the Republic of Lithuania on Concessions and other laws” (Republic of Lithuania Law on Investments, 1999, as last amended on 16 June 2009).

PPPs in Lithuania are regulated by the Law on Concessions, adapted in 1996 (amended 2011), Law on Investments(1999), Law on Public Procurement (1996), Resolution on Public-Private Partnership of the Government of Lithuania (2009), Law on Management, Usage and Disposal of State and Municipal Property, Civil Code, and other documents. Lithuanian legislation describes available schemes for PPP implementation: contractual and institutional Public-private partnership. The contractual partnership is carried out exclusively on a contractual basis without the establishment of a mixed investment project realization company (concessions, PFI). Institutional partnership is carried out by establishing a special purpose company - mixed capital (public and private) company. PPP projects can be implemented both at the central and municipal level (Manual for the Public–Private Partnership Projects, 2014). Legislation allows private entities to initiate PPP projects.

In 2009 there was a programme introduced by the Government to enhance PPP in priority sectors: transport, education, social housing, public order and safety. In 2009 Lithuanian Government authorized the public institution Central Project Management Agency (CPMA) to provide methodological and advisory assistance to the issues of the development and implementation of public and private partnership projects. PPP Competence Centre was set up by CPMA in 2010. PPP project development and implementation methodology was officially approved on 16 April 2013. According to the survey conducted by the European Bank for Reconstruction and Development Lithuania was ranked very high among other Eastern Europe countries for the comprehensiveness of PPP regulatory framework (1st place), PPP environment in general (2nd place) and for clearly defined institutional framework (3rd place) (The Economist Intelligence Unit, 2013).

The PPP development process of the state level projects in Lithuania, acting institutions and their functions are described in Figure 1. The PPP development process of the local level essentially corresponds to the state level procedures with the exception that PPP Commission is substituted by the Municipal Inspector and the Government – by the Municipal Council.

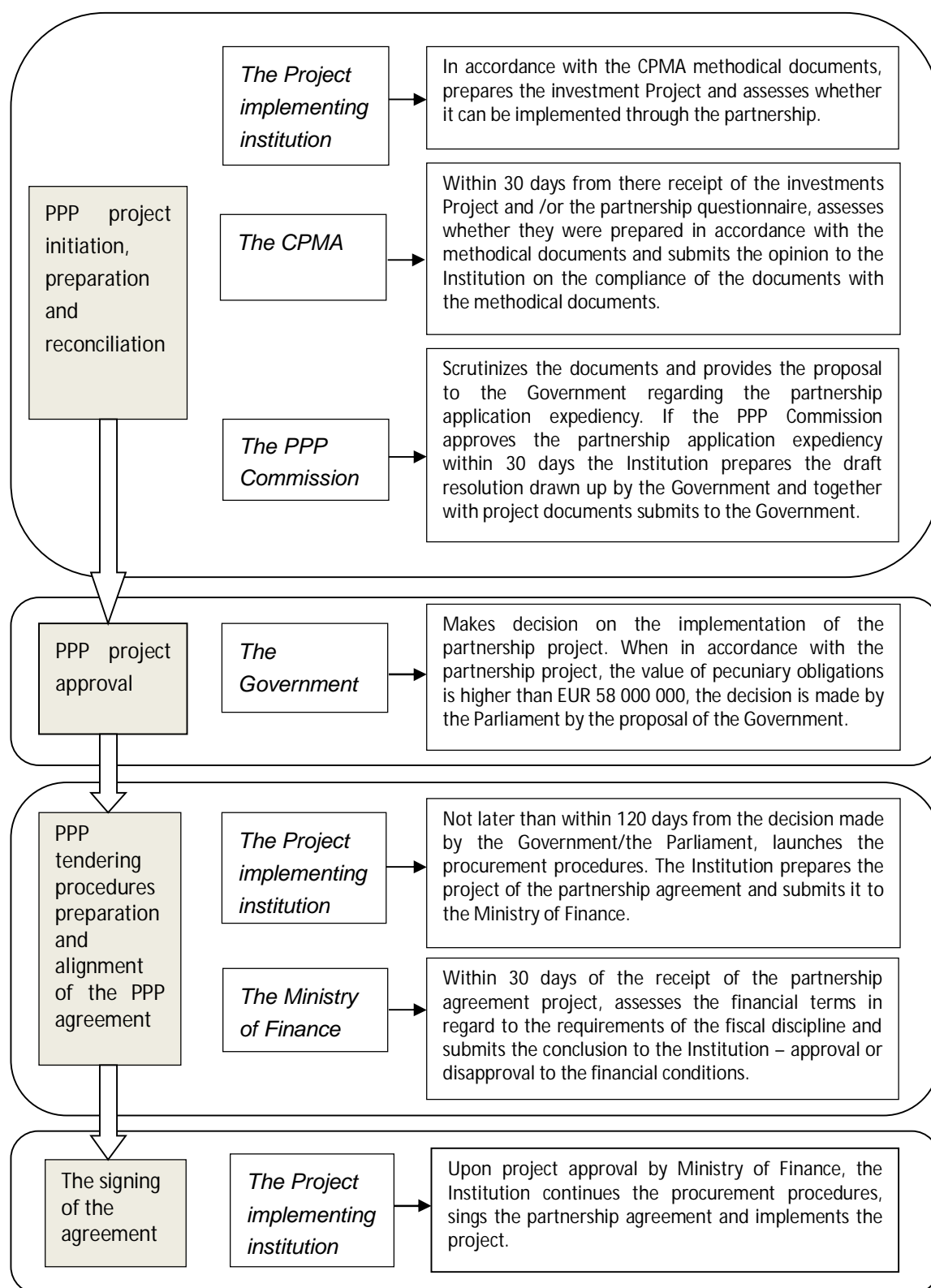


Figure 1: PPP project development model (adopted from PPP Competence Centre. *Viešojo ir privataus sektorių partnerystė: Lietuvos patirtis ir ateities perspektyvos [Public and Private Partnership: Lithuanian experience and future perspectives]*, 2014)

3. Public and Private Partnership Project Evaluation

As a result of recent scientific literature review, the main research areas were identified related to the PPP projects development (Table 1). While the foreign authors investigate financing and management problems, analyse different PPP application areas, share the best practise of the PPP coordinating institutions, European Commission Directorate - General for Regional Policy (2006) and most of the Lithuanian authors emphasize the significance of the criteria used to assess the PPP project effectiveness at the stage of feasibility study: political, administrative and legal environment, communication between the public and private sectors, etc. (Table 2).

Table 1. Research areas of PPP projects

<i>No.</i>	<i>Research areas</i>	<i>Authors</i>
1	<i>PPP projects implementation efficiency, financing and management problems</i>	<i>Mouraviev, Kakabadse 2014; Turhani 2013; Rufin, Rivera-Santos 2012; Makovsek 2013; Jasiukevičius, Vasiliauskaitė 2012.</i>
2	<i>Analysis of diversity and characteristics of PPP application areas</i>	<i>Rajan et al. 2014; Carpintero, Petersen 2014; Song et al. 2013; Cruz, Marques 2013; Gordon 2012; Jooste, Scott 2012; Grasman et al. 2014; Iliescu et. al. 2014 Devkar et al. 2013.</i>
3	<i>Best practice for PPP projects in the world: the coordinating institutions and their activities</i>	<i>Rossi, Civitillo 2014; Hwang et al. 2013; Rebeiz 2012; Chen, Hubbard 2012; Mouraviev, Kakabadse 2014; Silvestre, Feraz Esteves De Araujo 2012.</i>
4	<i>Criteria of PPP projects effectiveness</i>	<i>Skietrys, Raipa 2009; Vičkačienė 2010; General Directorate of Regional Policy of European Commission 2003; Šutavičienė 2013; Kavaliauskaitė, Jucevičius 2009.</i>

Table 2. Criteria of PPP projects effectiveness

<i>Authors</i>	<i>Criteria of PPP projects effectiveness</i>
<i>European Commission Directorate - General for Regional Policy (2003)</i>	<i>Free access to the market and fair competition Public interest advocacy and increasing of added value The optimal level of grant financing Selection of the most effective forms for partnership project</i>
<i>Skietrys, Raipa (2009)</i>	<i>Political, legal and administrative environment Aspiration of higher quality; Communication</i>
<i>Kavaliauskaitė, Jucevičius (2009)</i>	<i>Institutional environment; Staff performance and competence Managerial and organizational aspects Identification and coordination of different organizational cultures; Knowledge management Balanced stakeholder aspirations realization</i>
<i>Vičkačienė (2010)</i>	<i>Long-term investment plans for various sectors Legal and administrative system Clarity of the competences of the public sector Confidence of the private sector</i>
<i>Šutavičienė (2013)</i>	<i>Analysis of public needs; Legal environment; Clear vision, goals, objectives, main directions Dissemination of analytical information</i>

The existing PPP project evaluation stages and criteria from the perspective of the public sector in Lithuania are presented in the Figure 2. According to the Republic of Lithuania Government Decree No.1480, November 1, 2009 (last amended in 2015) PPP Commission approves/rejects the projects based on the CPMA recommendations and institution's financial capability. However, the National Audit Office Report (2013) states: "the areas to be improved include initiation and development of partnership projects. Prior to the preparation of feasibility studies, none of the analysed projects had been subject to detailed assessment in order to find out whether it is appropriate to carry out these projects in the form of PPP. Also, none of the feasibility studies evaluated the financial capacity of the institutions, although this is a very important criterion". In authors' opinion, public PPP commitments should have the financial limits, and clear and transparent criteria need to be established for project prioritization within the certain area. Thus, the set of the criteria (shaded area of Figure 2) was developed by the authors and is recommended to be used for the PPP project evaluation by PPP Commission from the public sector perspectives:

- **C1 - Impact on the regional labour market.** This criterion refers to the number of new job places created due to the project implementation and the number of unemployed people in the region, measured as a percentage.
- **C2 - Share of the project value per single consumer of project target group.** The ratio is calculated dividing the value of public sector capital investments and operation expenses by the number of targeted users (recipients) for whom the infrastructure and public services/ social economic benefits supposed to be created, calculated in EUR.
- **C3 - Complexity of the public services.** It reflects the responsibilities and risk acceptable by the private sector. Criterion is calculated taking into account different tasks/ services or groups of services to be transferred to the private sector during the project implementation and operation period.
- **C4 - Expansion of the provided services within the region.** It refers to the increased percentage of customers after the PPP project implementation in regard to the total number of people residing within the public institution's service territory.
- **C5 - Size of the target group within the region.** The criterion represents the proportion of the population in the region which receives the benefits of the implemented PPP Project, measured as a percentage.
- **C6 -Project priority in regards to regional strategic development plan.** It defines the priority of the project implementation area within the municipal/state strategic development plan. The criterion is measured on a scale from 1 to 10 points. Scores are calculated by dividing the project area priority number by the total number of priority areas and multiplying it by 10 - the number of max points. The project is of the highest priority when it's score is equal to 1.

The authors define the following advantages of the suggested methodology:

- Û accurate and clear criteria are used to prioritize the PPP projects of the same area;
- Û less projects are presented for Government, Parliament or the municipal council consideration;
- Û the most rational and sustainable PPP projects within the certain field are selected for funding by the end of the financial period.

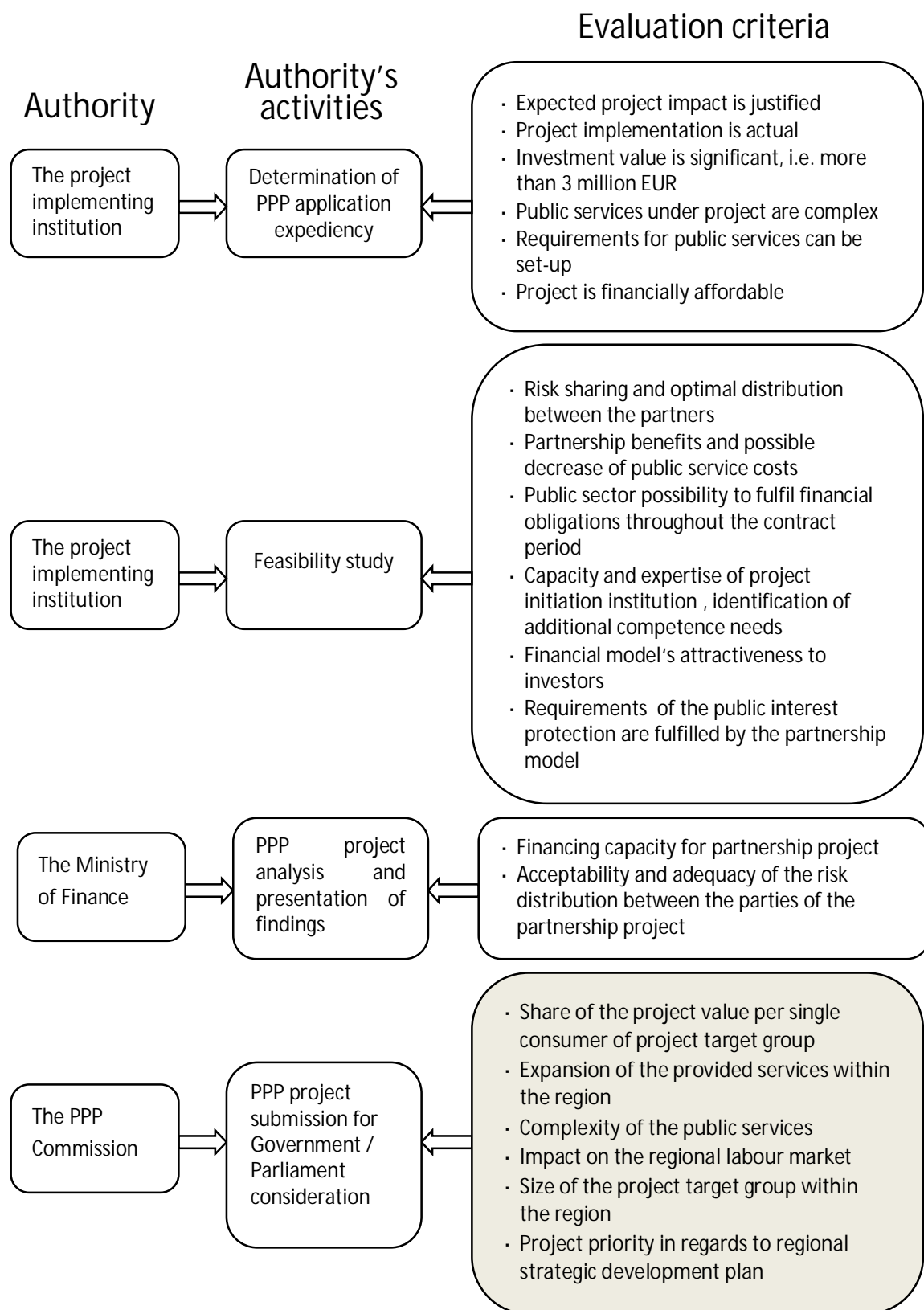


Figure 2: PPP project evaluation criteria

4. Effectiveness of PPP Projects: Case Study

Three Lithuanian public-private partnership projects were selected for analysis and priority identification. Information about all of these projects is presented on the PPP Competence Centre website (www.pppLietuva.lt) as well as the documents of public procurement. New construction or reconstruction of the existing buildings in all of the projects is planned to be carried out as well as building maintenance and operation services provided for the period of 25 years. In fact, two of these projects belong to the public security sector within the central government level, and the third one to the sports and leisure sector within the local (municipal) level. It is conditionally assumed that all projects are classified in the same area and are funded from the same source of the public sector, taking into consideration the limited availability of financial resources. The selected projects are:

A1 - Project of Vilnius County Police Headquarters. Project goal - to create the conditions for the proper performance of the police functions in Vilnius city by building and operating appropriate facilities for Vilnius Regional Chief Police Station Custody and Vilnius City 1st Police station. Project Owner - Police Department under the Ministry of Internal Affairs. Total area 8,155 m². Max Project value 57 million EUR. PPP Contract: Design-Build-Finance-Operate (DBFO). Project term - 25 years. Current status- Private partner selection.

A2- Sports palace renovation and wellness complex development project in Naujoji Akmenė city. The aim of the project - to ensure the sports and leisure facilities accessibility and attractiveness for community and tourists of Naujoji Akmenė municipality. Project owner - municipality of Naujoji Akmenė. Total area 3,625 m². Max project value 8 million EUR. PPP Contract: Design-Build-Finance-Operate (DBFO). Project term - 25 years. Current status – Preparation for tender.

A3 - Project of abandoned buildings reconstruction into the prison in Pravieniškės 1st prison territory. Project goal - to relocate the existing prison from the current Lukiškės remand prison in the central part of Vilnius to Pravieniškės. Project Owner - Prison Department of Lithuania. Project term - 25 years. Max Project value 30 million EUR. Total area 4,883 m². Number of prison places 320. PPP Contract: Design-Build-Finance-Operate (DBFO). Current status - Private partner selection.

The significance of PPP projects evaluation criteria was determined by using pair-wise expert evaluation method. The questionnaire was developed and electronic survey (www.manoapklausa.lt) was filled out by 28 experts who directly participate in public and private partnership projects initiation or development and work for the agency „Invest in Lithuania“, CPMA, Ministries of the Republic of Lithuania and local governments. In regards the results of expert evaluation the priority row of criteria was developed (Table 3).

The case study projects were analysed by applying multi-criteria evaluation methods: Simple Additive Weighting (SAW), Complex Proportional Assessment (COPRAS) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS).

Table 3. The weights of PPP criteria

No.	Criteria	Weights of significance
C2	Share of the project value per single consumer of project target group	0,23
C4	Expansion of the provided services within the region	0,19
C3	Complexity of the public services	0,18
C1	Impact on the regional labour market	0,15
C5	Size of the project target group within the region	0,15
C6	Project priority in regards to regional strategic development plan	0,10
	Total:	1,00

The matrix of initial data for the alternatives A1, A2 and A3 was created with the criteria values which were calculated by using data from PPP Competence Centre, public procurement documents, Lithuanian Statistical Department, also information received from project initiating institutions (Table 4).

Table 4. Matrix of initial data

	C1	C2	C3	C4	C5	C6
A1	0,34	799	9	12	22	6,67
A2	0,26	7404	13	13	14	6,00
A3	3,90	324566	9	105	0,0005	3,68
Optimality	Max	Min	Max	Max	Max	Min

By applying multi-criteria evaluation methods of SAW, COPRAS and TOPSIS, Project of Vilnius County Police Headquarters was identified as the most rational and sustainable from the public sector perspective. Sports palace renovation and wellness complex development project in Naujoji Akmenė city was selected as the second one in priority. The Project of abandoned buildings reconstruction into the prison in Pravieniškės 1st prison territory was assigned to the third place (Table 5).

Table 5. The summary results of multi-criteria evaluation

	SAW		COPRAS		TOPSIS		Final ranking
	Priority	Value	Priority	Value	Priority	Value	Priority
A1	1	0,59	1	0,33	1	0,49	1
A2	3	0,40	2	0,32	2	0,48	2
A3	2	0,56	3	0,31	3	0,46	3

5. Conclusions

Legal basis for PPP projects development in Lithuania was significantly improved during the period of 2010-2015. Up to date only two institutional PPP projects have been successfully implemented under the partnership scheme, but the number of new PPP projects is growing and the responsible institutions have to justify the public sector participation in the light of limited state/municipal budget resources. There is a need for the system of PPP project prioritization from the public sector perspective.

Analysis of Lithuanian PPP project development model was carried out and the conclusion was made that PPP model requires improvement, especially at the stage of feasibility study. By evaluating the projects in the early development stage it would be possible to identify the most efficient projects, thereby reducing the number of further activities and saving the costs.

The criteria set for PPP projects evaluation by PPP Commission was developed by the authors and according to the results of expert evaluation survey their relative weights were established. The following priority of criteria based on their importance was identified:

- Share of the project value per single consumer of project target group
- Expansion of the provided services within the region
- Complexity of the public services
- Impact on the regional labour market
- Size of the project target group within the region
- Project priority in regards to regional strategic development plan

Case study of the three selected PPP projects revealed the same priority line of projects' effectiveness by applying SAW, COPRAS and TOPSIS multi-criteria evaluation methods. This demonstrates the validity of the proposed evaluation methodology, thus it is recommended for practical application of PPP project assessment from the perspectives of Lithuanian public sector.

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Risk Identification for PPP Road Projects in Bangladesh

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Abstract

The Bangladeshi government is considering Public Private Partnership (PPP) procurement options in the road sector by encouraging the involvement of local and foreign investors. However, there is ongoing evidence of poor success rating in implementing road projects in Bangladesh. Although the policy makers, public sector clients, private investors and the lenders are aware of the benefits of road projects procurement under PPP arrangement, there is little information on the likely risks and their impacts on PPP road projects. This paper therefore identifies and prioritises the risks associated with PPP road projects in the context of Bangladesh through a questionnaire survey of public clients, contractors and consultants that are involved in road sector projects development. In order to prioritise the 36 previously identified risk factors associated with PPP road projects, a questionnaire survey was conducted among the three groups of respondents: public clients, contractors and consultants. The survey results show that availability of land is the most significant risk factor for PPP road projects in Bangladesh. The other top ranked risk factors are improper planning for PPPs, risk in financing in PPP road projects, delay in land acquisition, corruption in government sector and toll road acceptance by the public majority. It is concluded that these risk factors need to be prioritised and addressed through government initiatives in order to encourage local and foreign investors' participation in the PPP road projects in Bangladesh.

Keywords: Risk management, public private partnership, Bangladesh, road construction, project procurement

1. Introduction

Project implementation through Public Private Partnerships (PPPs) is now an accepted alternative to traditional procurement methods in delivering public service infrastructure facilities. The private partners can be engaged in delivering public services through different models of PPP procurement (Akintoye and Chinyio, 2005). It is widely used because of its special characteristics such as ease of pressure on public fund, proper allocation of project risks and efficiency in project completion with innovative design and construction methods, which encourage the public clients to initiate PPP-based infrastructure projects worldwide (Li and Akintoye, 2003).

Over the past two decades, private sector financing through PPPs has become increasingly popular as a way of procuring and maintaining public sector infrastructures, in the sectors such as transportation (roads, bridges, railways, ports, airports etc.), social infra-structures (schools, hospitals, prisons, social housing etc.), public utilities (water supply, waste disposal and treatment, water treatment etc.), power sector, government offices and accommodations and other special services such as communication networks, defence equipment. However, PPP project implement process comes across a number of risks in different forms such as political, cultural, technological, social, legal, environmental, financial, macroeconomic, project default risks etc. In addition, owing to its complex nature, large volume of capital investment, long- term concession period and involvement of diversified parties, project implementation through PPP models has been adjudged to be full of risks (Li and Zou, 2011). Moreover, in PPP road project, traffic revenue or demand risk, toll pricing and collection risks are other important factors that can create uncertainty in getting back the cost of capital and profit to the private entity by the end users throughout the long range concession period (Singh and Kalidindi, 2006).

Impact of risks in completing a PPP project is usually significant. Failure to manage the risks has direct or indirect impact on goals and objectives of the organisation. Thus, all the parties involved in PPP procurement need to know the nature and complexity of project risks. The public sector clients need to address the project risks for assessing financial and economic viability before embarking on any project (Singh and Kalidindi, 2006), preparing a successful concession agreement and transferring the major risks to the private sectors as they are best able to manage them (Ibrahim et al., 2006).

The Bangladeshi government is embarking on PPP options in the road sector by encouraging the involvement of local and foreign investors. However, there is evidence of poor success rating in implementing road projects in Bangladesh. Project procurement through PPP models in Bangladesh is new and at the embryonic stage; a few PPP projects have been started recently including two PPP projects in the road sector. The client organisations are being encouraged to procure PPP road projects. However, the policy makers, public sector clients, private investors and the lenders do not have enough information about the likely risks and their impacts on road projects procurement under PPP arrangement, Not too many private investors are expressing interests to take part in bidding competition for PPP projects because of risks that could be attributable to the procurement arrangement including lack of confidence on their return on

investment. This paper therefore identifies and prioritises the risks associated with PPP road projects in the context of Bangladesh

2. Risks associated with PPP road projects

Several studies (Xu et al., 2010; Chung et al., 2010; Singh and Kalidindi, 2006; Thomas et al., 2003) have identified the significant risks associated with PPP road projects, their impacts and development of risk management tools for different countries.

Wang et al. (2000) identified a list of risks in PPP road projects in the context of China. This comprises political risk factors such as change in law and policy, delay in approval, corruption in government, government's reliability and creditworthiness; and force majeure risks, which are regarded as the most critical risk factors affecting the BOT projects in China.

Thomas et al. (2003) identified the major risks in Indian BOT toll road projects and classify them into four different phases of a project. The first phase is the development phase which comprises of land acquisition/resettlement risk, permission/approval risk and delay in financial closure. This is followed by the construction phase risks comprising technological risk, design risk, project delay and cost overruns risk. The operation phase risks are traffic revenue risk, operation risk, demand risk, debt servicing risk. Lastly, the project life cycle risks comprise legal risk, political risk, partnering risk, regulatory risk, environmental risk and force majeure. In addition, Singh and Kalidindi (2006) emphasised risk in traffic revenue (i.e. demand risk) affecting the commercial success of PPP toll road projects in India.

Wibowo and Kochendorfer (2005) work on PPP toll road project in Indonesia shows that construction cost overruns, delay in land acquisition and total delay in project complementation, pricing of toll rate, estimation of future traffic volume, change in regulation and some macroeconomic factors such as inflation, interest rate are the most significant risks affecting the success of PPP toll road projects in Indonesia.

Ogunlana and Abednego (2009) listed risk factors for PPP road way and conducted a case study research on Cipularang Toll-way Project in Indonesia to identify the major risk factors on the project. The study shows that project financing, lack of government support, delay in decision/approval, problem with land acquisition and change in design affected mostly the success of the project.

Xu et al. (2010) identified 17 major risks associated with PPP road project; these are ranked in accordance with their importance on PPP Highway projects in China through Delphi questionnaire survey technique and identify the most critical risk groups using factor analysis. They concluded that government intervention (political interference on project procurement) and government maturity (corruption and poor decision making and inadequate law and order situation) are the two most critical risk groups affecting the success of PPP Highway projects.

Rajan et al. (2010) conducted a case study on East Coast Road project, a PPP road project in Chennai, India. The most critical risk factors identified on the project are project finance risk, poor decision making by the government, delay in land acquisition, cost overruns, risk associated with traffic revenue and collection of tolls.

In the Australian PPP road project, Chung et al. (2010) identified the most critical risk factors as fluctuating traffic volume, design and construction risk, operation and maintenance risk, risk for change in country's legislation and policy, pricing of toll, debt coverage risk and low level acceptance of toll road by users.

Li and Zou (2011) developed a fuzzy analytical hierarchy process (AHP) to assess the risks in PPP projects. They identified the risks associated with PPP roadway project in China which are verified by the PPP experts and assessed them using fuzzy technique. From this study, planning deficiency, low residual value, lack of enough competition, design risk, delay in approval, change in legislation and traffic volume risk were identified as the most critical risk factors for PPP highway projects in China.

Based on the literature above, Table 1 is produced which shows that fluctuating traffic (or demand risk) is the mostly cited risk factors associated with PPP road projects. The commercial success of PPP road projects depends in some ways on the toll collected from the traffic use of the assets if investors are otherwise not compensated by the public sector clients. Private investors perceive the returns on investment from PPP road projects is risky despite the assumption of any traffic revenue presented in the PPP business case by the client organisations (Singh and Kalidindi, 2006).

Delay in construction is another most cited important factor. Construction time overrun is a general factor for any type of project which could result from insufficient experience of the contractors, use of inappropriate construction methods, inaccurate time and cost estimating, improper project planning and scheduling, incompetent project team, unreliable subcontractor, obsolete technology etc. (Long et al., 2004).

Delay in land acquisition, frequent change in laws/policies and risk in operation and maintenance are the third most cited risk factors. Road project requires acquisition of public land. The acquisition process involves several steps such as estimation of land and other assets, supply of necessary documents; followed by a number of steps to get the final approval, which often consumes significant time and cost for the road projects (Wang et al., 2000). Risks associated with frequent change in law includes changes in government policies, laws and regulations related to public procurement, methods of handling inflation, fixation of currency conversion rate and methods of setting taxation rate by the different organisations of the government: these can hinder the success of a PPP road project (Wang et al., 2000).

Factors such as residual value risk, availability of land risk, unstable law and order situation, risks in evaluation of PPP procurement and delay in annuity payment are the least cited risk factors.

Table 1: Risk associated with PPP road projects (Content analysis)

Risk factors	Wang et al. (2000)	Kalidindi & Thomas (2003)	Wibowo & Kochendorfer (2005)	Singh & Kalidindi (2006)	Ogunlana & Abednego (2009)	Chung et al. (2010)	Xu et al. (2010)	Rajan et al. (2010)	Li and Zou (2011)	Total number of citations
Frequent change in policy /laws	x	X	x	x	x	x			x	7
Government intervention					x		x			2
Corruption in government sector	x						x			5
Delay in approval	x			x			x	x	x	5
Lack of government support		x			x					2
Unstable law and order							x			1
Lack of competition in bidding						x			x	2
High bidding/tendering cost	x								x	2
Bid evaluation risk (subjective)							x			1
Risk in contract management	x				x		x	x		4
Planning/pre-investment risk				x					x	2
Design risk					x	x		x	x	4
Availability of land				x						1
Delay in land acquisition	x	x	x	x	x			x	x	7
Resettlement/relocation risk				x						1
Cost overruns	x	x	x	x			x	x	x	6
Delay in construction	x	x	x	x	x	x	x		x	8
Change of project scope				x			x			2
Risk in quality control				x	x		x			3
Health and safety risk	x								x	2
Force majeure risk	x			x	x	x				4
Environmental risk	x							x	x	3
Commissioning risks	x								x	2
Operation and maintenance risks	x			x	x	x	x	x	x	7
Residual value risks									x	1
Fluctuating traffic /demand risk	x	x	x	x	x	x	x	x	x	9
Competing/alternative routes	x				x	x				3
Risk in collection of toll		x						x	x	3
Pricing/fixing of toll rates	x	x	x		x	x		x		6
Acceptance of toll road		x				x				2
Project financial closure risk		x		x	x		x	x		5
Debt servicing risk		x				x		x		3
Delay in annuity payment				x						1
Fluctuation of exchange rate	x				x		x			3
Fluctuation of interest rate	x		x	x	x		x	x	x	7
Inflation	x		x		x		x		x	5

3. Research Method

The principal objective of the study was identification of significant risks in PPP road projects in the context of Bangladesh. To identify the risk associated with PPP road projects, the available literature on risk associated with PPP road projects have been analysed and the risk factors have been listed in a tabular form through content analysis (after Bryman, 2008). A total of nine research papers on risk in PPP road projects have been reviewed to identify the risks associated with PPP road projects. Based on the nine research papers, 36 risk factors were identified (after Xu et al., 2010) as shown in Table 1.

A questionnaire survey which contains all 36 identified PPP road risk factors have been used to gain a wider spread of opinion on risk factors in the context of Bangladesh PPP road projects based on a 5-point Likert scale (5=Very important; 4= Important; 3=Moderately important; 2=Less important, and 1= Unimportant). The questionnaire was piloted with 5 road procurement experts. Construction professionals both in government and private sectors as well as consulting firms, who have vast experience in procurement of road projects in Bangladesh were targeted.

The respondents are (i) public sector client respondents drawn from Roads and Highways Department (RHD), Local Government Engineering Department (LGED), Bangladesh Bridge Authority (BBA) and City Corporations; (ii) private sector contractors who are road project construction experts from national level construction firms (enlisted by the public procurers) in Bangladesh; and (iii) consultants who are public procurement consultants working in consulting firms, donor aided public procurement project and as freelance consultants.

As there was no systematic database for the road construction professionals in Bangladesh, non-probabilistic quota sampling technique instead of random sampling was used with a view to comparing the perceptions on PPP road risks from the three groups of respondents. A total of 120 respondents (40 from each group) was asked to rate the factors based on their experience in road project procurement. The questionnaires were self-administered in Bangladesh over a period of two months. A total of 82 completely completed questionnaires was returned, representing a response rate is 68.33% (public clients 80%, contractors 75.5% and consultants 52.5%).

These risk factors are presented to Bangladeshi respondents. Mean score (MS) for each risk factor from the 5-point Likert scale was calculated (after Chan and Kumaraswamy, 1996) as follows:

$$MS = \frac{\sum_1^5 (f \cdot s)}{N}$$

Where f = frequency of each rating for each risk factor; s = score given to each risk factor by the respondents (ranging from 1 to 5); and N= total number of responses for each risk factor. In addition, the standard deviation of the MS for each factor is provided to show the variability.

4. Results of the Survey

Table 2 shows that 61% of the respondents had over 10 years of experience in road projects construction and procurement; suggesting that the majority of the respondents were operating at senior level of construction professional experience.

Table 2: Experience level of the respondents

Years of experience	Overall		Public Clients		Private Contractors		Consultants	
	No.	(%)	No.	(%)	No.	(%)	No.	(%)
Less than 5 years	9	11%	8	25%	1	3%	0	0%
5+ to 10 years	23	28%	12	37.5%	9	31%	2	10%
10+ to 20 years	38	46%	8	25%	13	45%	17	80%
More than 20 years	12	15%	4	12.5%	6	21%	2	10%
Total	82	100%	32	100%	29	100%	21	100%

4.1 Ranking of risks in PPP road projects

The responses of clients, contractors and consultants are ranked based on their mean score (MS) and standard deviation of a list of 36 identified risk factors involved in PPP road projects. Also, an overall ranking of the risk factors is presented by combining the data from all respondents.

Table 3 shows ranking of the risk factors by the three respondent groups and the overall ranking from all the three groups of respondents. The mean scores ranged from 4.43 to 2.13. Availability of land (MS = 4.43), improper planning for PPP project procurement (MS = 4.33), financing in PPP road projects (MS = 4.27), delay in land acquisition (MS = 4.24) corruption in government sector (MS = 4.09), acceptance of toll roads (MS = 4.02) are considered the top most risk factors by the respondents.

The top most significant risk factors for clients are: delay in acquisition of land for the projects (MS = 4.50), initiating PPP projects without proper planning by the client organisations (MS = 4.41), availability of sufficient land for construction of road projects (MS = 4.38), lack of qualified bidders to invest in large scale road projects (MS = 4.13), financing in PPP road projects (MS = 4.06), resettlement and relocation of utilities (MS = 4.03), frequent changes of laws, rules and regulations related to public procurement of Bangladesh (MS = 4.00).

The most significant risk factors by contractors are: availability of land (MS = 4.55), financing in PPP road projects (MS = 4.48), corruption in government sectors (MS = 4.41), improper planning for PPP road projects (MS = 4.34), government intervention in large scale project procurement (MS = 4.28), and delay in land acquisition (MS = 4.14).

The most important risk factors associated with PPP road projects in Bangladesh identified by the consultants group are availability of land for road project (MS = 4.33), financing in PPP road projects (MS = 4.29), improper planning for PPP road projects (MS = 4.19), acceptance of toll

road by the users (MS = 4.14), corruption in government sector (MS = 4.05), delay in land acquisition (MS = 4.00), government intervention in project procurement (MS = 3.90), unstable law and order situation (MS = 3.86) and lack of qualified bidders (MS = 3.76).

Table 3: Rankings of risks in PPP road projects in Bangladesh from different perspectives

Risk Factors	Overall			Clients		Contractors		Consultants	
	R	MS	SD	R	MS	R	MS	R	MS
<i>Risk of availability of land</i>	1	4.43	0.817	3	4.38	1	4.55	1	4.33
<i>Improper planning for PPP</i>	2	4.33	0.771	2	4.41	4	4.34	3	4.19
<i>Risk of financing in road PPP projects</i>	3	4.27	0.847	5	4.06	2	4.48	2	4.29
<i>Delay in land acquisition</i>	4	4.24	0.639	1	4.50	6	4.14	6	4.00
<i>Corruption in government</i>	5	4.09	0.820	11	3.81	3	4.41	5	4.05
<i>Risk in acceptance of toll road</i>	6	4.02	0.801	10	3.88	7	4.10	4	4.14
<i>Government intervention</i>	7	3.98	0.875	13	3.75	5	4.28	7	3.90
<i>Lack of qualified bidders</i>	8	3.94	0.880	4	4.13	9	3.86	9	3.76
<i>Unstable law and order</i>	9	3.90	0.730	9	3.97	10	3.86	8	3.86
<i>Delay in getting approval</i>	10	3.80	0.761	8	4.00	11	3.76	11	3.57
<i>Frequent change in laws</i>	11	3.79	0.698	7	4.00	12	3.72	12	3.57
<i>Delay in construction</i>	12	3.59	0.816	12	3.81	14	3.31	10	3.62
<i>Risk in collection of toll</i>	13	3.55	0.996	18	3.25	8	3.90	13	3.52
<i>Risk in resettlement</i>	14	3.52	0.959	6	4.03	17	3.00	14	3.48
<i>Inflation</i>	15	3.29	0.839	20	3.13	13	3.38	15	3.43
<i>Risk in contract management</i>	16	3.29	0.853	16	3.41	15	3.21	17	3.24
<i>Increase in project cost</i>	17	3.28	0.879	14	3.47	18	3.00	16	3.38
<i>Operation & maintenance risks</i>	18	3.06	0.791	21	3.09	19	2.97	20	3.14
<i>High tendering cost</i>	19	3.04	0.909	31	2.81	16	3.14	18	3.24
<i>Fluctuation of interest rate</i>	20	3.00	0.770	24	2.97	20	2.93	19	3.14
<i>Fluctuating exchange rate</i>	21	2.98	0.769	27	2.94	22	2.93	21	3.10
<i>Subjective tender evaluation method of PPP</i>	22	2.94	0.998	19	3.22	23	2.55	23	3.05
<i>Maintaining quality of works</i>	23	2.91	0.973	15	3.44	29	2.24	22	3.05
<i>Unwillingness of the government for PPPs</i>	24	2.88	1.011	17	3.28	25	2.41	24	2.90
<i>Fluctuating traffic volume</i>	25	2.80	1.048	26	2.94	21	2.93	31	2.43
<i>Force majeure risks</i>	26	2.77	0.907	25	2.97	24	2.48	25	2.86
<i>Existing/alternative routes</i>	27	2.67	0.969	28	2.94	26	2.31	26	2.76
<i>Fixing the toll rates</i>	28	2.57	1.089	22	3.09	31	2.10	32	2.43
<i>Variation in scope of works</i>	29	2.55	0.918	33	2.75	28	2.28	28	2.62
<i>Environmental risk</i>	30	2.54	0.971	30	2.84	32	2.10	27	2.67
<i>Delay of annuity payment</i>	31	2.52	1.009	32	2.81	27	2.31	35	2.43
<i>Changes in design of work</i>	32	2.51	0.878	29	2.84	30	2.17	29	2.48
<i>Payment of debt</i>	33	2.51	1.009	23	3.00	33	2.00	30	2.48
<i>Health and safety risk</i>	34	2.34	0.864	34	2.72	35	1.86	33	2.43
<i>Commissioning risk</i>	35	2.23	1.010	36	2.63	34	1.90	36	2.10
<i>Risk in residual value</i>	36	2.13	1.167	35	2.69	36	1.34	34	2.38

*R = Ranking, MS = Mean score, SD = Standard deviation

Spearman correlation analysis results for the 10 most important risk factors to test for any agreement between various groups of respondents is presented in Table 4. This shows that there is general agreement between the consultants and contractors in respect of the ranking of the top ten risk factors, whereas there are significant disagreements between clients and contractors, as well as clients and consultants. This test reinforces the concordance of perception between the two private sector groups (contractors and consultants).

Table 4: Test for agreement on the overall ranking of the 10 most important risk factors as perceived by different group of respondents

<i>Groups of respondents</i>	<i>r_s</i>	<i>t</i>	<i>Reject H₀?</i>	<i>p-value</i>
<i>Clients and Contractors</i>	-0.297	-0.880	<i>No</i>	<i>Not significant</i>
<i>Clients and Consultants</i>	-0.103	-0.293	<i>No</i>	<i>Not significant</i>
<i>Contractors and Consultants</i>	0.867	4.914	<i>Yes</i>	<i>Significant, <0.05</i>

*r_s = Spearman's rank correlation coefficient; t = t-statistics; H₀ = null hypothesis; p = probability that rejects the null hypothesis.

5. Discussion of the results

Overall, the survey results show that risk in availability of land for road projects, improper planning for PPP procurement, risk in financing, delay in land acquisition, corruption in government sector and risk in acceptance of toll roads are the top ranked factors in the context of Bangladesh. However, the prioritisation based on the Table 1 (undertaken through content analysis of literature review) is quite different from this survey result. For example, availability of land is mentioned as a significant risk factor in only one of the literature, whereas, it is ranked first in this study. On the other hand, fluctuating traffic revenue is cited in all the research papers; however, this factor is ranked 25th important factor in Bangladesh.

It is noted that the three respondent groups (clients, contractors and consultants) ranked the risk factors associated with PPP road projects according to their objectives and interest in road sector project development. However, the consistently least important risk factors overall and within the groups for PPP road projects in Bangladesh are the risks associated with residual value of the asset, commissioning of the asset, health and safety, payment of debt to the financial institutions and changes in design of works. The top ranked risk factors and how they could impact the success of PPP road projects in Bangladesh are discussed as follows:

Availability of land for PPP road projects: The risk of availability of land for PPP road projects is ranked 1st overall. This is not surprising given that availability of land is a common problem for road project for the countries with high population density like Bangladesh; availability of land is regarded as one of the significant risk factors for PPP road projects in India (Thomas et al., 2003). Bangladesh is an agriculture-based country with high density of population. Road construction projects need considerable land and in Bangladesh it is associated with high market price. In addition, a PPP new road project development might lead to a need to demolish high-rise buildings, markets and other structures which are located adjacent to the existing roads. Thus scarcity of land creates high barrier to the implementation of road projects in Bangladesh. For

example, it was speculated that one of the large PPP road projects in Bangladesh, Dhaka Elevated Expressway (with the estimated cost of over US\$ 1 billion), would fail at its initial phase because of insufficient and costly land in Dhaka city (GOB, 2011).

Improper planning for PPP procurement: Although 'improper planning for PPP procurement' is identified as one of the least cited factors in the literature reviewed, this factor is ranked 2nd in the context of PPP road projects in Bangladesh. This is a critical risk factors for Bangladesh as development of most road projects in Bangladesh is considered on the basis of political imperatives. The financial and economic needs are often ignored while initiating projects. As a result, many road projects in Bangladesh have been known to experience time and cost overruns and in some cases abandoned due to improper procurement choices and planning.

Financing of PPP road projects: The risk factor ranked 3rd overall is ranked 5th by clients and 2th by both contractors and consultants. This is an important factor to contractors and lenders as it may affect the project revenue and cash flow regime, which has a direct impact on payment for the services provided by the asset and consequently the recovery of capital invested by the lender. Lenders perhaps perceive PPP investment risk as a 'business' risk and are rightly concerned if this is inappropriately passed to the project consortium. Increase in project cost, government intervention, corruption, fluctuating traffic volume, change in laws/policies by the government etc. are some of the factors which could create risk and uncertainty of the investment in PPP road projects for investors.

Delay in land acquisition: Delay in land acquisition is ranked fourth overall. While clients ranked it as first, the contractors and consultants have ranked the factor as sixth. For road projects construction in Bangladesh, the public clients have had acrimonious experiences with land acquisition. Land acquisition requires a number of steps to get the approval needed coupled with associated complexities, which could lead to considerable time and cost overruns. The impact could mean that the contractor is not able to start the physical work on site or the work is delayed during the construction stage until the problem is resolved. There are evidence of poor performance of road project developments in Bangladesh due to land acquisition problems.

Corruption in government sector: Overall, the risk factor is ranked fifth (third by contractors, fifth by consultant and eleventh by clients). Corruption is prevalent in Bangladesh public sector (Zafarullah and Siddiquee (2001). Bangladesh is ranked among the top corrupt countries based on corruption index by Transparency International. As a result, contractors and consultants often give corruption in public sector as a reason for delays in project execution. The corruption activities could be found in every aspect of construction including tendering process, necessary documents approval, interim payment, utility connections etc. A high level of corruption in the public sector of a country could demotivate local and foreign investment in PPP projects.

Acceptance of toll roads by the end users: This risk is ranked sixth by all the respondents. This is not surprising given that the road users in Bangladesh are not used to paying tolls for the use of roads and bridges; road assets are traditionally constructed and maintained by the public sector. There is a risk that the end users may divert to non-tolled routes to avoid paying tolls on PPP

roads, which may hinder generation of revenue needed to cover the investment and profit margin of PPP road investors.

6. Conclusion

Given some benefits acclaimed to project procurement through PPP models over the traditional procurement methods, governments in both the developed and developing countries, are encouraging the private investors in the delivery of public facilities and services through PPP procurement. However, PPP procurement involves a complex procurement process, multi-party involvement and high capital investment along with long-term concession period, which sometimes discourage the private contractors to invest in the uncertain business environment. PPP has been used to deliver infrastructure in many countries where there is not enough public sector funding.

Hence, PPP procurement method could become one significant option for the government of Bangladesh to develop its road sector projects. This has the potential to reduce pressure on the government associated with: huge public sector funding, need for foreign loans, timely completion of road projects; attracting local and foreign investors; etc. However, PPP road projects procurement is adjudged to have many risks that must be mitigated or properly allocated to parties involved in the development.

In PPP projects, the private investors normally assume the revenue/demand risk for the use of the asset including the risk in design, finance, construction and maintenance, although sometimes demand risk may be shared by the public sector assuring the guarantee of a minimum level of use. The results of the survey of Bangladesh respondents show other risks that should be considered. These are availability of land and delay in land acquisition, improper planning for PPP procurement by the government, risk in financing in PPP road projects, corruption in public sector, government intervention and risk in acceptance of toll roads. These are the top risk factors that might affect the success of PPP road projects in Bangladesh.

In order to encourage the private sector (financial institutions, private investors, contractors, etc.) involvement in PPP road project, the government of Bangladesh should initiate processes and guidelines to minimising the impact of the above mentioned risk factors. Land for road projects seems to be a major risk factor that should be addressed in terms of on how to make this available or work with the community in order to gain the trust of investors and to achieve successful road projects development through PPP. The policy makers should also engage pressure groups and stakeholders in a constructive dialogue and involvement very early in a PPP road project development on the requirements of PPP road projects and associated tangible and intangible benefits. Creation of a sound business environment through development of policy and legal framework and guidelines for PPP should be considered a priority by the government in order to gain the trust of both the local and foreign investors. In addition, the planning and procurement processes should be given very care consideration coupled with the engagement of the right professionals from both the public and private sectors very early in the process.

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Methodological Proposal for the implementation of fuzzy logic in the allocation and risk quantification for social infrastructure projects under PPP modality in Colombia

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Abstract

In recent years, Colombia has had strong economic growth. The constant need to expand infrastructure have led to the development of road projects in the form of public-private partnerships (PPP). However, draft social infrastructure has been stalled by the lack of legislation to help correct equitable allocation and quantification of risks between the private and the public sectors. Therefore, this paper seeks to make a methodological proposal of an equitable allocation and quantification of risks for the public and private sectors in Colombia for the development of social infrastructure projects under the framework of PPPs. This work is done through the verification of international experiences and previous local studies on the determination of the factors that affect the decision of the existing risk situation, and with this basis, we seek to find the feasibility of establishing a methodology capable of quantifying and allocating risks through a fuzzy logic approach and mathematical models for the modeling and parameterization of the risks associated with the awarding of contracts and delivery of such projects.

Keywords: Public-Private Partnerships, Fuzzy logic, social infrastructure, Economy

1. Introduction

Following the steady economic growth that has taken Colombia over the past two decades, the state has been forced to consolidate government plans based on building national infrastructure to boost a developing economy. Thanks to the consolidation of economic treaties and projects that enable or facilitate the dynamic economic policy, the C.E in the country during the past three years has averaged the third highest in Latin America with an average of 4.9 percent annually. From this, one of the main needs of the country is the construction and maintenance of transport infrastructure; the

so called 4th generation (4G) projects have been promoted through joint (public and private) resources in order to expedite construction and to distribute the associated risk. However, with the enhancement of private public associations in the country, given already years ago, different challenges arise even today, after having consolidated a law focused on this issue are pending.

So far, efforts have been focused on PPPs for road infrastructure as Colombian law scheme is specifically suited for road concessions without going into much detail about other schemes. However the demand for other type of services in the country requires this model to also be applied to other projects like social infrastructure development. However, even when the risks and financial income are different, law conditions are equally enforced; therefore, the private investor bears some suspicion when proposing or seeking social infrastructure PPPs. This is evident in projects declared void because no private was presented.

To partially solve to this problem, the authors propose a methodological approach for the correct risk allocation and quantification in social infrastructure projects based on a fuzzy logic approach. This mathematical models allow the modeling and parameterization of the risks associated with the procurement, contracting, and implementation of such projects. This article seeks to stablish the feasibility of the implementation of such a methodology in the Colombian context under the current conditions.

The remain of this article is as follows: First, we contextualize the reader on Social Infrastructure PPPs and their current state of risk quantification and allocation. Then we state a theoretical and conceptual framework on fuzzy logic and risk in PPPs. Later, we develop a methodological approach for the implementation of this concepts in risk allocation and quantification in PPPs and, finally, we state some recommendations about it applicability in the Colombian context.

2. Public-private partnerships in social infrastructure projects.

Social infrastructure projects are developments identified by the government or the private sector in search of promoting development and investment in urban and rural areas nationwide. Projects of this type seek to satisfy basic and complementary needs of a population in terms of the development of basic rights and government plans. Examples of such projects are schools, in search of the right to education; hospitals, searching for the right to health and life; prisons, with a view to safety plans; service networks or road axes, allowing the development of the country.

However many of these projects cannot be realized due to the lack of public resources. On other occasions, the project life cycle requires maintenance and strict control that is out of the functions of a public body. For these cases, a figure, which allows a partnership between the public sector and the private sector, is often encouraged. The private sector contributes a certain amount of resources that allow the state to carry out such projects. The private meanwhile, expects an economic return for the execution of the project and/or its operation and maintenance, where the investment will be paid.

Additionally, these projects carry great uncertainty and risk for both parties. Therefore you should always pre-assess the suitability of each project using this form or simply make a project through public procurement if the private cannot take the risk assigned. Basically the study currently undertaken by public organizations to establish the viability of these projects is based on a quantitative analysis intended to estimate revenues, costs and project risks.

When there is doubt about the most convenient way, financially speaking, a project (CP or PPP) is performed what is known as value for money. This concept defines Grove (Grove, 2012) as:

"The result of the comparison of the present value of risk-adjusted costs to develop a public project (Project Public Reference) with the present value of risk-adjusted cost of the same project developed under a PPP scheme."

This analysis should ensure that with the proper development of the project, if realized in the form of a PPP, it will be economically sustainable from a level of initial investment, operating cost, and worthiness of assuming the risk associated. For this, the risks should be allocated between the private and the public parties so that each sector assumes those factors that it is able to efficiently manage (Loosemore & McCarthy, 2008). In this sense, there are two kinds of risks: the risk transferred, which assumes the private; and the risk retained, which assumes the public.

In this order of ideas, the cost of risk of the project refers to monetary impact on the initial budget due to the occurrence of the risk. Although current analysis to define this type of project is done in a quantitative way, this method has serious shortcomings because it does not consider elements of decision. For this reason, countries such as Peru, Chile and Mexico, more developed in the implementation of PPPs, have sought to incorporate in their quantitative analysis the relevant dimensions of subjective nature. However, these efforts have been corrected by the inclusion of the probabilities in the analysis.

Some other experiences (citas...) have proposed the implementation of a system based on fuzzy logic to develop the quantitative analysis of income, cost and risk in PPP projects. These authors have identified that this method is preferable because...

Accordingly, the authors propose a fuzzy logic mathematical approach to apply it in the allocation and quantification of infrastructure projects in Colombia for PPP project development. For this, we have identified four steps in the application of quantitative methods of analysis for the implementation of projects financed in Colombia, Chile and Peru: Identification, Assignment, Measurement, and Mitigation. However, the opinions of experts vary depending on particular interests, and therefore it is difficult to have a unanimous opinion that allows the correct setting of the parameters for these 4 steps. That's why, as part of the validation of information, and in order to find a balanced response should be performed fuzzy analysis of subjective responses for both the public and private sectors.

3. Theoretical and conceptual framework

Classical logic holds that an event may or may not belong to a certain universe as if it contains conditions of ownership within this set. As before, a car can be considered if its full commercial value is high, if your engine is powerful, if the finishes are unique and if production is restricted. In this sense a Ferrari belongs to high-end set while a Renault does not. Classical logic is clear in the separation by placing barriers between each set of elements.

However, because the division between sets depends on subjective or undefined conditions, this membership is not always so simple. Therefore, it is not clear to say that an event belongs entirely to a set. This concept is more clearly belonged-law one meets most conditions but not all event; in these cases could not make the event one party or another set, then what happens? Fuzzy logic postulates the determined degree of membership for which an event may partially belong to one or more sets as the case requires. Alfa Romeo trucks, following the example of cars, belong to the set of high-end and mid-range set with a degree of partial belonged; It is not fully acknowledged within a set.

The same happens with millions of things based on linguistics. What is the limit that marks whether something is high, medium or low? How to know if a temperature is cold or hot? How to tell if something is white or black? These are all vague concepts that classical logic fails to establish clearly, just remember that an object can not only be white or black -that known that Eskimos recognized more than 20 shades of white. Fuzzy logic is a more flexible and complete logic in these situations. A level of 100% owned within a set put us in a particular case of fuzzy logic that corresponds to the classical logic.

A basic definition of risk according to the RAE is "Contingency or proximity of damage ". This risk must be understood on two parameters: the threat and vulnerability (Davis, 2007). These are listed in the following equation.

$$\text{Risk} = \text{Hazard} \times \text{Vulnerability}$$

The threat understood as a magnitude of harm and vulnerability as a possibility of such magnitude occurs. The vulnerability can be expressed by the following relationship:

$$\text{Vulnerability} = \text{exposure} \times \text{susceptibility} / \text{resilience}$$

In mathematical modeling the risk is understood as a stochastic parameter. This leads to the risk is subject to random events. These random events are what are called environment of uncertainty within a mathematical model. These mathematical models with uncertainty are represented by fuzzy variables. For practical purposes, the risk is modeled through these variables.

These fuzzy variables have a "probability space", which is expressed by the degree of membership, or occurrence, within an event. For example, a variable called earthquake that represents the risk of

an event of occurrence of an earthquake in the construction of a building project, is composed of a threat and vulnerability. Threat is understood as the involvement of the structure, and a vulnerability that the probability of this natural event will actually occur during project implementation. Therefore, as denoted expression before, if the threat is high but very low probability, the risk is low. Similarly, although the threat is low, if the probability is high, the risk will remain high because the occurrence of the event is high.

There are two types of uncertainty: stochastic and also known as lexical or inaccuracy. The stochastic uncertainty focuses on the occurrence of an event, it is a question with two possible solutions. (Akbiyikli & Eaton, 2004) We base the lexical uncertainty on the vagueness of the events and the way of perception of events. It is related to how to evaluate concepts and draw conclusions. In this case, complex situations are evaluated using abstraction and referring to analogies. An example is, will it or not be white? Or will it cost more than planned?

Assuming that not all events can be simulated within the parameters of the theory of probability, it is difficult to define the perceived events. That is, the theory of probability to define both an A or B event can occur; however it cannot stipulate the behavior of A or B, or rather cannot define what is A, B or AB. An example of this is seen in the following sentence:

"The projects in the form of public-private partnership, the risk of over-construction costs is taken by the private and vulnerability to the risk of occurrence is high."
(J.Cala, 2015)

The probability theory can model whether or not the risk will occur, however cannot be implemented due to the combination of subjective categories in the process. In other words, it cannot be said to be high or low (Figure 1 and Figure 2).

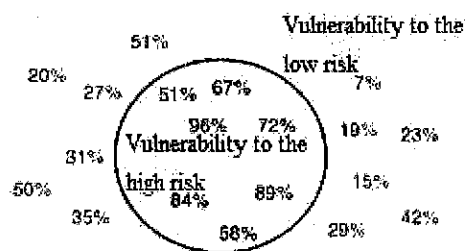


Figure 1. Representation of a set. Classical logic.

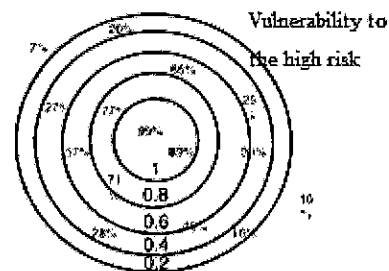


Figure 2. Representation of set b. fuzzy logic.

In the assembly (Figure 1), we have the traditional logic, which is necessary to group the myriad of events in two categories. The events occurring must belong to the set high or not high, that is, in a mathematical reasoning take the values $[0, 1]$.

In Figure 2, a fuzzy set is observed. This type of assembly does not categorize the countless events such as high or higher; but sets limits or levels not clearly defined, the high set membership. That is,

to mathematically model a situation an event rather than "0" or "1" can take values between [0,1]. In this vein, the value of the events within the group can be represented by the function $\mu_A(x)$ in which x is the variable represented within a range between 0 and 1. (Ponz Tienda, Pellicer, & Yepes, 2011)

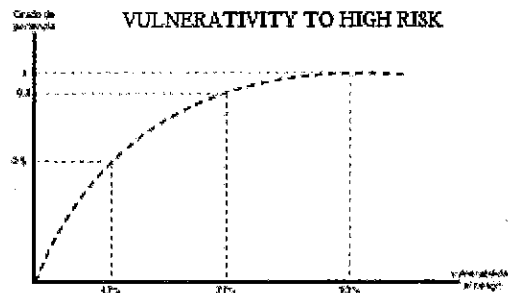


Figure 3. Function belonged Simple variable high risk vulnerability

In the example in Figure 3 it shows that for an event which should be considered if the vulnerability to risk is high, when we have 47% of vulnerability we no longer say it is on the whole not high, but It is set high in a degree of membership of 0.5. That is 0.5 would be correct to say that you have a high vulnerability. As can be seen, the function defines a set belonging Fuzzy. This comes to be understood as an input to the system established with a domain generating a specific grade of membership.

However, the perception of the variable fuzzy logic allows us to combine multiple subject categories. So, for the variable risk vulnerability there will be low, medium, high categories. For each category there will be a membership function. An example of this will be below.

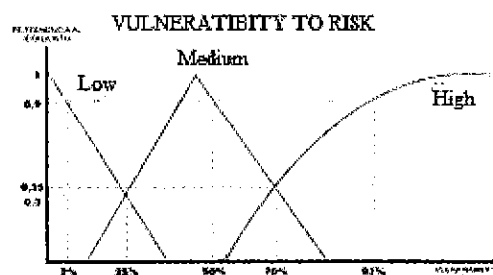


Figure 4. Function Vulnerability categorized variable irrigation.

In Figure 4, the function categorized, in which a specific event may be included within two categories exemplified. Vulnerability of 25% can be understood in two sets with a 0.3 belonged: the

low set and the environment. Vulnerability 70% can be understood as high or medium with a membership of 0.35. Because of this we can create new scenarios of reasoning.

This leads us to believe if necessary and / or desirable to categorize the variables so as to obtain a function categorized rather than a simple? What variables can be categorical? How to define these categories? And even more importantly, how to define functions belonged depending on the variable?

On the issue of risk it is very important to understand that both affect a decision. Moreover, in areas where public-private partnerships, apart from having to see who takes the risk and the percentage, the quantification of this and belonged in the allocation. Therefore, each process variable is intended to model under fuzzy logic has to first go through a process of "fuzzification" that will allow us to develop operations and parameters analysis under the same logic. That is, a normal variable you want to reach fuzzy variable characteristics.

3.1 Fuzzy number and fuzzy set

First, a set of elements in which the degree of membership is continuous and abrupt, is called fuzzy set. Similarly, a fuzzy number is set. This, however, must be convex and regular; you must have a continuous function and sectioned membership. Fuzzy numbers are generally triangular, as seen in the example above: A triangular fuzzy set can be the means allocation in the example of vulnerability to risk. His fuzzy number is given by [10/45/80] all in percent.

Other concepts to consider are the core, the lower support and the upper support. For this case, the core corresponds to the value 45% and has a membership of 1, and supports the values 10% and 80% respectively belonging 0. Another common way to find these kinds of numbers is the keystone; these are not already defined by three but by four values. These will define the larger base with a zero belonged and belonged with a smaller base 1.

3.2 Fuzzy Order

The ordering of fuzzy numbers is the greatest difficulty when performing arithmetic operations or generate conclusions. Clearly with the naked eye, two triangular numbers are impossible to compare if they share a range of values. In the following chart, we show an example of a quantitative analysis of risk quantification, we have two triangular fuzzy numbers and we want to know which of these two numbers is greater.

To accomplish this, there is a method of the centers of gravity, which is to determine the centroid of each of the triangles and compare them. This centroid corresponds to the center of mass number, which can be applied to any type of fuzzy number and it is not triangular.

QUANTITATIVE ANALYSIS OF RISK QUANTIFICATION

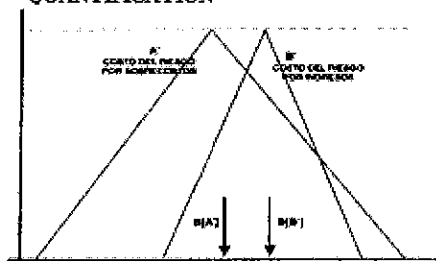


Figure 5. Example diffuse management

Supporting the idea above, normal or sharp numbers are a special case of fuzzy logic, as was mentioned previously. In these numbers the core and the supports coincide.

For the example, although the number A 'has a higher top bracket, the centers of gravity of the triangular numbers do not lead to the conclusion that the cost of risk is greater than the cost income over costs.

3.3 Steps to risk management using the concept of fuzzy variables for the validation of information

Below will be shown as each of the previously mentioned steps for the proper use of risk can be seen from a fuzzy plane.

3.4 Identification: Typology of assessed risks in quantitative analysis.

Within the current methodology of analysis, risks are divided into two groups: on one side are the costs of risk of cost overruns, corresponding to the deviation of the investment costs; and secondly the risk of hospitalization costs corresponding to the deviation in the expected revenue. (Ministry of Economy and Finance of Peru, 2014)

These two kinds of risk are what we call as direct financial cost risk of diversion. This is the first approach to identifying risks public-private partnerships. Generally the costs associated with income risk are taken by the public body; And for purposes of the methodology that should always be made and supported by the public sector. An example of this is the fact that the public sector ensures a minimum rate of vehicles per year traveling on a road made in the form of PPP. Therefore, it is stricter than the rules established by income customers must be made and secured to the private sector from the public.

For the risks of cost overruns must first perform a literature review that includes the study of projects in other countries, which have already been detected, analyzed and categorized into different kinds of risk.

From this shortlist of good risks reported in past studies must make a selection to identify which of all these risks, literature, are more relevant to the national level, for social infrastructure and for future allocation and quantification. In this order of ideas, the dispute moves to identifying the risks of cost overruns, in which engineering risk, bad weather, public policy and others are included.

It is important to emphasize "systematic risk management enables early detection of risks and encourages PPP stakeholders to identify, analyze, quantify and respond to the risks and take measures to introduce risk mitigation policies". (Akbiyikli & Eaton, 2004) An approach to the screening of the risks presented by a project under the PPP mode evidence is presented in Table 2. This identification work is summarized from a literature search to a selection process through a multi-criteria selection or MAUT.

For this selection we should identify the different risk categories that mainly influence the risks associated with operating, legal risks, risks from natural events, risks of social and cultural factors and uncontrollable risks from macroeconomics. All these groups are going to have in all events associated with cost overruns.

To establish the risks to be assessed, quantified and assigned, a project must recognize the principles and factors that influence the equitable allocation of risks APP Projects (Xu, Yeung, Chan Chan, & Wang, 2010). It must be taken into consideration that this identification affect either medium or long-term economic stability of the project, the strength and the tax base and the scope and impact of the project.

Once the pre selection has been made based on "best practices" and review of the literature, a technical level review must be conducted by a panel of experts to verify the validity of these risks on projects associated with the national situation. For which they should introduce a series of questions in order to verify which of the identified groups has greater influence on each project to be assessed. The experts will give a quantitative value from 1 to 5, where 1 corresponds to a group that does not have any influence and 5 to a group that strongly affects the project. Following this evaluate each event affects both identified belonging to the group using the same quantitative criterion.

Once these subjective values have been established, because they come from a personal opinion a fuzzy logic validation should be performed. This will lead us to find the value associated with the vulnerability of the project to each event and risk group using the methodology of "defuzzification" of barycenter's. With the previous result we will know what are the real risks to be considered for allocation. This identification process should be a part of a database that both the public sector and the private sector have for any project, whether it is a school, a hospital, a highway, or a government building.

3.5 Assignment: Application of fuzzy logic in the current model

The mapping process should be run from an academic background in order to ensure the validity and transparency of the risk equitably. Therefore the first thing to be done is to find patterns and mapping projects in other countries, such as assuming a theoretical panel of experts. It will assess and identify at least 10 times the allocation of a specific risk for other projects in order to have a representative base dice.

This process should be performed observing projects corresponding to the same type of infrastructure. Once you have this review, the result of this will be taken into account as part of the real expert panel, consisting of engineers, economist, and administrators. This new panel of experts should, in its sole discretion, assign to 1-5 risk to each party; 1 corresponds to a whole risk associated with the public sector, the value 5 corresponds to an assumed entirely by the private risk and a value of 3 corresponds to a risk assumed alike. (Chang, Jimenez, McAleer, & Pérez, 2011)

The validation of these opinions will be performed using fuzzy logic. Using the centroid again reach a value assignment for each of the associated risks. Based on these opinions we will get the fuzzy number vertices. From there all alpha cuts are calculated.

The center of gravity, which in this case corresponds to the value 1.87, is calculated. Corresponding rule 3 to approximately 80% allocation for the public sector and 20% private. Once the academy has reached a value of allocation should be socialized with stakeholders. Each party must be able to assume the risk percentage by value of quantification.

3.6 Measurement: Application of fuzzy logic in the current model.

Once the assignment has been made, you begin to speak of retained risk (public sector) and transferred risk (private sector). At this time, the current methodology introduces the concept of public private CPP or comparator. This is an element of analysis of revenues and costs required by law and regulated by the National Planning Department in 2014.

Measurement, attempts to quantify the impact that affects the cost of the project investment. For this you must keep in mind two scenarios: the first one is where it is assumed that the risk does not occur and where the expected value of the project cost is about zero. In the second scenario, the risk occurs with an estimated probability and the associated loss is a factor (fraction) between zero and one of the investment cost (CI). Therefore, the value associated with the project cost overrun in a given risk, taking into account the two scenarios is equal to the product of the probability factor and together with IQ. (Ministry of Economy and Finance of Peru, 2014)

$$E \text{ (on cost)} = \beta * P * CI \text{ (occurrence of risk)}$$

However there will always be controversy about the factor to use for each risk and the likelihood of risk. These values, according to the methodology proposed must be extracted through two processes. The first is the review of projects, previously selected and classified according to their type, which will form a guide of good practices that will be the starting point of our analysis. First you should evaluate projects from different countries to Colombia with great power in the field of infrastructure projects PPP mode. These countries are Chile, Mexico, Peru, United Kingdom, Australia and China, as they have found in this investigation.

Analyzing these projects should find the rate of occurrence of each risk assigned. Likewise you have to keep track of the percentage cost overruns on each CI I entail. Once the data is available, and the sample is representative for the type of project to be analyzed we should perform a statistical analysis to see the spread of the data and to validate them. Once this analysis is obtained and data validity checks, these are modeled on fuzzy numbers, following the model presented in the allocation. Subsequent to this review, you should check for similar projects already undertaken at the national level. If there is need to perform the same analysis with external projects.

Now the second process for risk measurement is performed through a panel of experts. Which must establish a professional approach and an analysis of the project it is the probability of occurrence of risk and budgetary factor involvement. These subjective values of each expert be validated by fuzzy numbers. They also correlate with those found in the literature search. In order to reach a unified consensus value range of each parameter.

Now this expected value should bring this value to perform the proper analysis taking into account the value of money over time. However, this discount rate with which it is done must be projected inflation. This process must also find the factors of each risk analyzed in order to determine patterns of error. These error patterns form the guide of good practices for projects in Colombia.

4 Conclusions

A base for future development of the country lies in the development of its infrastructure. There is currently a strong impetus to the construction of road infrastructure; however it is necessary to encourage private and public initiative towards the implementation of social infrastructure projects. A fundamental part of this is the regulation of identification standards, allocation and measurement of the risks associated with such projects. Colombia currently has no specific and clear rules to regulate the methodology of these three concepts. Therefore an approach to a new equitable and transparent methodology for risk management does believe that Colombia could become one of the most developed region in terms of social infrastructure countries.

Finally, it is up to the academic to be the mediator in all the interests of both parties (public and private). Fuzzy logic, like many academic data validation tools can handle capturing subjective data, which is necessary for these cases. To achieve a correct and complete risk management public-private partnerships would be the main engine of social development in the country for the coming years, as seen from the construction sector.

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Risk Assessment Proposal for Social Infrastructure through Public-Private Partnerships in Colombia

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Abstract

The implementation of Public-Private Partnerships (PPP) has provided an opportunity to cover the need for investment on social and economic infrastructure. The success achieved with the development of PPP projects on countries such as Australia and the United Kingdom, has established a significant start point for countries like Singapore, China and Mexico. International experience and many studies have identified that the viability and success of PPP projects in social infrastructure depend on two main factors: a strong public policy and adequate risk management among participating parties. This research presents a methodological proposal for risk allocation in social infrastructure projects in developing countries, adapted to the especial characteristics of the Colombian context, partially filling the existing gap in scientific literature. This paper is divided in two parts. First, the authors argues the benefits of creating, and establishing a national public policy based on the legal implementation and development of PPP projects in the pursuit of economic, social and environmental prosperity. Finally, this study presents a proposal for the creation of a reliable and practical model to achieve an adequate risk allocation for social infrastructure, based on the selection of 17 critical risks using the multi-criteria decision method and the design of a structured interview for experts in different contexts.

Keywords: Public-private partnerships, social infrastructure, risk management, national strategy

1. Introduction

The scheme of Public Private Partnerships (PPP) has been presented as an opportunity to bridge the gap of infrastructure deficiency without compromising national resources, obtaining more efficient and higher quality projects. Especially, PPP is the provision of a public service by a distribution of responsibilities and risks between a public actor and a private actor. Since its implementation in 1992 in the UK, 193 countries around the world have implemented and accomplished projects under this scheme (Chou & Pramudawardhani, 2015). This worldwide application of PPPs has been used in a variety of projects ranging from energy supply projects (Pongsiri, 2004), to telecommunications and subsidized housing (Efficiency Unit, 2003). However, given its complexity and nature, its implementation has not always been successful.

One of the main causes of failure is the improper risk allocation management. (Efficiency Unit, 2003).

The implementation of PPP schemes in emerging economies has been slow due to diverse political, social and economic factors. In Latin America it has been specially difficult as a result of: (a) political instability in the region, (b) the challenging assimilation process of changes to the traditional status-quo, especially given to the presence of private operators in the provision of public services, and (c) the high risk premiums demanded by private participants in the development of projects due to high initial investments, distant cash flow incomes and the country economic risk (Engel, Fischer, & Galetovic, 2008).

Although there are many studies in risk management for PPP, in the analyzed literature, no studies were found which evaluated the risk allocation for social infrastructure in developing countries. Therefore, to partially fill this gap, the authors propose a risk allocation methodology for social infrastructure projects in developing countries, adapted to the Colombian context.

This exploratory research is divided in two stages. The first one follows a PPP qualitative approach which is based in a comprehensive review of related literature and the identification of the most relevant risks in the PPP projects. Stage two follows a quantitative approach for risk identification thoroughly an analysis of the Colombian context. The risk selection process was conducted through two steps. (1) Pre-selection of most relevant risks in literature choosing those that appeared in 5 or more studies. (2) A final selection was made by the method of Multi-Attribute Utility Theory MAUT. For each risk, 5 criteria were analyzed and objectively quantified when possible and subjectively qualified by experts on a scale of 1-9: (A) Scientific literature relevance. (B) National impact, (C) Applicability to social infrastructure (schools, hospitals, government buildings, plant sewage treatment, etc.), (D) Public-private relationship and allocation, and (E) Value For Money (VFM) impact (Economic viability for the public sector). Finally, a proposal for risk assessment is made to allocate the identified and qualified risks.

To introduce this proposal properly, section 2 deals with the advantages of PPP as a strategy for growth and improved competitiveness and the specific issue of social infrastructure development. Section 3 illustrates the state of the art for risk management in PPP. Section 4 gives an introduction to the Colombian context. Section 5 exposes the proposal of risk allocation and finally conclusions, limitations and future extensions of the research are drawn.

2. Public Private Partnerships

The collaboration between public and private sector has been materialized in the concept of Public-Private Partnerships (PPP) that are related to the contractual cooperation between public authorities and various private agents to achieve objectives for the public goods provision and its corresponding services. According to the World Bank (2012), PPP have four characteristics and relevant principles: a) Projects with a long-term development, b) Private investors participates in the financing of the project, c) The private investors is responsible for the infrastructure

maintenance and operation, d) The relationship between the public and private parties must establish an appropriate risks distribution.

There are three advantages in PPP contracts implementation (CAF, et al., 2010): a) Technical innovation due to the competition between proponents and the inclusion of the private agent in the design, construction, financing, maintenance and operation of the project, b) The private sector investment in social infrastructure set free the public budget for other types of investments, c) Improvement in the project quality due to strong monitoring and evaluation from public institutions.

However, the main opponents of the PPP procurement system identifies two disadvantages for its execution (CAF, et al., 2010): a) PPP transaction costs are higher than transaction costs generated by traditional public project, b) The PPP require greater financial cost compared to a public project financing through public project.

National infrastructure, both physical and digital, is an important instrument of social interconnection (CAF, et al., 2010). It has the ability to integrate space, improve accessibility and make certain the equality on populations. A good infrastructure guarantee of international competitiveness, job creation and economic stability. Yescombe (2007) Identified two infrastructure types: a) Economic: Describe all assets or property that aims to provide a function and economic activity. E.g. road, canals, and railroads, b) Social: Infrastructure dedicated to provide a public service with social purposes. This projects are usually smaller in scale and, therefore, tend to be complex, given the close and ongoing involvement with the community (Jefferies & McGeorge, 2009).

There is a confrontation of opinions on the purpose of carrying out projects under the scheme PPP. For example, Leone (1999) establishes that PPP projects are a "words game" created by the leaders to hide the privatization of assets and present an "attractive idea to the voter's minds". On the other hand, McGeorge (2009) establishes that PPPs are a funding mechanism for the public sector where the private sector assumes responsibilities and risks. Although the discussion is also presented in economic infrastructure, the development of PPP projects in social infrastructure increases and amplifies the discussion. This is mainly due to the presence of a private operator in the provision of public services which are directly related to the person, because it makes it particularly difficult to accept by the user and citizen. Jefferies & McGeorge (2009) identify this discussion as one of the primary constraints to the development of PPP projects in social infrastructure as "private-sector bidders are often presented with a situation where the financial rewards are less and the operational demands are more complex than for hard economic PPP projects".

3. Risk management in PPPs

As mentioned by Seldon Global SC (2014) , "the key to understanding the role of risk in a PPP is the link between the way in which the risks are managed and the degree of efficiency achieved in the projects". The development of a public-service project whit private participation requires it to

assume certain responsibilities to ensure the quality and continuity of the service. The transfer of risk to the private agent is the most appropriate way that it assumes responsibility for the project development. However, this also means that the private sector have to effectively minimize their risks, get a maximization of economic benefit, considering that the materialization of risks results in high costs and potential economic losses. Accordingly, risk quantification and allocation determined the economic viability of the project and the benefits obtained by the government for developed the project through the PPP scheme. Therefore, as shown, risk management plays a key role in all stages of project development, from planning to operation and maintenance.

Cases such as Indonesia and Thailand, reflect the importance of proper risk management. In those, the increase in economic rates, regulatory changes and land acquisition did not allow the private party development the project properly and the project had high economic costs and created absolute mistrust between participating sectors (Ogunlana, 1997). On the other hand, cases such as Hong Kong and the United Kingdom are a clear example of successful implementation of the PPP scheme, Bing, et al (2005) argued that the high success rate of PPP in the UK was due to effective risk allocation caused by the properly communication between the parties involved on.

Finally, risk management defines competitive advantage of a private proponent within the local market. Basically, experience, innovation for cost reduction and the perception of risk assumed by the private agent are the factors that will define the competition for the development of a proposal for allocation risk in social infrastructure PPPs.

4. Colombian context

Latin America and the Caribbean have shown an increasing economic growth since the beginning of the millennium, demonstrating its solid growing potential. This is often encouraged by the development of infrastructure projects as it provides the means for increasing national competitiveness and directly improves employment rates. The growth rates of these emerging economies reached 10.5% and 9.0% respectively (Inter-American Development Bank, IDB, 2008).

In the Colombian context, the National Competitiveness Report (Private Council on Competitiveness, 2014) shows a current worrying situation in the country weakening from 68th place among 139 countries to 66th place among 144 countries. Despite the successful growth of the Colombian economy in the last decade and the implementation of programs of social and economic development (seventh place in Latin America), Colombia is so far away from the goal set for 2032, in which it was intended to be the third most competitive economy in Latin America. This may be the evidence that the country is in a development stage and that the infrastructure development instruments have not been appropriate to achieve a more competitive economy.

The most concerning issues the country should focus on, obtained from the Private Council on Competitiveness (2014) are: a) Health and elementary education: In this issue Colombia has fallen 26 places since 2010 and is currently ranked 105th worldwide and 14th in the region. As mentioned above, human capital is one of the bottlenecks in productivity in Latin America,

especially in Colombia. For example, the coverage of elementary education is a great concern. That is to say, it is not just a quality problem regarding teachers training, it is also educational infrastructure coverage, access to it and therefore, financing of it. The main issue with the health system is it is difficult to access and of low quality. b) Efficiency of the employment market: The country is currently ranked 84th worldwide (15 places down from 2010), this element is directly related to regulatory and legal subjects around minimum wage laws and tax issues. c) Infrastructure: The country is currently ranked 84th in the world in reference to this issue, with more than 30 stalls difference with Uruguay, the country with the third most competitive infrastructure in Latin America. Beyond the lack of road, rail, port and airport infrastructure, Colombia has deficiencies in sectors such as energy supply, where it is identified that the main constraints are the efficiency of the industry and regulation of the sector. Nowadays it is developing the structure of the fourth generation of road concessions, where it is expected to reduce the deficit of road infrastructure. d) Innovation: This pillar has lost 12 positions, reaching 77th place in the world and ninth out of 13 Latin American countries in 2014, this is worrisome because the country has 346 investigators per million of citizens. According to the World Management Survey (World Bank, 2014), the country is the worse qualified in terms of quality management in Latin America, the central problem of this issue is the absence of a medium and long-term public policy. According to the Private Council on Competitiveness, "the country still lacks an effective structure that allows to align the different public and private stakeholders in initiatives that generate productivity and sophistication of national production through the use of local competitive advantages" (Private Council on Competitiveness, 2014).

Devlin and Moguillansky (2009) identified different countries that achieved during 2003 to 2012, closing the income gap compared to richer countries in more than ten points. This was the case of Spain, Finland, Ireland, Korea, Singapore, Australia and New Zealand. Despite their difference, several important similarities for obtaining these national achievements in economic progress were identified. Mainly, the remarkable development of these countries has its basis in the formulation and implementation of a strategy in the medium and long term to promote accelerated production change. That means, establishing lines of action with specific objectives to determine and achieve international integration of the country, reduction of poverty and increased productivity, and therefore increased competitiveness. These strategies can be based on the development of multi-year plans that should have the following priorities: a) Economic stability, b) Robust tax policy, c) Solid investment rates, d) International dynamic, e) Innovation and human development, f) Conservation of national practices.

Hausmann, Rodrik and Velasco (2006) identified that due to market failures, these strategies tend to be selective because governments have limited resources to carry out projects, programs and promote resources for development. Moreover, unlike the nineteenth century where the public sector were the main sponsor of the market, nowadays the private investments dominates the production sector. Therefore, the development of countries requires cooperation between the public sector and the private sector, which allows them to "get the opportunities of social benefits and resolve the primary constraints of new productive activities" (Devlin & Moguillansky, 2009). Through a PPP scheme, the public sectors could get involved in a partnership with private sectors for the development of infrastructure.

5. Proposal for risk assessment for social infrastructure PPPs in Colombia

The proposal for risk assessment is divided into two stages. The first one stage is the risk identification and selection for the assessment process. The second stage is the proposal for risk assessment.

5.1 Risk identification and selection

Multiple previously studies have concentrated its efforts in identifying, measuring and mitigating risks process involved in developing projects through PPP. For example, Bajaj, Oluwoye, & Lenard (1997) focused on analyzing the methodologies used for identifying risks. They found the most commonly method used was the top-down strategy. This analysis makes a hierarchical list based on stages, each stage more detailed than the previous one. Another frequent method is the brainstorming process as a system for the risks identification and quantification, in which staff involved experienced engineering and senior officer's judgment (Baker, et al., 1999). Similarly, other authors such as Bing, Akintoye, & Edwards (2005) , and Heravi & Hajihosseini (2013) have focused on summarizing the positive and extensive experience of countries like Australia, India and the United Kingdom respectively. Recent studies as those conducted by Chan, et al (2011), Hwang, et al (2012), and Wang, et al (2004) based the development of their research in countries that are just implementing the PPP scheme as China, Singapore, and developing countries such as Chile and Mexico. These researches reach similar conclusions about the need for a risk allocation model on PPP projects implementation. To achieve a risk allocation model, they run the methodology used by Bing, et al (2005) . This development is based on a questionnaire of three sections. In the first part is evaluated the personal knowledge about the PPP subject and its influence and membership within the construction industry. In the second section it is established the risk assessment asked. This is done through an evaluation system 1 to 5, wherein the scale represents: 1 = totally assumes the public sector, 2 = mostly assumes by the public sector, 3 = equally shared by public- private, 4 = mostly assumed by the private sector and 5 = fully assumes by the private sector. As a result from the preview studies, 72 risks in PPP projects were initially identified.

After the risk identification from literature review, a specific selection process was conducted through two steps:

Pre-selection from repetition in previous studies: the type of risks that had been previously studied in different countries was analyzed and summarized by recording the frequency in which each risk appeared in one of the studies identified. The risk that appeared in more than 5 studies was pre-selected. Thus, 27 definitive risks where selected to be quantitatively categorized.

Table 1: 72 Risks identified on the literature review

RA1	Unstable government	RA19	legal/regulatory framework	RA37	High finance costs	RA55	Technological risk
RA2	Expropriation of assets	RA20	contract variation	RA38	Residual risk	RA56	Operation default
RA3	Poor public decision-making	RA21	Immature juristic system	RA39	Delay in project approvals	RA57	Organization and co-ordination risk
RA4	Strong political opposition/hostility	RA22	Improper of contract	RA40	Design deficiency	RA58	Inadequate distribution of risks
RA5	support from government	RA23	standard model for agreement	RA41	engineering techniques	RA59	distribution of authority
RA6	Corruption and bribery	RA24	Inability of concessionaire	RA42	Scope variation	RA60	Differences in working method
RA7	Government's intervention	RA25	private provision of public services	RA43	Workmanship	RA61	Lack of commitment from either partner
RA8	Government's reliability	RA26	Level of public opposition	RA44	Construction cost overrun	RA62	Private investor change
RA9	government support network	RA27	Market demand change	RA45	Construction time delay	RA63	Third Party Tort Liability
RA10	Termination of concession	RA28	Force majeure	RA46	Material/labor availability	RA64	Staff Crises
RA11	Inflation rate volatility	RA29	Geotechnical conditions	RA47	Poor quality workmanship	RA65	Competition (exclusive right)
RA12	Interest rate volatility	RA30	Weather	RA48	Insolvency of sub-contractors	RA66	Tarif change
RA13	Influential economic events	RA31	Environment	RA49	Site safety and security	RA67	Payment risk
RA14	Foreign exchange and convertibility	RA32	Land acquisition)	RA50	Operation cost overrun	RA68	Lack of consortium expertise
RA15	Financial risk	RA33	Uncompetitive tender	RA51	Operational revenues	RA69	Subjective evaluation
RA16	Legislation change	RA34	experience in PPP projects	RA52	Low operating productivity	RA70	Insufficient financial audit
RA17	Change in tax regulation	RA35	Availability in finance	RA53	Maintenance costs higher	RA71	Construction/operation change
RA18	Industrial regulatory change	RA36	Financial attraction	RA54	Maintenance more frequent	RA72	Intellection property

Final selection, Multi-Attribute Utility Theory MAUT: Each risk was analyzed on the basis of 5 criterions, objectively quantifying them when possible and subjectively qualifying them by a pool of 6 experts in a focus group session. A percentage weight was assigned to each criteria and each risk was evaluate against every criteria through a scale of relevancy 1 to 9.

- A. Scientific literature relevance: frequency of appearance previously outlined was taken into account. For this criteria was defined a weight of 25%.
- B. National impact: each risk is placed within the national context. That is, the applicability to the reality of the Colombian construction industry is sought. For this criteria was defined a weight of 10%.

- C. Applicability to social infrastructure: In this criterion is evaluated the degree of risk for the development of social infrastructure projects such as schools, hospitals, government buildings, plant sewage treatment, etc. For this criteria was defined a weight of 20%.
- D. Public-private relationship and allocation: This criterion aims to capture the concerns about risk allocation. That is to say, questions whether the risk has a tendency to be adopted by default to any of the (public or private) agents or risk allocation is a real unknown quantity. This section was given a special importance because these are the risks that the study aims to concentrate. For this criteria was defined a weight of 20%.
- E. Value For Money (VFM) impact (Economic viability for the public sector): Since the risks are significant in the economic analysis of the project and the VFM, it is taking the economic risk into the account associated with each risk. For this criteria was defined a weight of 25%.

After this evaluation, the importance of each risk was calculated as the sum of the multiplication of the percentage weight by the scale of relevancy. Thereafter, the average of the all risks weight was determined. Finally, 17 risks were located over the average and these were selected as the most relevant risks that affect the successful implementation of PPP on the issue of social infrastructure projects these risks are presented in Table 2.

5.2 Risk assessment proposal

Most of the studies reviewed based on the generation of a questionnaire which is directed at people with experience in the construction industry, in the public sector, private sector and academy. However, the main problem of these questionnaires is the low response rate. Roughly, the response rate is around 20% and 40% (Akintoye, 2000). Consequently, the amount of sent questionnaires needed for effective data analysis represents a serious problem. Additionally, it is not always possible to guaranty the reliability and quality of responses. Therefore, it is often proposed to conduct a number of structured interviews to characters with high experience and knowledge on PPP in the specific context where the risk management process is taking place.

The interviews have to be made to PPP experts from the academia, public sector and private sector. The involvement of academia is essential. As manifested Osipova & Erikson (2013), the best method to achieve agreement on the management of risk is with the incursion of the academic world to determine an optimal method where several opinions about risk management, are combined. Likewise, it is important to involve some private sector agents and governmental organizations who have exercised the function of regulatory body of the PPP's. Within the national framework, it is suggested the involvement of the National Planning Department, the Ministry of Finance and the Ministry of Education.

The interview will be divided into three stages, such as the questionnaire division given by Chou, et al. (2012):

The first stage involves a socialization and context with the interviewee. Initially, it will be explained to the person to conduct the study, the objectives, the methodology followed in the

interview and the importance of the study. Similarly, in this part some specific data will be asked to the interviewee to evaluate the credibility of his answers in the following stages. The necessary data to request are: Sector in which works (public, private or academic), and years of work experience in construction projects and projects under PPP mode.

Table 2: Selected risks

<i>Risk</i>	<i>Group membership</i>	<i>Definition</i>
<i>Expropriation of assets</i>	<i>Governmental</i>	<i>Given political, social or economic pressures, the government take ownership of the project without proper compensation to private.</i>
<i>Corruption</i>	<i>Governmental</i>	<i>Selection and development of projects under illicit schemes and decisions to promote other interests.</i>
<i>Inflation rate</i>	<i>Macroeconomic</i>	<i>Unexpected and significant changes in interest rates and inflation, due to immature economy and a local non-consolidated market.</i>
<i>Interest rates</i>	<i>Macroeconomic</i>	
<i>Legislative changes</i>	<i>Legal</i>	<i>Vulnerability to a change in government regulations, including tax policies, which affect income or established project costs from the viability stage.</i>
<i>Tax regulation changes</i>	<i>Legal</i>	
<i>Demanding market</i>	<i>Social</i>	<i>Inadequate methods for determining demand stage project operation and maintenance requirement.</i>
<i>Environment</i>	<i>Environment</i>	<i>Public regulation with high requests on the environmental impact of the project.</i>
<i>Land acquisition (availability)</i>	<i>Project selection</i>	<i>Difficulty in time and / or costs to acquire the land needed for the project.</i>
<i>Residual risk</i>	<i>Residual</i>	
<i>Delay in project approval and permits</i>	<i>Residual</i>	<i>Difficulty in obtaining documents required for a legal framework for the proper development of the project.</i>
<i>Operation cost overrun</i>	<i>Operation</i>	<i>Higher costs than expected in the operation stage.</i>
<i>Public private coordination</i>	<i>Operation</i>	<i>Lack of coordination and coherence between public and private.</i>
<i>Low experience in PPP projects</i>	<i>Project selection</i>	<i>Low national experience in the development of social infrastructure projects under PPP scheme.</i>
<i>Absence of a legal framework.</i>	<i>Legal</i>	<i>Inappropriate or contradictory legal framework to the development of projects under PPP scheme.</i>
<i>maintenance costs</i>	<i>Operation</i>	<i>Higher than expected costs in maintenance of assets.</i>
<i>Technological risk</i>	<i>Operation</i>	<i>Project vulnerability to technological disadvantages and therefore the presence of a constant need to update.</i>

The second stage involves the assessment of previously identified risks. To perform this method, three important aspects must be considered. First, a dictionary of risks to ask must be prepared if the respondent does not easily recognize the applicability of risk in a PPP project. Second, it is recommended that the respondent, with the aim of further analysis, give an opinion about the role of these risks in social infrastructure and economic infrastructure. To facilitate this discussion, the risks should be asked in the context of an important project (hypothetical or real) in public politics. That is an important current project is introduced like a complex of schools or hospitals and it is compared against the development of a concessioner highway. Finally, assess their responses on a scale of 1-5, where the scale represents 1 = totally assume for the public sector, 2

= most assumes for public sector, 3 = equally shared by the public and private sector, 4 = assumed mostly by the private sector and 5 = fully assumes the private sector.

The last step is a final stage of completion where it is located different questions related to the future of PPPs in social infrastructure. For example, you can ask:

- What is the next step for PPPs in social infrastructure evolve?
- Do you believe that PPPs in social infrastructure will become of the magnitude and importance of the concession highways?
- How important is the PPP scheme to satisfy social public policies?

6. Conclusions

This study is divided into two parts. In the first part, the benefits of the implementation, develop and evolve of PPP contract scheme is exposed. Beyond the typical discussion of PPP efficiency gains and cost reduction, this study defines PPP as a government instrument to carry out projects of national importance. Given the nature and characteristics of the projects, PPP acts as a central hub for the establishment of a national policy in the medium and long term, which seeks an economic, social and environmental well-being and, ultimately, an axis of development and productive transformation.

The last part analyses the importance of risk management and the role of risk allocation through international experiences of private investment in social infrastructure. Formerly a proposal for the process of risk allocation for social infrastructure projects in Colombia is developed. In order to do so, an extensive literature review about the risks involved in the development of PPP projects was made. In this research, a list of 72 risk was obtained on the basis of their relevance in reviewed literature and subsequently narrowed down to 17 critical risks using multi-criteria analysis. Five evaluation criteria were used: frequency of appearance in reviewed literature, national impact, criticality in social infrastructure, public-private definition and economic impact.

Lastly, an expert opinion evaluation to effectively allocate risks is suggested. Given the low response rate of questionnaires, the development of semi-structured interviews to a selected group of experts from the industry, the public sector and the academy is proposed as an alternative.

For the purposes of validating and enhancing this model, it is suggested that further research focuses on the selection of a representative project sample in Colombia to implement the risk allocation process proposed in this research and evaluate the feasibility of the development of this type of projects under the PPP scheme on the basis of the concept of Value For Money. The resultant adjusted proposal should be implemented in Colombian social infrastructure policies.

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Clients' Perception on Risk Sharing in Construction Projects

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Abstract

Risk Sharing is a concept of equitable allocation of identifiable and quantifiable risks at pre-contract stage, followed by their dynamic management at post contract stage, for which general/flexibility provisions should be made in the contract conditions, because not all risks are foreseeable/predictable and/or quantifiable at the planning stage. Moreover, risks may change with project progress: some risks may become more critical, some other risks may disappear, while some other risks may need some degree of joint efforts of contracting parties for their effective management. The objective is to minimize the risk and total cost of risk to a project, not necessarily the costs to each party separately. On the basis of such conceptualization, the present paper summarizes the outcomes of a questionnaire survey that examined the perceptions of 48 respondents from construction clients in Brunei on present and preferred sharing of 28 common risk items, as well as the criticality (or severity index) of those risk items in terms of their importance and frequency of occurrences. The respondents have considerably differing perceptions of risk allocation, with extreme divergence in most of the risk items. Despite such divergence, respondents have demonstrated a general enthusiasm towards shared or joint management of risks as they opted for about 18-53% of expected shared risks. Three risk items were identified as 'most important' in terms of their importance index, with the most of the remaining risk items are 'more important'. No risk item was verified as 'most critical', but most of the items were 'more critical'. Moreover, there seem to be no clearly identifiable relationship between the degree of risk sharing and critical index of the risk items. The outcomes are expected to allow the clients to better formulate construction contracts to effectively manage construction risks. It is also expected to further allow a better understanding of dynamic risk management and the need for proactive contracting in construction.

Keywords: Construction industry, proactive contracting, risk allocation, risk sharing, risk importance

1. Introduction

One of the principles of risk allocation is that the party best able to manage a risk should bear the risk. However, clients are seen to exculpate risks to contractors, especially in the traditional procurement regimes, without considering if contractors can manage those risks. Contractors too assume those risks, without considering if they can manage those risks, in order to do business, and survive (Ahmed *et al.* 1999). Obviously, contractors may better manage some of the risks, but clients may better manage some other risks, and some other risks may better be shared or managed jointly by clients and contractors. The goal of optimal risk management should be to (a) “minimize risk – whomever risk it may be” (ASCE 1979), and (b) minimize the total cost of risks to a project, not necessarily the costs to each party separately (CII 1993).

Construction risks are often project specific, and allocated to different parties through definitive contract conditions, on the basis of information available at the time of contracting. However, the nature and extent of such project-specific risks can only be realistically appreciated at later stages during the project execution. The nature and extent of risks may change along with project progress. New risks may emerge and existing risks may disappear or change in importance or be re-allocated. Any such changes may also ease or aggravate some other risks. Moreover, some of the risks may occur more frequently than some others, and some of the risks may have more impact on project objectives than some others. Some of these risks may also need to be shared between contracting parties or managed using the combined efforts of contracting parties for their effective management. Therefore, proper and exhaustive allocation of risks cannot be achieved through contract conditions alone. Instead, what needs to be done, is to equitably allocate all identifiable and quantifiable risks at pre-contract stage, on the basis of available information. This needs to be coupled with some flexibility crafted in the contract documents, in order to allow proactive appreciation of any changes to those allocated risks, identify any new risks, assess or re-assess them, re-allocate and/or share those risks and jointly manage them with the collaborative efforts of major contract parties at post contract stage, using a joint risk management (JRM) strategy, and as the situation requires (Rahman and Kumaraswamy 2002).

Two previous studies in this area were conducted by Hartman et al. (1997) in Canada, and Rahman and his collaborators in Hong Kong (Rahman 2003, Rahman and Kumaraswamy 2002, 2004). The Canadian investigation compared perceptions on present and preferred allocation of risk. In addition to that, the Hong Kong study addressed attitudinal aspects of contract parties towards the suitability of any shared parts of any risks leading to a probable JRM model. The present study goes further from these two studies and investigates both present and preferred risk sharing arrangements between client and contractor, as well as attempts to assess criticality of various risk items in terms of their frequency and impact on project objectives.

2. Methodology

The overall research project was designed with literature review, and two surveys. The present paper summarises the interim outcomes of the study, on the basis of first questionnaire survey,

which was focused on respondents from cliental organisations only. The objectives of this paper are twofold:

- To compare the perceptions on present and preferred risk allocation between clients, contractors, and 'shared' between them; and
- To assess criticality of various risk items in terms of their frequency and impact on project objectives.

Data was collected using a structured questionnaire survey. The questionnaire was carefully designed to meet the above objectives, pilot-tested by two industry experts, and improved based on the opinions obtained from the experts. There were four sections in the questionnaire. Section One included an 'introduction' clarifying the risk sharing concept and solicited experience based opinions of the respondents. Section Two was designed to collect respondents' information for the survey sample composition. Section three contained an inventory of 28 risk items. All the 28 risk items have been shown in their entirety in Tables 2 – 5. The risk items were mainly sourced from Rahman and Kumaraswamy (2002), but adjusted to suit local situations and to meet the opinions obtained from two experts during the pilot test. Most of the risk items that were identified and verified in this manner, are also commonly reflected in standard forms of construction contracts, since risks are allegedly allocated through the conditions of contract. The respondents were requested to reflect their opinions on the above mentioned 28 risks in terms of their perceptions of present and preferred risk allocation in conventional construction contracts, i.e. what percentage of a particular risk presently lies or they prefer to be:

1. with the client (X, from 0 to 100);
2. with the contractor (Y, from 0 to 100); and
3. shared between the client and the contractor (Z, from 0 to 100); in such a way that the sum of X, Y and Z equals to 100.

Section four contained the same 28 risk items and was designed to collect information on their frequency of occurrence and importance or impact, if they occur. Respondents were asked to assess and write scores on a scale from 1 to 5: 1 being the 'least frequent/important' and 5 being the most frequent/important. Additional spaces, to both the inventory of risk items in sections 3-4, were provided requesting respondents to add any risk items if they think important, and to assess the same. Moreover, blank space was also kept at the end of the questionnaire to allow the respondents to provide any comments / suggestion on effective risk management in general.

Public Works Department (PWD) of the government of Brunei Darussalam assisted in distributing the questionnaire to its officers and collecting the responses from them. As such, 48 responsive responses were received, with an average total work experience of 10.13 years, and average experience directly in construction of 9.38 years, as shown in table 1. This may relate to the quality of the data, as they are considered to reflect the experiential knowledge of the respondents. During the time of the survey, respondents were working on an array of positions, and with various kinds of managerial (e.g. project manager, assistant project manager, quantity surveyor, site supervision, and contract manager) and engineering type of responsibilities (e.g.

structural designer/ engineer, architects, architectural designer, and quantity surveyor). There were 17 engineering, and 29 managerial respondents. Two respondents did not mention their designation and/or nature of job. The data may therefore be considered to represent the public sector of Brunei, both in terms of coverage of works related to public services, and types of job, i.e. nature of experience of the responses.

Table 1: Summary of respondents' profile

<i>Description of information</i>	<i>Total sample</i>	<i>Engineering</i>	<i>Managerial</i>
<i>Responses received</i>	48	17	29
<i>Average Total work Experience (years)</i>	10.13	9.38	10.57
<i>Minimum work experience (years)</i>	1	1	1.4
<i>Maximum work experience (years)</i>	27	25	27
<i>Average experience in construction (years)</i>	8.33	8.06	8.5
<i>Minimum experience in construction (years)</i>	1	1	1
<i>Maximum experience in construction (years)</i>	27	25	27

3. Perception of risk allocation

Responses on risk allocation directly indicated the percentages of risk related to each risk item that is perceived to lie with the client, contractor and shared between them. The analysis was done by arithmetically averaging these figures for each risk item, separately within the total sample of 48 responses, as well as within each group based on nature of job (e.g. engineering and managerial). However, this paper presents summary results only, hence only the outcomes from the total sample are presented.

Table 2 shows perceptions of risk in percentage terms that presently lies with clients for the total sample of 48 responses, along with the respective standard deviations (SDs), minimum scores and maximum scores. It is seen that, except for the two risk items, minimum scores for all the risk items are zero, meaning clients are not allocated any risk on these items. On the other hand, 17 risk items have 100% scores, meaning clients have the entire amount of risks of those items. The maximum score of the remaining 11 risk items vary from 50% to 90%. On the whole 16 items have extreme divergence (i.e. minimum zero and maximum 100). Such diverse minimum and maximum scores produced averages from 19.0% to 52.1%, along with high standard deviations (SDs), which in turn also indicate a wide spectrum of responses. Although not shown here, similar pattern of responses (i.e. general diversity with extreme divergence on most of the risk items) was observed for the rest of the options on risk allocation, both for present allocation and preferred allocation. Such a widespread divergence within the same contract party (i.e. client) may relate to their superficial involvement in preparing and managing contracts, and resulting in to a kind of subconscious demotivation or disinterest, as consultants prepare and manage contracts for them. Such divergence may well arise from varied personal experiences and therefore highlight a need for cooperative learning as well.

Table 2: Average perceptions of present allocation of risks with clients (in % terms)

<i>Risk ID</i>	<i>Risk description</i>	<i>Average</i>	<i>SD</i>	<i>Minimum</i>	<i>Maximum</i>
<i>F-01</i>	<i>Acts of God/nature</i>	<i>39.7</i>	<i>35.2</i>	<i>0</i>	<i>100</i>
<i>F-02</i>	<i>Change in scope of work</i>	<i>43.9</i>	<i>23.2</i>	<i>10</i>	<i>100</i>
<i>F-03</i>	<i>Change order evaluation & negotiation</i>	<i>39.5</i>	<i>15.6</i>	<i>10</i>	<i>80</i>
<i>F-04</i>	<i>Changes in codes and regulations</i>	<i>32.7</i>	<i>23.3</i>	<i>0</i>	<i>100</i>
<i>F-05</i>	<i>Discrepancies / Conflicts in documents</i>	<i>29.5</i>	<i>19.8</i>	<i>0</i>	<i>80</i>
<i>F-06</i>	<i>Contractor competency</i>	<i>32.0</i>	<i>26.6</i>	<i>0</i>	<i>100</i>
<i>F-07</i>	<i>Cost of legal processes</i>	<i>31.2</i>	<i>23.8</i>	<i>0</i>	<i>80</i>
<i>F-08</i>	<i>Defective design</i>	<i>51.9</i>	<i>26.5</i>	<i>0</i>	<i>100</i>
<i>F-09</i>	<i>Long lead time / Delay in payments</i>	<i>35.1</i>	<i>24.9</i>	<i>0</i>	<i>100</i>
<i>F-10</i>	<i>Delays in resolving contractual issues</i>	<i>52.1</i>	<i>23.2</i>	<i>0</i>	<i>100</i>
<i>F-11</i>	<i>Delays in resolving disputes</i>	<i>45.9</i>	<i>20.0</i>	<i>0</i>	<i>100</i>
<i>F-12</i>	<i>Environmental hazards (project area)</i>	<i>39.7</i>	<i>28.5</i>	<i>0</i>	<i>100</i>
<i>F-13</i>	<i>Financial failure of client (Owner)</i>	<i>40.3</i>	<i>30.5</i>	<i>0</i>	<i>100</i>
<i>F-14</i>	<i>Financial failure of contractor</i>	<i>41.1</i>	<i>30.6</i>	<i>0</i>	<i>90</i>
<i>F-15</i>	<i>Indemnification and hold harmless</i>	<i>33.5</i>	<i>26.6</i>	<i>0</i>	<i>100</i>
<i>F-16</i>	<i>Inflation and exchange rates</i>	<i>25.3</i>	<i>27.4</i>	<i>0</i>	<i>90</i>
<i>F-17</i>	<i>Labor quota / problems</i>	<i>19.0</i>	<i>15.8</i>	<i>0</i>	<i>50</i>
<i>F-18</i>	<i>Availability of equipment</i>	<i>25.0</i>	<i>21.5</i>	<i>0</i>	<i>80</i>
<i>F-19</i>	<i>Labor and equipment productivity</i>	<i>17.9</i>	<i>17.8</i>	<i>0</i>	<i>70</i>
<i>F-20</i>	<i>Material and equipment quality</i>	<i>30.8</i>	<i>24.6</i>	<i>0</i>	<i>90</i>
<i>F-21</i>	<i>Permit and ordinance</i>	<i>26.2</i>	<i>21.5</i>	<i>0</i>	<i>100</i>
<i>F-22</i>	<i>Quality of work / Workmanship</i>	<i>49.7</i>	<i>32.8</i>	<i>0</i>	<i>100</i>
<i>F-23</i>	<i>Safety at site / Health & Safety</i>	<i>21.1</i>	<i>16.5</i>	<i>0</i>	<i>80</i>
<i>F-24</i>	<i>Site access upon contract award</i>	<i>36.5</i>	<i>32.6</i>	<i>0</i>	<i>100</i>
<i>F-25</i>	<i>Subcontractor failure</i>	<i>23.4</i>	<i>21.4</i>	<i>0</i>	<i>100</i>
<i>F-26</i>	<i>Third party delays</i>	<i>32.8</i>	<i>29.1</i>	<i>0</i>	<i>100</i>
<i>F-27</i>	<i>Unforeseen site/ ground conditions</i>	<i>37.1</i>	<i>19.6</i>	<i>0</i>	<i>100</i>
<i>F-28</i>	<i>Availability of materials</i>	<i>31.3</i>	<i>28.6</i>	<i>0</i>	<i>95</i>

Table 3 shows the difference between average ‘present shared’ allocation with that of ‘expected shared’ allocation, along with the ranks for differences in shared allocation. Negative sign indicates increase in allocation. All the risk items are seen to have increased in ‘shared allocation’ of varying degrees. Nine items (ranks 20-28) are seen to have increased shared allocation of risks by less than 10% only. However, 13 (ranks 7-19) items increased by 10-20%, and remaining six items (ranks 1-6) increased by 21-30%. These increases occurred from reduced expected allocation either to both parties; or to one party but with resulting reduced expected allocation.

Table 3: Comparison of present and expected risk allocation

Risk items	Expected allocation		Difference between present and expected allocation	
	Shared	Rank	Shared	Rank
<i>F16: Inflation and exchange rates</i>	51.1	2	-24.5	1
<i>F15: Indemnification and hold harmless</i>	53.0	1	-24.2	2
<i>F02: Change in scope of work</i>	37.0	8	-23.8	3
<i>F05: Discrepancies / Conflicts in documents</i>	46.3	4	-23.8	4
<i>F27: Unforeseen site/ ground conditions</i>	39.6	5	-21.6	5
<i>F21: Permit and ordinance</i>	38.8	6	-21.1	6
<i>F13: Financial failure of client (Owner)</i>	35.5	9	-19.6	7
<i>F20: Material and equipment quality</i>	33.6	13	-19.5	8
<i>F28: Availability of materials</i>	33.4	15	-18.0	9
<i>F17: Labor quota / problems</i>	30.2	17	-17.6	10
<i>F03: Change order evaluation & negotiation</i>	34.7	10	-17.1	11
<i>F04: Changes in codes and regulations</i>	49.6	3	-16.0	12
<i>F22: Quality of work / Workmanship</i>	27.4	21	-15.0	13
<i>F09: Long lead time / Delay in payments</i>	30.6	16	-15.0	14
<i>F18: Availability of equipment</i>	27.3	22	-14.3	15
<i>F19: Labor and equipment productivity</i>	26.9	23	-13.9	16
<i>F24: Site access upon contract award</i>	28.7	19	-13.0	17
<i>F23: Safety at site / Health & Safety</i>	25.6	24	-12.1	18
<i>F25: Subcontractor failure</i>	24.0	25	-11.5	19
<i>F26: Third party delays</i>	34.7	12	-8.7	20
<i>F08: Defective design</i>	27.8	20	-8.4	21
<i>F06: Contractor competency</i>	28.8	18	-6.6	22
<i>F01: Acts of God/nature</i>	37.1	7	-6.3	23
<i>F12: Environmental hazards (project area)</i>	33.5	14	-5.8	24
<i>F14: Financial failure of contractor</i>	18.3	27	-5.1	25
<i>F11: Delays in resolving disputes</i>	17.9	28	-4.1	26
<i>F10: Delays in resolving contractual issues</i>	19.7	26	-2.9	27
<i>F07: Cost of legal processes</i>	34.7	10	-0.1	28

‘Expected shared’ allocation of risks are seen to range from 17.9% to as high as 53%. On the whole, two risk items are seen to be shared by above 50%, two risk items by 40-50%, 13 risk items (ranks 5-17) by 30-40%, eight risk items (ranks 18-25) by 20-30% and three risk items are by less than 20% with the least one of 17.9%. Such a higher degree of expected sharing of risks may indicate respondents’ general enthusiasm towards joint management of risks in general,

which might have been influenced by elsewhere, or simply form their consciousness. This may be indicative of attitudinal changes of the public sector towards embracing ‘modern’ contracts.

4. Criticality of risk items

Table 4 summarises the count of responses on ‘frequency of occurrences’ of the risk items that was asked in section four of the questionnaire.

Table 4: Count of responses on frequency of occurrence

<i>Risk Items</i>	<i>Count 1</i>	<i>Count 2</i>	<i>Count 3</i>	<i>Count 4</i>	<i>Count 5</i>
<i>F01: Acts of God/nature</i>	13	14	9	10	2
<i>F02: Change in scope of work</i>	1	5	17	13	12
<i>F03: Change order evaluation & negotiation</i>	6	8	22	7	4
<i>F04: Changes in codes and regulations</i>	19	16	11	1	1
<i>F05: Discrepancies / Conflicts in documents</i>	3	13	15	14	3
<i>F06: Contractor competency</i>	3	7	20	14	4
<i>F07: Cost of legal processes</i>	12	18	13	3	1
<i>F08: Defective design</i>	7	15	18	8	0
<i>F09: Long lead time / Delay in payments</i>	1	2	20	19	6
<i>F10: Delays in resolving contractual issues</i>	1	12	21	11	3
<i>F11: Delays in resolving disputes</i>	3	11	22	11	0
<i>F12: Environmental hazards (project area)</i>	11	14	17	6	0
<i>F13: failure of client (Owner)</i>	22	8	13	3	2
<i>F14: Financial failure of contractor</i>	4	4	23	15	2
<i>F15: Indemnification and hold harmless</i>	10	12	19	3	0
<i>F16: Inflation and exchange rates</i>	21	11	15	1	0
<i>F17: Labor quota / problems</i>	7	12	21	6	2
<i>F18: Availability of equipment</i>	4	13	19	10	2
<i>F19: Labor and equipment productivity</i>	3	13	23	7	2
<i>F20: Material and equipment quality</i>	0	13	21	11	3
<i>F21: Permit and ordinance</i>	6	23	14	4	1
<i>F22: Quality of work / Workmanship</i>	1	4	17	16	10
<i>F23: Safety at site / Health & Safety</i>	1	4	15	19	9
<i>F24: Site access upon contract award</i>	6	15	21	4	2
<i>F25: Subcontractor failure</i>	5	14	19	9	1
<i>F26: Third party delays</i>	4	19	17	4	4
<i>F27: Unforeseen site/ ground conditions</i>	3	9	20	13	3
<i>F28: Availability of materials</i>	5	16	16	9	2

Respondents gave their opinion on frequency of occurrences, and importance or impact on project objectives, of the 28 risk items on a scale from 1 to 5: 1 being the ‘least frequent/important’ and 5 being the ‘most frequent/important’. As such, the column labelled with ‘Count 1’ shows the number of respondents who scored 1. Similarly, the column ‘Count 2’ shows the number of respondents who scored 2, and so on. As seen from the table, all the risk items have scores from 1 to 5, except a few. Similar pattern of responses was also received for ‘importance or impact’ of various risk items on project objectives, using the same scale of 1 to 5. For comparison purposes, all such responses were calculated in to a single representative score of ‘frequency index’ (FI) and ‘importance index’ (II) (Lim and Alum 1995) as:

$$\text{Frequency (or Importance) Index} = (5n_5 + 4n_4 + 3n_3 + 2n_2 + n_1) / \{5(n_1 + n_2 + n_3 + n_4 + n_5)\}$$

where,

- n_1 the number of respondents who scored 1 or “least frequent / important”,
- n_2 the number of respondents who scored 2 or “less frequent / important”,
- n_3 the number of respondents who scored 3 or “frequent / important”,
- n_4 the number of respondents who scored “more frequent / important”, and
- n_5 the number of respondents who scored 5 or “most frequent / important”.

The above two indices were then converted in to an overall index called “Severity Index” (SI), by multiplying the frequency index and importance index. The severity index was used to rank the overall implication of each risk item on project objectives.

$$\text{Severity Index} = \text{Frequency Index} \times \text{Importance Index}.$$

As used in this study, $FI \text{ and } II \geq 0.8$ was considered ‘most frequent / important’, between 0.60-.80 ‘more frequent/important’, between 0.4-0.6 ‘frequent / important’, between 0.2-0.4 ‘less frequent/important’, and ≤ 0.2 ‘least frequent / important’ or negligible. For $SI \geq 0.64$ most critical, between 0.36-.64 more critical, between 0.16-0.36 critical, and ≤ 0.16 less critical.

Table 5 shows the above three indices of 28 risk items, along with their respective ranks, arranged in order of the rank of severity index. Health and safety, change in scope of work, workmanship and delay in payments are seen as the most frequent risk items with ranks from 1-4. These are also seen as the top-ranked risk items in terms of importance indices. At the bottom of the table, ranks of different risk items in the two category are seen closer, but not exactly of same rank. For example, ‘cost of legal processes’ ranks 25 as per its frequency index, compared to rank 26 as per importance index. ‘Inflation and exchange rates’ ranks 28 in both category, but ‘permit and ordinance’ ranks 22 and 25 respectively. Similar pattern is also seen around the middle of the table. Thus, both the indices may be taken to be considered to form similar pattern in terms of their ranks. However, their ranges are different.

For example, the range of frequency indices is 0.729 to 0.383, compared to importance indices of 0.854 to 0.525. However, 10 risk items are seen more frequent, 16 risk items are frequent, and

only two risk items are less frequent. On the other hand, three risk items are seen as most important, 21 risk items are more important and four risk items are important. These resulted in to no risk item in the category of ‘most critical’, but 18 risk items as ‘more critical’ and 10 risk items are critical.

Table 5: Comparison of criticality of different risk items

<i>Risk item</i>	<i>Frequency</i>		<i>Impact</i>		<i>Severity</i>	
	<i>Index</i>	<i>Rank</i>	<i>Index</i>	<i>Rank</i>	<i>Index</i>	<i>Rank</i>
<i>F23: Safety at site / Health & Safety</i>	0.729	1	0.854	1	0.623	1
<i>F02: Change in scope of work</i>	0.725	2	0.821	2	0.595	2
<i>F22: Quality of work / Workmanship</i>	0.725	2	0.800	3	0.580	3
<i>F09: Long lead time / Delay in payments</i>	0.713	4	0.763	5	0.543	4
<i>F27: Unforeseen site/ ground conditions</i>	0.617	7	0.775	4	0.478	5
<i>F06: Contractor competency</i>	0.638	5	0.746	8	0.475	6
<i>F14: Financial failure of contractor</i>	0.629	6	0.750	7	0.472	7
<i>F05: Discrepancies / Conflicts in documents</i>	0.604	10	0.763	5	0.461	8
<i>F20: Material and equipment quality</i>	0.617	7	0.729	10	0.450	9
<i>F10: Delays in resolving contractual issues</i>	0.613	9	0.717	13	0.439	10
<i>F11: Delays in resolving disputes</i>	0.574	12	0.719	12	0.413	11
<i>F25: Subcontractor failure</i>	0.546	15	0.733	9	0.400	12
<i>F18: Availability of equipment</i>	0.571	13	0.679	16	0.388	13
<i>F28: Availability of materials</i>	0.546	15	0.708	14	0.387	14
<i>F03: Change order evaluation & negotiation</i>	0.579	11	0.663	19	0.383	15
<i>F26: Third party delays</i>	0.538	17	0.700	15	0.376	16
<i>F08: Defective design</i>	0.513	20	0.729	10	0.374	17
<i>F19: Labor & equipment productivity</i>	0.567	14	0.658	20	0.373	18
<i>F24: Site access upon contract award</i>	0.521	19	0.675	17	0.352	19
<i>F01: Acts of God/nature</i>	0.492	21	0.667	18	0.328	20
<i>F17: Labor quota / problems</i>	0.533	18	0.613	22	0.327	21
<i>F12: Environmental hazards (project area)</i>	0.475	23	0.654	21	0.311	22
<i>F21: Permit and ordinance</i>	0.479	22	0.575	25	0.276	23
<i>F13: Financial failure of client (Owner)</i>	0.413	26	0.613	22	0.253	24
<i>F07: Cost of legal processes</i>	0.443	25	0.570	26	0.252	25
<i>F15: Indemnification and hold harmless</i>	0.468	24	0.536	27	0.251	26
<i>F04: Changes in codes & regulations</i>	0.388	27	0.608	24	0.236	27
<i>F16: Inflation and exchange rates</i>	0.383	28	0.525	28	0.201	28

A further examination indicates that the degree of criticality (i.e. rank of SI) is less likely to have any strong relationship with the degree of 'expected shared risk'. For example, a few risk items have the same or closer ranks in both category: unforeseen site conditions' and 'site access' rank 5 and 19 respectively, in both category. 'Availability of materials' ranks 14 in SI, but ranks 15 in the other category. Some factors seem to be inversely related. For example, the three least ranked risk items in terms of SI tops the list in terms of expected shared risk. They are: indemnification and hold harmless, changes in codes and regulations, and inflation and exchange rate. Factors that may be loosely considered in this group are health & safety (ranks 1 and 24), workmanship (ranks 3 and 21), contractor competency (ranks 6 and 18), third party delays (ranks 16 and 12), acts of God (ranks 20 and 7), and permits and ordinances (ranks 23 and 6). The remaining risk items seem to form no clearly identifiable pattern.

5. Conclusions

This interim report on an ongoing study attempted to estimate the present and expected risk allocation profile, and was focused on construction clients. Both incorporated a provision for risk sharing, i.e. to identify the attitude towards a strategy for joint management of risks, possibly in a teamwork based collaborative manner. It is seen that the contracting parties had inherently different perceptions, and extremely opposite in most of the cases (i.e. 0% and 100%), of both present and expected allocation of risks, although they all work for public clients. Such diverse perception might have shaped from diverse individual experiences that may be bad or good. Nevertheless, they indicate the need for a cooperative learning. Interestingly, a markedly positive attitude towards shared management of risk was observed. Most of the respondents opted for risk sharing between 18% - 53% for all of the 28 risk items used in the survey. In doing so, respondents generally reduced the present risk liabilities of either one or both of the contracting parties (i.e. contractors and clients). This may be an indicator of the long awaited paradigm shift from the existing traditional construction industry environment towards a friendly and teamwork based culture. This result seems to support the argument that most of the risks need joint efforts of varying degrees from both contracting parties for their effective management.

This survey also identified the criticality of different risk items, which lacks to have any identifiable pattern of relationships with the degree of their sharing. All these are expected to help clients to better appreciate the impacts of different risk items and suitable approaches for their effective management. The next step of this study is to extend the survey to contractors and consultants, to tap their opinion in the first place, and then identifying a set of strategies for wider adoption of risk sharing in construction.

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Extra Contractual Concerns and Their Contractual Consequences in the Near East: The Turkish Experience

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Abstract

While there seems to be a vast literature on the administration of construction contracts, we have yet to understand the complexities of extra contractual concerns and their contractual consequences, especially in the Near East. Pre-conceived biases, expectations and perceptions of obligations and intricate behavioural patterns are often the sources of confusion and poorly functioning contractual relationships.

The present paper will attempt to shed some light on some of these issues, drawing on observations of cases from Turkey and the Turkish contracting experience overseas. The method adopted can be best described as “participant observation” through the authors’ intensive involvement with contractual claims as experts and consultants.

The main focus of the paper is the identification of reciprocal and one-sided patterns of contractual behaviour of Turkish employers and contractors operating in the Near East. Reciprocal patterns are those exhibited by both employers and contractors and include “honeymoon patterns” and obscure documentation practices. One sided patterns include employers’ and contractors’ practices, such as deliberate preservation of ambiguity in contracts and contractual behaviour, fears of violating public welfare, fears of being included in the “Black List”, fears of challenging prominent main contractors and “face value” issues, resulting in complex adversarial relationships, complicated disputes and, occasionally unexpected outcomes. The paper discusses these patterns from a performance perspective and concludes with a set of recommendations for further research into contractual behaviour.

Keywords: Construction contracts, Near East, disputes, relational governance, survival

1. Introduction

The ENR Sourcebook is an annual publication that offers rankings of international contractors and design firms based on contracting revenues generated abroad. ENR Sourcebook's figures include prime contracts, subcontracts, design –build contracts, construction management-at-risk contracts and shares of joint ventures.

ENR's "The World's Top 250 International Contractors" list published in August 2015, based on 2014 figures, included 43 Turkish contractors. Turkey kept its second position in the list after China for the eighth year. The total revenues of the 43 Turkish companies placed on the ENR list increased by 43.4 percent to \$29.3 billion in 2014 compared to the previous year. Thus, the total share of Turkish companies, which was 3.8 percent in 2013, increased to 5.6 percent in 2014 (The 2015 The Top 250 International Contractors 101-200, 2015).

Construction has played a significant role in the economic development of Turkey since the 70's, currently accounting for 5.9 % of GDP. The share of GDP attributable to construction may be as high as 30% if the impact of the construction sector on other sectors of the economy are taken into consideration according to a report by the European International Contractors (FIEC Construction Activity in Europe ,2015).

Turkish contractors undertook approximately 7500 projects in 103 countries between 1972-2014 (6 months). The total value of these projects is estimated around 285 billion USD (Türk Yurtdışı Müteahhitlik Hizmetleri, 2014).

The foregoing seems to be a success story. The realities of construction contracting are, of course, more complex. The sheer size of the overseas market is not an indicator of high performance by itself. Only one Turkish design firm took place in the ENR Top 100 International Design Firms list (ENR bases Top Design Firm rankings on total revenue of design services from projects within their region during the previous calendar year. Firms are also ranked by design specialties and disciplines)

Turkish construction projects are characterized by adversarial relationships, confrontational disputes, abandonment, early termination, contractual deadlocks, low satisfaction and other complex issues. The present paper shall not attempt to analyse the competitive advantage of Turkish construction firms, as this has been undertaken by many researchers (Giritli et, al., 1990, Günhan and Arditi, 2005, Özorhon et al. 2010, Batmaz et. al, 2010). Instead the paper shall try to identify patterns of behaviour prevailing in contractual relations in Turkey and the Near East, drawing on the authors' experiences as expert witnesses and claim consultants over a period of twenty years in the Turkish construction sector. In addition, the paper shall attempt to raise questions about best contract administration practices, firm survival and firm performance.

The cases examined were observed during the authors' involvement with construction claims over a period of twenty years. As such, the method approximates participant observation in the sense that the researchers have shared the activities of the parties.

The paper describes patterns of observed behaviour and provides a brief discussion of non-legal sanctions and rewards exercised by the parties. Raising questions of sustainability in the long run, the paper concludes with suggestions for further qualitative and longitudinal studies to offer insights into contractual behaviour.

2.Turkish Contractors in the Near East

2.1 Brief History

Most of the Turkish contractors moved into the Middle Eastern market in the late 70's as subcontractors following a recession. By the early 80's most were working as prime contractors. Between 1978 and 1987, about 60% of the value of work undertaken came from Libya and 31% from Saudi Arabia (Giritli et. al. p. 417). At that period, opportunities of work were created by several mechanisms, including soft loans (government to government loans), joint economic cooperation systems (such as the Turkish Libyan and Turkish –Iraqi Joint Economic Cooperation Agreements), barter agreements and military construction projects. Turkish contractors gained considerable competitive advantage through the operation of these mechanisms (Sözen, 1998).

The situation, however, started to change by mid-80s. There were several reasons behind the transition, including the saturation of the Saudi Arabian market, the influx of South Korean, Pakistani, Chinese and Bangladeshi firms with highly competitive labour costs and governmental supports (such as tax breaks), while the end of the barter agreements with Libya generated cash flow problems and the crisis that eventually led to the Gulf War created adverse conditions for Turkish contractor firms (Sözen, 1998).

The decline in the overseas market resulted in insolvency: 23 of the 50 contractor firms studied by Sözen in the years 1981-82 had closed down by 1992 (Sözen, 1992; Sözen, 1998). Risk taking and competitive firms had entered new markets, e.g. the Russian federation and the Turkic Republics, whereas firms that had put all their eggs in one basket (e.g. firms concentrating activities in Libya or the domestic market) were forced out of business.

Following the economic crisis of 2001, the volume of contractual activity overseas increased sharply. The explanatory factors offered were the following:

The decline of domestic investments following the economic crisis in 2001 resulted in abnormally low offers

Creation of opportunities overseas by booming oil prices

Accumulation of overseas expertise and entrepreneurial learning

The leading markets since 2013 have been Turkmenistan, Russian Federation, Azerbaijan, Iraq, Kazakhstan, Algeria, Saudi Arabia, Angola, Libya and Kuwait.

2.2 Background

The authors' experiences as expert witnesses and claim consultants in the construction sector indicate that contractual relationships of Turkish contractors in the Near East are characterized by a lack of trust in the other party (employer or subcontractor) crystallizing in:

- Mistrust in the other party, confrontational attitudes, adversarial atmosphere;
- Deterioration of employer-main contractor/ main contractor-subcontractor working relationships;
- Disappointment and dissatisfaction with DAB decisions, arbitral awards and court decisions;
- Relinquishment of contractual rights because of insufficient or non-disclosable contract documentation;
- Inertia in pursuing claims because of "black list" exposure;
- Prolonged dispute resolution processes or contractual deadlocks;
- Dependence on foreign design and technological know-how in complex, multidisciplinary EPC projects.

Yet, the survival of Turkish firms in the Near Eastern market deserves an objective explanation. There are a number of rival theories about the survival of firms in organisation theory. "Liability of newness" and "liability of adolescence" models have found widespread empirical support (Freeman, Carroll et al., 1983; Bruderl, Preisendorfen et al.1992, Bruderl and Schussler, 1990).

Among models based on firm dynamics, the most influential is perhaps the passive learning theory by Jovanovich, who contends that the longer a firm operates in a market, the more it learns and the more efficient it becomes (Jovanovich, 1982). The basic assumption in the passive learning model is that firms learn without engaging in active learning effort, e.g. research and development.

Frankish et al (2007) offer an alternative but interesting explanation: It is possible that entrepreneurs do not learn:" *Here, even if business success is a chance event, an individual who continues to buy tickets for the lottery will enhance their probability of being successful at some point in time. It does not mean that they have 'learnt to play the lottery'. It merely means they have bought more tickets.*" (Frankish et. al. 2007, p.4).

As to the role of unwritten codes of conduct that powerfully affect inter-firm behaviour Macaulay, in his classic article argues that "*Not only are contracts and contract law not needed in many situations, their use may have, or may be thought to have, undesirable consequences.*" (Macaulay, 1963, p.64). Macaulay's argument has lent support to the relational governance literature associated with trust (Poppo, 2002). The underlying argument is that formal contractual relations and enforcement of contractual obligations undermine exchange relationships based on trust, whereas relational governance reduces friction between the parties, increasing flexibility and adaptability.

One of the most important questions that needs to be addressed is whether Turkish contractors have passively learned behavioural patterns that somehow fit with the contracting environment in the Near East despite active engagement in R&D and investment in trust. The answer to this question is not simple and certainly deserves empirical investigation. Even then, this is a shaky foundation and there would be problems of measurement in an empirical investigation.

3. Observed Patterns of Behaviour

The following section shall attempt to identify observed reciprocal and one sided patterns in contract performance. Reciprocal patterns are those shared by employers and contractors. One sided patterns seem peculiar to employers or contractors.

3.3 Reciprocal Patterns

Honeymoons

Like any social relationship, the contractual relationship is likely to experience a honeymoon period during the early phases of contract performance. This period is typically characterized by leniency in contractual enforcements, goodwill, trust and tolerance of contractual breaches.

Almost all contracts set out obligations and responsibilities of the parties relative to performance and claim notices. Claim notice provisions describe procedures that must be strictly followed in notifying the other party before claims can be pursued. Likewise these provisions typically include deadlines for notification, known as time bars.

Similarly contracts contain provisions that any changes made to a contract are ineffective unless made in writing and signed by or on behalf of both parties. This is known as the variation clause and aims to prevent oral variations

At the honeymoon stage, however, both parties are disinclined to require strict compliance with contractual provisions: time bars are often overlooked and oral change orders are executed. This is a widely observed behavioural pattern and is interpreted by both parties as an exhibition of mutual goodwill. There is nothing inherently wrong with this approach as long as the relationship endures within an amicable atmosphere. However, the honeymoons typically do not last long and mutual goodwill eventually evolves into “constructive acceptance”.

During the execution of a large scale infrastructure project under FIDIC Silver Book in Istanbul, time bars were ignored by the contractor and late submission of notices was accepted by the public authority employer during the initial stages of contract performance. At a late stage when the relationship between the parties deteriorated into an antagonistic one, the employer refused a late notice by the contractor based on employer’s rights under clause 20.1, which stipulated that any claim to time or money would be lost if there was no notice within the specified time limit. The contractor took the employer’s determination to the Dispute Adjudication Board, with supporting

evidence that previous late notices had been accepted by the employer earlier. The DAB interpreted this as constructive acceptance against the employer.

Duplicate or non-disclosable documentation

Most projects produce duplicate documentation. The reason for this anomaly is the difficulty in obtaining approval of authorities having jurisdiction over the design documents or frequent changes in legislation. The basic intention of the parties is to comply with existing codes, while reserving the potential to make alterations to a scheme after it has been granted planning approval. In a majority of cases duplicate drawings are preserved, one official, the other non-official. In a potential claim situation, however, submission of documents can present a problem, since only official documentation may be submitted to a court or an arbitral tribunal. Duplicate documentation poses difficulties in filing claims, as a party can only claim what she/he can demonstrate transparently.

In a recent case, a contractor was barred from claiming site office and head office overheads for a standby period of 9 months because of non-disclosable documentation.

Another case demonstrates the impasse reached by the parties .A widely used contractual arrangement in Turkey is financing of construction costs by sharing independent units between the employer and the contractor. During the construction of high rise a mixed-used luxury building located close to the centre of Istanbul under a similar arrangement, the landowner/employer and the contractor had a disagreement about the appropriation of areas and spatial arrangements. There were considerable discrepancies between the official projects that had obtained planning consents and the actual drawings. The actual drawings included alterations beyond the scope of permission. This incongruity presented a major obstacle in taking the disagreement to court and the disagreement still remains unsolved.

3.4 Employer's Patterns

Ambiguity

Aoki and Allison (2005) argue that it may not always be desirable for all parties to a social relationship to account precisely and accurately for actions. The authors use the term ambiguity in its sense of admitting multiple interpretations. Thus, ambiguity is created to provide personal space in social relationships.

Creation of ambiguity is a pervasive pattern in contractual relations. The employer usually refrains from approving contractual documents to provide “contractual space” in a reflex action that functions to reserve future defences.

During the performance of a large scale project under FIDIC Silver Book in Istanbul, the employer never officially approved the work programme submitted by the contractor. Thus, there was no baseline schedule that is typically intended to measure and control project activities. The

absence of a baseline became a major problem during the resolution of a major time extension claim.

Public welfare concerns

Liability for public welfare offences is a major determinant of contractual behaviour for the public employer in Turkey. The public authority is particularly sensitive to cost claims filed by the contractor, while granting extension of time is not a major issue. Cost claims in compensable delay cases can be a serious cause of concern for public employers.

The proliferation of DAB referrals by the contractor was a phenomenon that took us years to understand. Ultimately it turned out that the contractor was encouraged by the employer to take money claims to the Dispute Boards, as complying with a Board decision was less risky for the employer than granting entitlement to cost through an employer's determination.

In one particular case, where the contractor proposed a value engineering solution that reduced cost at the expense of quality, the proposal had to be accepted by the contracting public authority. In the final account, protection of the public fisc mattered in a government audit. The regulatory government audit mind set is difficult to understand and accountability for costs can be interpreted as a public welfare offence.

Grossly one sided contracts

Employers (clients and main contractors) tend to drive the contractor/subcontractor into a corner by means of grossly one-sided contracts that minimize employer risks while imposing onerous terms on the contractor. These contracts are characterized by exclusions of damages, disclaimers for the owner and limitations of remedies for contractors. The question is, of course, why a contractor/subcontractor would ever sign such a burdensome contract. Surprisingly, both parties are of the opinion that (unstructured interviews of the authors) that nothing eventually happens because when the contractor fails to strictly comply with a particular provision of a contract, the employer often delays its attempts to enforce such provision. The employer is well aware that severe losses may force a contractor out of business, resulting in a failure to complete the work, with the inevitable delays, and the attendant delays, high monetary and non-monetary costs on the parties.

3.5 Contractor's Patterns

Black List concerns

Contractors working with the public employer or powerful private employers are generally disinclined to file or pursue claims in fearful anticipation of being included in the "black list" which implies serious problems in securing future contracts. In compensable delay situations, time extension claims are fairly well tolerated by the employer, whereas money claims are risky for the procurement of future projects from the same employer.

A Turkish contractor working for a Middle Eastern employer under FIDIC was terminated for convenience. Under FIDIC conditions, the employer is not allowed to terminate the contract in order to execute the works himself or to arrange for the works to be executed by another contractor. In this particular case, however, the employer did outsource the remaining works to another contractor. The reaction of the terminated contractor was “to remain silent”. Eventually, the terminated contractor was awarded another contract by the employer.

In another case where an eminent Turkish main contractor and a Turkish subcontractor were working on a project in Azerbaijan, the main contractor breached the subcontract repeatedly. The subcontractor refrained from raising claims for a considerable amount of time. Finally when it did bring the matter to international arbitration, there were problems in finding experts to provide an expert report in favour of the subcontractor. The subcontractor sought amicable settlement and the matter eventually faded off.

Saving “face”

Contractors and subcontractors alike display ambivalent attitudes toward powerful clients. Contract administration manuals generally provide templates for different kinds of claims, such as: “ *We hereby give notice in accordance with Sub-Clauseof the Conditions, that during the execution of our Works, we have encountered adverse physical conditions in the form of located which in our opinion was Unforeseeable because..... We will be maintaining such contemporary records as we believe necessary or may be required by you, to substantiate our additional costs/and support our request for an extension of time pursuant to Sub-Clause....* ”. However, the standard claim template is too aggressive for the Turkish contractor.

Notices served under contracts have to be worded carefully in order to refrain from offending the employer. As a result, the standard claim letter is unassertive and maintains a degree of ambiguity as to the consequences of the claim.

“The employer’s representative is offended and turns his head when we meet on the site just because we filed a claim against the employer although we were fully entitled to do so” ,complained a contractor once while admitting that he had similarly been outraged by a subcontractor filing a (rightful) claim and never awarded a subcontract to the same firm again.

4. Discussion

The motive for the present paper was the authors’ failure to understand and interpret the results of contractual actions or inactions of the parties and to draw straightforward conclusions from them.

The foregoing observations certainly do not depict best practices in contract administration. Yet the survival of Turkish contractor firms in the international market deserves attention and empirical investigation.

The observations suggest that relational governance and contractual enforcements do not always complement each other. It is true that Turkish contractors and employers frequently call upon or depend upon non-legal sanctions (black list threats) and rewards (securing future contracts by remaining silent in potential claim situations). This may be interpreted as “passive learning” and probably has contributed to the building of stable market ties in the Near East, but the question is whether reliance on non-legal sanctions or rewards is a sustainable behavioural pattern in the long run.

Many key questions remain unanswered. For instance why is the formal execution of contracts been substituted by relational governance without the expected positive effects on exchange performance and cooperation? Or put more simply, why do the parties rely on non-legal sanctions or rewards in the absence of trust? What then is good performance in the administration of construction contracts if the intended benefits are not realised? Or have the Turkish contractors have simply bought more tickets in a lottery?

Cognitive biases of the parties are affected by the environment in which they occur. This is why interactions and influences of organisational culture and climate also need to be taken into account.

5. Conclusions

In this paper, we have sought to raise a number of research questions related to how contractual relations are understood and performed in the working practice of Turkish contractors at home and in the Near Eastern market. Obviously, the paper is based on non-systematic observations of the authors and as such, has important limitations that imply caution in generalizing the findings. In this sense, although the study falls short of developing a formal diagnostic tool it draws a picture of a complex situation. The study, being of an exploratory and interpretive nature, raises a number of opportunities for future research, both in terms of theory development and interpretation of contractual relations.

Further work is clearly needed to explore the relationship among the features of governance that support contractual relations. Further research can thus shed light on the dynamics of interfirm behaviour, sharing and exchange in the construction sector. Qualitative and longitudinal studies carried out could offer insights into these complex mechanisms. Understanding of organisational cultures could also provide great insights into why certain behaviours do and do not emerge.

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Legal Developments in Relation to Concurrent Delay: The Position of the English and Scottish Courts

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Abstract

In the UK over the last 50 years, legal developments in relation to extensions of time and/or monetary compensation for delays in construction and engineering projects, have been both cautious and incremental. In order to contend with the practical difficulties inherent in these industries, the courts have established various common law concepts and principles. The efficacy of many of those principles remains to a degree intractable, perhaps none more so than those relating to concurrent delays. Abstracted from wider doctoral research into how extension of time and/or monetary claims are dealt with in the UK courts, this paper explores the concept of concurrent delays and explains (through analysis of case law and legal commentary) how recent court decisions have, in effect, confirmed a doctrinal split between English and Scots Law. The paper also identifies the reasons for those differences, and poses further questions which require to be investigated and addressed, in order to move towards a more satisfactory and consistent approach as to how the UK courts deal with concurrent delay. Unless and until more is done to stabilise the common law concepts and principles relating to concurrent delay, such as arriving at a definitive working definition, determine conclusively the ratio for adopting the dominant cause test (or otherwise), adequately clarify why the prevention principle should (or should not) prevail, elaborate on critical path methodologies and justify which approach to causation to apply and why, then confusion over how concurrent delay will be dealt with by the judiciary will remain unsettled. Perhaps the most expeditious and pragmatic way to settle issues relating to concurrent delay should, in the first instance, be dealt with in the various standard forms of contract. This is justified as a reliance on common law principles to provide an equitable solution to concurrent delays, has had limited success. Indeed the current approach has witnessed UK judges struggling to harmonise their decisions, given under differing contract conditions and compounded by often opaque evidential constraints on projects which are factually complex. It is suggested that until concurrent delay clauses are incorporated into the standard forms, the current approach engendered by the courts, will be susceptible to imprecise, unreliable and incorrect judgements, which may not reflect the original contractual intentions of the parties.

Keywords: Construction law, prevention principle, concurrency, apportionment

1. Introduction

Complex building and engineering projects are susceptible to delays. In 2008 the Chartered Institute of Building conducted a survey of more than two thousand schemes and found that over two thirds, were delayed beyond the original completion date, and around a fifth of those projects were late by over 3 months¹. There are a myriad of reasons why construction projects are delayed such as: labour shortages, contractor errors, poor management, employer variations to the original work scope, unforeseen ground conditions, design delays/omissions and adverse weather conditions. The list is interminable.

In construction and engineering projects, delays can be divided into both excusable delays (either with or without compensation), or culpable or non-excusable delays. Excusable delays are the contractual responsibility of the employer and entitle the contractor to an extension of time, and/or compensation depending on the event and the specific contract terms. Culpable or non-excusable delays are the contractual responsibility of the contractor, and do not entitle the contractor to an extension of time or any compensation.

Where excusable delays are identified, the standard forms of construction and engineering contracts such as the JCT, NEC and FIDIC suites, entitle the contractor, under certain criteria and conditions, a right to an extension of time and/or compensation. By definition, an extension of time clause revises the original contract completion date set out in the contract, which has been affected by delaying events which are the contractual responsibility of the employer.

Extension of time clauses protect and provide, a benefit to both the contractor and the employer. They are primarily regarded as being a benefit to the employer in that *“it establishes a new contract completion date, and prevents time for completion of the works becoming ‘at large’”*². They are also a benefit to the contractor as they *“relieve the contractor of liability for damages for delay (usually LD’s)”*³

Notwithstanding the standard forms attempts to provide the parties with cohesive guidance and clear obligations with respect to the management of delays and/or the associated compensation, unfortunately they are often unable to deal effectively with many of the inherent complexities which exist in construction and engineering projects of scale. In consequence, there have been various common law interventions, where the courts have been compelled to establish various dicta and principles and formulate dicta, necessitated by the limitations of the standard forms. An area where both the standard forms of contract, and the common law have struggled to provide unanimity, is in relation to concurrent delay⁴ (hereinafter referred to as ‘concurrency’).

¹ Chartered Institute of Building Website: <http://www.ciob.org/insight/timep-management.htm>, based on the CIOB Report titled *Managing the Risk of Delayed Completion in the 21st Century* conducted between December 2007 and January 2008.

² The Society of Construction Law, Delay and Disruption Protocol, Oct 2002, p. 10

³ *ibid*

⁴ David Barry, *Concurrent Delay in Construction Law: Lord Drummond Young’s Volte Face*, 2011 27 Const.L.J, issue 3. p 1.

Recent jurisprudential developments in the UK have revealed a steady departure in how the English and Scottish courts deal with concurrency. Indeed in 2012, Mr Justice Akenhead took the opportunity to review the relevant body of precedent on this matter and provided an obiter commentary, as to the English courts approach to concurrency, and how it now departs from the Scottish courts approach:-

“The two schools of thought, which currently might be described as the English and the Scottish schools, are the English approach that the Contractor is entitled to a full extension of time for the delay caused by the two or more events (provided that one of them is a Relevant Event) and the Scottish approach which is that the Contractor only gets a reasonably apportioned part of the concurrently caused delay.”⁵

2. Concurrency, a moveable feast?

In the UK, despite a wealth of judicial and professional commentary on the subject, a definitive and workable definition of what constitutes concurrent delay in construction and engineering projects and how it is measured in practice, remains elusive⁶. Learned debate centres on whether concurrency exists where delay events begin at the same time in the project, begin and end at the same time, overlap at the same time, or, as it has been suggested, “...*need not involve delays felt at the same time*”⁷. Indeed the last 15 years or so have seen many and varied definitions from both the courts and legal commentators alike, none of which have been universally accepted⁸. The difficulty in arriving at a definitive definition has not, however, been a barrier to the courts commenting upon issues of concurrency.

Current literature identifies, at a somewhat summary level, the jurisprudential reasoning as to the underlying reasons why the English and Scottish courts have arrived at their requisite positions⁹. However it is suggested that more should and could be done to challenge the common law principles / concepts relied upon, such as Prevention, Dominant Cause, The Malmaison Approach, Apportionment and Causation, and in particular how those principles interplay with one another in practical terms.

It is important to note that the key common law developments in the UK, in relation to concurrency, have in general, been based on various iterations of the Joint Council Tribunal

⁵ *Walter Lilly & Company Limited v Giles Patrick Cyril McKay and DMW Developments Limited* [2012] EWHC 1773 (TCC) – need to get paragraph.

⁶ Matthew Cocklin, *International Approaches to the Legal Analysis of Concurrent Delay: Is there a solution for English Law*, A paper based on the first prize entry in the Hudson Prize essay competition 2012, presented to a meeting of the Society of Construction law in London on 9th April 2013 p 1.

⁷ Franco Mastrandrea *Concurrent delay: an alternative proposal for attributing responsibility*, CLJ 2014 Vol 30 (3) p 173-181 and Lord Osborne’s view in *City Inn Limited v Shepherd Construction Limited* [2010] CSIH 68 CA101/00, para 49

⁸ Lord Osborne in *City Inn Limited v Shepherd Construction Limited* [2010] CSIH 68 CA101/00 at para 49 provides some guidance on what concurrent delaying events may mean.

⁹ Please refer to references (at p.12) for various commentaries.

(‘JCT’) Standard Forms of Contract¹⁰. Therefore, it is worth reiterating John Marrin QC’s guidance on common law approaches to concurrency when he said:

*“....there is one truth which can scarcely be over-emphasised. The answers to the questions raised will depend on the terms of the contract which governs the relationship between the parties.”*¹¹

Finally, it is also significant that, despite a plethora of literature and obiter commentary, the Scottish case of *City Inn v Shepherd*¹² is somewhat remarkably, the only reported construction case where concurrency was actually found to exist.

3. Concurrency in the English Courts: The Current Position

Perhaps the most widely accepted definition of concurrency in England, first proposed by John Marrin QC, in 2002¹³, referred to in *Keating on Construction Contracts*¹⁴ and echoed in the case of *Adyard Abu Dhabi v SD Marine Services*¹⁵, is as follows:

“the expression ‘concurrent delay’ is used to denote a period of project overrun which is caused by two or more effective causes of delay which are of approximately equal causative potency”

There are three important points that can be derived from this definition:-

- The “two or more effective causes of delay”, must relate to both employer¹⁶ and contractor events for concurrency to exist¹⁷;
- The causes do not have to be concurrent in time; and
- Where on examination, the effective causes of delay are not of “approximate equal causative potency”, i.e. one is effective and the other is not, the minor cause will be treated as not causative¹⁸. Where an event has greater causative potency, notwithstanding it may be co-critical¹⁹, it has sometimes been referred to as the dominant event or cause. Whether the use of the ‘dominant cause’ to separate causes, which do not have equal

¹⁰JCT is the English version of the Standard Forms, the Scottish equivalent is the Scottish Standard Building Contracts (‘SBCC’).

¹¹John Marrin QC *Concurrent Delay Revisited*, A paper presented to the Society of Construction Law at a meeting in London on 4th December 2012, p 19

¹²*City Inn Ltd v Shepherd Construction Limited* [2007] CSOH 190

¹³John Marrin QC *Concurrent Delay*, A paper given at a meeting of the Society of Construction in London on 5th February 2002, p 3

¹⁴*Keating on Construction Contracts*, Chapter 8, Section 3, Sub-section (c), para 8-025.

¹⁵*Adyard Abu Dhabi v SD Marine Services* [2011] EWHC 848 (Comm), [2011] 384, 136 Con LR 190, para 277.

¹⁶Causes of employer delay are known as Relevant Events in JCT Contracts. See note 28 below.

¹⁷*Walter Lilly & Co Ltd v MacKay & DMW Ltd* [2012] EWHC 1773, [2012] BLR 503, para 366.

¹⁸John Marrin, note 11, page 3.

¹⁹Co-critical – both delay events are identified on the critical path and have the same effect on the completion date when either one is omitted, often calculated using Critical Path Analysis Techniques.

causative potency, but could still be deemed effective causes of the delay, is still good law in England has been subject to increasing debate²⁰.

The genesis of the current English approach to concurrency was first established in 1999, in the case of *Henry Boot v Malmaison*, where Mr Justice Dyson J (as he was then) stated:-

*"... it is agreed that if there are two concurrent causes of delay, one of which is a relevant event, and the other is not, then the contractor is entitled to an extension of time for the period of delay caused by the relevant event notwithstanding the concurrent effect of the other event."*²¹

This approach, commonly referred to as the 'Malmaison Approach', has been adopted in subsequent English cases²², culminating in what can be considered the most recent decision in the UK courts, *Walter Lilly v McKay*, where Mr Justice Akenhead said, *obiter*²³:

*"...I am clearly of the view that, where there is an extension of time clause such as that agreed upon in this case and where delay is caused by two or more effective causes, one of which entitles the Contractor to an extension of time as being a Relevant Event, the Contractor is entitled to a full extension of time. Part of the logic of this is that many of the Relevant Events would otherwise amount to acts of prevention and that it would be wrong in principle to construe Clause 25 on the basis that the Contractor should be denied a full extension of time in those circumstances. More importantly however, there is a straight contractual interpretation of Clause 25 which points very strongly in favour of the view that, provided that the Relevant Events can be shown to have delayed the Works, the Contractor is entitled to an extension of time for the whole period of delay caused by the Relevant Events in question...The fact that the Architect has to award a "fair and reasonable" extension does not imply that there should be some apportionment in the case of concurrent delays. The test is primarily a causation one."*²⁴

Therefore in terms of 'delay' to the works, where concurrency is deemed to exist, the contractor will be entitled to an extension of time to completion for that period, notwithstanding his own delays which may also have delayed completion of the works by the same period.

²⁰Support for the dominant cause test is found in *Keating on Contracts* 9th Edition, Chapter 8, Section 3, Sub-section (c) 8-022, and *City Inn v Shepherd Construction Ltd* [2010] CSIH 68, [2010] BLR 473, para 42. However there has been increasing criticism of whether the dominant test is still applicable in England, Jeremy Winter, Matthew Totman and Sunil Mawkin, *Concurrent Delay 2011 at* http://www.whitepaperdocuments.co.uk/index.php?option=com_docman&task=doc_download&gid=1544&Itemid=2 and John Marrin QC note 11 page 13, Vincent Moran QC *Causation in Construction Law: The Demise of the 'Dominant Cause' Test?*, A paper presented to the Society of Construction law at meetings in reading 8th May and Glasgow on 15th May 2014.

²¹ *Henry Boot Construction (UK) Ltd v Malmaison Hotel (Manchester) Ltd* (1999) 70 Con LR 32, para 13

²² *Steria Ltd v Sigma Wireless Communications Ltd* [2008] EWHC 3454, *De Beers UK Ltd v Atos Origin IT Services UK Ltd* [2010] EWHC 3276, [2011] BLR 274, 134 Con LR 151, *Adyard Abu Dhabi v SD Marine Services* [2011] BLR 384, *Walter Lilly & Co Ltd v MacKay & DMW Ltd* [2012] EWHC 1773, [2012] BLR 503.

²³ In relation a contract let under a JCT Standard Form of Building Contract 1998 Edition, Private without Quantities (with various amendments)

²⁴ *Walter Lilly*, note 5, para 370

How the contractor's 'loss and expense' associated with concurrent delay, is to be dealt with by the English courts, was clarified in *De Beers V Atos Origin*, where Mr Justice Edwards-Stuart said:

*"The general rule in construction and engineering cases is that where there is concurrent delay to completion caused by matters for which both employer and contractor are responsible, the contractor is entitled to an extension of time but he cannot recover in respect of the loss caused by the delay."*²⁵ [emphasis added]

Taking precedent into consideration, the following statements can be concluded as to how the English courts will deal with concurrent delay and the associated loss and expense:

- Where there are two or more effective causes of delay which are the contractual responsibility of both the employer and the contractor, but have unequal causative potency the dominant cause may prevail. Marrin QC, however argues that the lack of judicial support, among other things, may provide room for doubt as to whether the dominant cause approach would be adopted by the English Courts²⁶.
- Where there are two or more effective causes of delay, which are the contractual responsibility of both the employer and the contractor, and have equal causative potency, then the contractor will be awarded an extension of time for the concurrent delay. The reasoning behind Mr Justice Akenhead's decision is two-fold:-
 - Firstly, that to deny the contractor an extension of time would amount to an act of prevention²⁷; and
 - Secondly, the contract expressly provides that the contractor is entitled to an extension of time, for a Relevant Event²⁸. There is nothing in the contract, which states that the contractor will be denied an extension of time, should he be responsible for a concurrent delaying event.
- Where there are two or more effective causes of delay, which are the contractual responsibility of both the employer and the contractor, and have equal causative potency, then the contractor will not be entitled to claim loss and expense for that period²⁹. The logic here is that the contractor cannot recover damages, because he would have suffered the same loss and expense due to the delays for which he is responsible³⁰. Loss and expense in this instance would generally take the form of prolongation costs, such as site management, site accommodation, transportation and the like.

²⁵ *De Beers v Atos Origin IT Services UK Ltd* [2011] BLR 274, para 177.

²⁶ Marrin note 12 p. 13.

²⁷ See p. 5 above – Mr Justice Akenhead's decision in *Walter Lilly* – note 24 refers..

²⁸ Relevant Events are risk events which are the contractual responsibility of the employer, and depending on the circumstances, allow the contractor extensions of time, and or monetary compensation. The specific term 'Relevant Event' is particular to the JCT Standard Forms of Contract, but can and often is, understood in a similar manner, in any of the standard forms, where events/actions are the contractual responsibility of the employer.

²⁹ This is relevant if the contractor cannot satisfy the "but-for test" of causation that his losses would not have occurred in any event during the concurrent period. Keating on Contracts, Section 5, para 9-062.

³⁰ *De Beers*, note 25 para 178.

4. Concurrency in the Scottish Courts: The Current Position

In light of recent case law, it is considered that the closest current definition of concurrency as it is understood in Scotland defined in the case of *City Inn*, is as follows: “*true concurrency between a relevant event and a contractor default, in the sense that both existed simultaneously, regardless of which started first...*”³¹. However in the appeal to the Inner House to this decision, Lord Osbourne widened the definition of “true concurrency” by saying: “*the focus of attention has moved, rightly in my opinion, from events themselves and their points and durations in time to their consequence upon the completion of the works*”.³²

Until 2004, there was no material inconsistency in how the Scottish and English courts dealt with concurrent delay and/or the associated loss and expense. However Lord Drummond Young’s judgement in *John Doyle Construction v Laing Management (Scotland)* began what is now seen, as a departure between the Scottish and English courts.³³ Although predominantly known as a case concerning global claims, the learned judge had some interesting and diverging opinions on losses incurred due to concurrent delay: “*...even if it cannot be said that events for which the employer is responsible are the dominant cause of the loss, it may be possible to apportion the loss between the causes for which the employer is responsible and other causes.*”³⁴[emphasis added]

In England, at that time, in light of the *Malmaison* decision, the contractor was deemed disentitled to any loss or expense associated with events which were concurrent. It was not until 2007, in the seminal case of *City Inn v Shepherd Construction*, that a Scottish court was clear that it was taking a different approach from that in the English courts. Lord Drummond Young (now a pivotal figure on this matter) had some difficulties in agreeing with the English courts view on how concurrency should be dealt with³⁵, both in terms of loss and expense and extension of time claims. Considering mostly English precedent and taking some guidance from the US courts, he said:

In terms of dominance: “*I agree that it may be possible to show that either a relevant event or a contractor’s risk event is the dominant cause of that delay, and in such a case that event should be treated as the cause of the delay*”³⁶

³¹ *City Inn*, note 12, para 18.

³² *City Inn*, note 8, para 52

³³ *John Doyle Construction Ltd v Laing Management (Scotland) Ltd* [2004] S.C.L.R. 872 B.L.R. 295

³⁴ *ibid*, para 16.

³⁵ His difficulties were based on Judge Richard Seymour QC’s decision in *Royal Brompton Hospital NHS Trust v Hammond* (No.7), (2001) 76 Con LR 148 at paragraph 31, where he had suggested that should a contractor already be in culpable delay, and an employer’s Relevant Event arises (such a inclement weather), is concurrent for a period of time, but does not affect completion, then the Relevant Event should not be considered. Lord Drummond Young, said “*It should not matter whether the shortage of labour developed, for example, two days before or two days after the start of a substantial period of inclement weather, in either case the two matters operate concurrently to delay completion of the works.*”

³⁶ *City Inn*, note 12, para 21. His support for the dominant cause approach is found in *Leyland Shipping Company Ltd v Norwich Union Fire Insurance Society Ltd* [1918] AC 350.

In terms of delay: “Where true concurrency between a relevant event and a contractor default, in the sense that both existed simultaneously, regardless of which started first, it may be appropriate to apportion responsibility for the delay between the two causes, obviously, however, the basis for such apportionment must be fair and reasonable”³⁷

In terms of loss and expense³⁸: “In this respect the decision in *John Doyle Construction Ltd v Laing Management (Scotland) Ltd*, *supra*, may be relevant. In that case it is recognised at paragraphs [16]-[18] that in an appropriate case where loss is caused by both events for which the employer is responsible and events for which the contractor is responsible it is possible to apportion the loss between the two causes. In my opinion that should be done in the present case.”³⁹

His judgement was affirmed by a majority in the Inner House of the Court of Session⁴⁰, notwithstanding a dissenting view from Lord Carloway.

Taking current precedent into consideration, the following statements can be concluded as to how the Scottish courts will deal with concurrency, both from a delay, and loss and expense perspective⁴¹:-

- Where there are two or more effective causes of delay, which are the contractual responsibility of both the employer and the contractor, and have unequal causative potency, the dominant cause will prevail.
- Where there are two or more effective causes of delay, which are the contractual responsibility of both the employer and the contractor, and have equal causative potency, again the dominant cause will prevail and it may be appropriate that the delays will be apportioned between the parties. On analysis of Lord Drummond Young’s decision, the reasoning behind his position is as follows:-
 - Contrary to Judge Seymour QC’s view in *Royal Brompton*, the employer event and the contractor event, do not have to happen simultaneously and both should be treated as concurrent causes whichever happened first⁴².
 - The architect should exercise his judgement to determine what has delayed the works, on a fair and reasonable basis⁴³. Precisely what is fair and reasonable must turn on the facts and circumstances of the case.⁴⁴
 - Apportionment is supported by US law⁴⁵, where he referred to a Board of Contract Appeals case which stated:- “Where a contractor finishes late partly

³⁷ City Inn, note 12 para 18.

³⁸ In this instance, prolongation costs.

³⁹ City Inn, note 12 para 166.

⁴⁰ City Inn, note 8.

⁴¹ Note to facilitate a comparison, the phrasing of concurrency in this instance has been chosen, to be consistent with the conclusions drawn from the English courts.

⁴² City Inn, note 12.

⁴³ Lord Drummond Young attaches “considerable importance to these words”, see note 12, para 20.

⁴⁴ City Inn, note 12, para 18. The “fair and reasonable” approach is taken from clause 25 of the JCT Conditions, (Private Conditions with Quantities) (1980 edition), with amendments.

⁴⁵ *Chas. I. Cunningham Co*, IBCA 60, 57-2 BCA P1541 (1957) the Board of Contract Appeals.

because of a cause that is excusable under this provision and partly because of a cause that is not, it is the duty of the contracting officer to make, if at all feasible, a fair apportionment of the extent to which completion of the job was delayed by each of the two causes, and to grant an extension of time commensurate with his determination of the extent to which the failure to finish on time was attributable to the excusable one.”

- Causation in practise works in a complex manner, in ways that does not permit the easy separation of causes, meaning the Architect or court must apply judgement, which can take the form of apportionment.⁴⁶
- When an apportionment exercise for delay is carried out, the methodology is similar to that found in contributory negligence among joint wrongdoers.⁴⁷
- Contrary to significant emphasis being placed from the English courts, he does not consider the principle of prevention in any meaningful detail.
- Where there are two or more effective causes of delay, which are the contractual responsibility of both the employer and the contractor, and have equal causative potency, then the losses may be apportioned between the parties⁴⁸. The logic being similar to that adopted for concurrent delays.

5. Discussion

Taking the foregoing into consideration, it is evident that there are inconsistencies in how the Scottish and English Courts approach the matter of concurrency. In order to find a more consistent and satisfactory direction for both jurisdictions, requires further research and discussion into the following areas:

- **Definitions:** Unless and until a definitive definition of concurrency can be commonly understood by both the English or Scottish courts, then it is likely that difficulties in relation to concurrent delay will prevail. For example, it is still to be understood in practice whether “*true concurrency*”⁴⁹ i.e. employer and contractor delay events which overlap in time, as defined in City Inn, will be dealt with any differently to employer and contractor delay events which do not overlap in time, neither of which is dominant, but act together to delay the completion date. If the employer and contractor events are deemed concurrent because they do not overlap in time, but in *effect* cause delay to the completion date, why are these not merely delay events that are calculated as part of the delay analysis. Furthermore, why would they be deemed “*concurrent*” at all?
- **Dominant Cause v Effective Cause:** The advancement of the “*effective cause*” approach in England, may suggest the demise of the dominant cause test, although this remains unconfirmed. It is suggested however, that it is possible in many instances for experienced construction professionals and the courts, to identify the dominant cause

⁴⁶ City Inn, note 12, para 22.

⁴⁷ City Inn, note 12, para 158.

⁴⁸ Although Lord Drummond Young stated that prolongation *costs* “*need not automatically follow success in a claim for extension of time*”, note 12, para 166

⁴⁹ City Inn, note 8 para 50.

between two events which may appear to have approximate equal causative potency, and appear co-critical in the programme. It is important to maintain a differentiation, because if dominance can be established, then it may be the parties could have chosen alternative mitigation strategies, to avoid their delays impacting the completion date. If that is the case, it is suggested that there is no reason, why the dominant cause approach is not adopted in the first instance. It is also respectfully suggested, that the term “*effective cause*”, is too general in description, which may only confuse matters when applied practically. Concurrency should only exist, it is suggested, once dominance cannot be established.

- **Prevention Principle:** In England, prevention is the first of two ratios in support of the Malmaison Approach; however there are conflicting judgments as to whether prevention actually exists in relation to concurrent delays⁵⁰. In Scotland, there is ongoing debate as to whether the judge’s ability to apportion concurrent delay and/or loss actually offends this principle in any event?
- **Express terms of the Contract:** In England the second and main ratio, in support of the Malmaison Approach centres on a literal interpretation of the contract (at least a JCT contract), which expressly allows an extension of time for employers Relevant Events. However, it must be explored as to why the architect or contract administrator should be precluded from taking other events (not expressly stated) into consideration, which also have an impact on the completion date. One must consider the original intention of the parties, and what would the outcome be for standard forms of contract, other than the JCT suite, which requires the architect to act fairly and reasonably? In Scotland it would appear that in evaluating concurrent delay and its effects on the completion date, the architect should do what is fair and reasonable, taking into consideration Relevant Events and events which are not expressly stated in the contract.
- **Causation:** The standard causation criteria, commonly referred to as “*but for analysis*” is suspended adopting the Malmaison Approach in England, and is also suspended in Scotland if the dominant cause approach is accepted. It must be asked, have the courts decided suspend the standard criteria for causation as a matter of Policy, if so on what basis?
- **Contributory Negligence:** The apportionment of concurrency in Scotland has been likened to contributory negligence between (joint wrongdoers (tortfeasors))⁵¹. There are conflicting arguments as to why a similar approach cannot be adopted in the law of Contract, which require further analysis?
- **Obiter commentary:** As mentioned previously, apart from one reported construction case, both English and Scottish courts commentary on concurrency has been given in obiter dicta. Indeed in *City Inn*, the judge merely suggested that apportionment “*may*” be appropriate. It is obvious therefore that the issue of concurrency is far from settled, and divergence between the English and Scottish courts may not be as immobile as is generally considered?

⁵⁰ *Jerram Falkus Construction Ltd v Fenice Investments Inc* (No 4) [2011] EWHC 1935 (TCC), [2011] BLR 644, 138 Con LR 21, [2011] CILL 3072.

⁵¹ *City Inn*, note 12, para 158.

- **CPA: Programme Analysis / CPA.** It is inadequate to consider the legal understanding and application of concurrency without considering the forms of delay analysis which may be adopted to evidence same. It is imperative that more should be done to align how the legal principles will actually work in practise.
- **Redrafting of the Standard Forms:** Workable definitions could and should be provided by the standard forms of contract, such as JCT, NEC3 or FIDIC suites⁵². Admittedly, it is possible that the definitions of concurrency when included in the standard forms may be different⁵³, but at least the parties would have more certainty on what terms they were entering into. Furthermore it would be helpful if the delay analysis methodology was outlined, because it is an integral and perhaps inseparable element in analysing delays to completion.
- **Policy considerations:** Given the relatively low profit margins of contractors of scale, it may be of benefit to acquire a deeper understanding of whether in matters of concurrency, is it fairer to award time, but no money, or apportion both time and money. For example in general, liquidated damages would be considerably higher than prolongation costs, should that influence the decision making process?
- **Hybrid Solution:** Considering all of the above, is there a viable argument to suggest that the contractor is entitled to an extension of time, but only a proportion of the money for concurrent delays? This is significant because, by way of example, if a project overruns because of a number of employer events, but only one contractor event, then there is no incentive or control for the contractor to mitigate his delays, if he is in the knowledge that he will not be able to recover or reduce his prolongation costs in any event, due to delays caused by concurrent employer events. A form of pacing delay which brings its own complexities.

6. Conclusions

This paper has identified the jurisprudential differences between the English and Scottish Courts, and how they may deal with concurrent delay in construction and engineering projects in the future, and how these differences manifest themselves in the decision making process.

It is essential that first and foremost the parties involved in construction and engineering projects, must refer to the particular terms of their contract, to understand their immediate rights and obligations in relation to how concurrency is to be administered. More often than not, the parties will have contracted using one of the standard forms, which are in general silent on how concurrency is to be dealt with. In consequence, divergences in how the English and Scottish courts deal with concurrency, will prevail and common law solutions will have limited efficacy. It is suggested that unless and until the aforementioned considerations are addressed, it is likely that problems articulating and measuring concurrency will persist for the foreseeable future.

⁵² Currently the only standard form of contract to define concurrency is found in the CIOB Complex Contract Conditions, 2013.

⁵³ Indeed the current common law differences on concurrency between the Scottish and English Courts may require a departure between the JCT suite in England and its SBCC equivalent in Scotland.

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Selection of Delay Analysis Methods in Construction Projects

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Abstract

Delays in construction projects may seem to be easy to analyze, however, in many cases, the process is complex and difficult. As a result, many methods were developed for analysing project delays. With projects varying in nature and complexity and the availability of several delay analysis methods (DAMs) that produce different results for the same project and set of facts, conflicts started arising in projects over which DAM should be used and why. This paper examines the commonly used DAMs in construction projects and the factors that could influence the decision as to the selection of the appropriate delay analysis method adopted by Contractors.

The analysis of five case studies found that there is agreement on what is considered acceptable framework of performing delay analysis by Contractors. The research found support for using the Time Impact Analysis (TIA) Method, as this was considered the most reliable and acceptable method to Contractors in UAE. The main factors affecting the selection of the DAM were the attitude of the opponent party, experience of the delay analyst, complexity of the project, stage of the project at the time of performing the analysis, and the available time and cost for performing the analysis.

Keywords: Delay analysis, extension of time, claims, selection factors, time impact analysis

1. Introduction

Delays are commonly in many construction projects and researchers. Braimah and Ndekugri, (2008) argued that it is rare that a project finishes without time overruns. Delay analysis methods (DAMs) are essential tools for assessing the effect/impact of a delay, particularly in complex projects. While there is an agreement over the possible approaches to analyze the delay, there appears to be a disagreement over which DAM is the most appropriate or preferred, if any. Researchers have concluded that there is no one DAM than can be universally applied (Arditi & Pattanakitchamroon, 2006).

Researchers identified multiple factors affecting the selection of the DAMs. The most recognized work in relation to delay and disruption are that of the Society of Construction Law (SCL) delay and disruption protocol (SCL, 2002) and the American Institute of Advancement of Cost Engineering International (AACEI) recommended practice 29R-03 (AACEI, 2011). Both documents provide invaluable information as to delay analysis types and selection factors. However, they do not provide sufficient guidance as to how such factors influence the selection and application of the DAMs. D'Onofrio (2015) reviewed the work of both SCL and AACEI and concluded that the preferred DAM is the Time Impact Analysis (TIA). This view, however, was undermined by the issue of Rider 1 to the SCL delay and disruption protocol (SCL, 2015), which excluded the preference of the TIA method and encouraged the utilization of the factual based methods, particularly for analyzing delays at a time distant from the event.

The aim of this research is to investigate the most appreciate DAM, if any, and the relevant influencing factors for selection and acceptance. The research main objectives are to identify the main factors influencing the selection process, the commonly used and most acceptable DAM(s).

2. Delay Analysis and DAMs

One of the early decisions the delay analysts have to make before selecting a DAM is whether to perform a forward perspective or backward retrospective path calculations. This decision is influenced by initial factors such as the timing of performing the analysis and its purpose (Kao and Yang, 2009) which in turn would influence the decision of whether to follow an observational or a modelling approach of the delay (SCL, 2002).

Some methods, such as the TIA are categorized as complex while some others, such as the Impacted As Planned (IAP) are considered as simple methods. Complex in this context means requiring analysts to have certain level of experience, the necessary records and willingness to invest significant effort

into the exercise (Braimah & Ndekugri, 2008). Therefore, each of the DAMs can be performed to a different level of detail; such detail level is influenced by the availability of the records as well as the time, money and resources available to perform the analysis (Braimah & Ndekugri, 2008).

There are various types of DAMs that are commonly used in the construction industry. The name and type of the DAM does not really matter as long as the delay analysts explain and justify their selection and performance technique (D'Onofrio, 2015). Yang and Kao (2012) note that none of the existing DAMs are perfect as they all require assumptions and contains theoretical forecasts and subjective assessments.

SCL (2002) and Arditi and Pattanakitchamroon (2006) suggested that four methods are the most common in the construction industry which are the As Planned vs. As built Windows Analysis (APvAB), Impacted as Planned (IAP), collapsed as Built (CAB) and the Time Impact Analysis (TIA) method. *APvAB* compares the planned activities (Baseline) with the as built activities. Yusuwan and Adnan (2013) describe it as the most preferred method as it is simple and produces fair and reasonable results. SCL (2015) recommends using this method when performing the analysis distant from the event. Its main features are that it does not present a complex analysis, rely on the baseline network, or require any computerised software, however, it is based on heavy subjective views and assumptions. While this method is relatively easy to perform, it requires analysts to have relevant experience and it may not be sufficient to deal with concurrent delays or the dynamic nature of critical path (Braimah and Ndekugri, 2008). The *APvAB* method requires a baseline and an as-built schedule or as-built records. It might be suitable for simple and complex cases. SCL (2015) also refers to the Longest Path Analysis method as something similar, but different in that it requires as built schedule and looks at the delay at one point whereas the *APvAB* may utilise any available as built records and can be performed in window periods.

IAP method simply influences all delay events on the baseline schedule in a prospective way on the assumption that the baseline logic, sequence and durations have not changed (Arditi & Pattanakitchamroon, 2006). *IAP* may be sufficient to predict future delays but it will not give adequate results when analysing on-going or completed projects (Braimah & Ndekugri, 2008). Kao and Yang (2009) suggested alternative names for the *IAP* method: 'as planned', 'what-if', impacted baseline schedule', 'as planned plus delay analysis' and the 'affected baseline schedule' methods. The *IAP* method requires a baseline schedule and knowledge of the delay events and it is not recommended for complex cases and completed projects.

Collapsed/‘But for’ As-Built Analysis method analyses the delay using the final as built schedule or creating one including all network logic along with all delay events and their impacts and then start excluding the impact of the delay events to see what would have been the case but for such delay events (Braithwaite and Ndekugri, 2008). This method is moderately complex and requires an as-built schedule and knowledge of the delay events. It is suitable for complex cases but cannot deal with concurrency issues and the changing nature of the critical path.

TIA is a dynamic method that allows for initially creating a separate sub-network for each of the events, which can be agreed between the parties, and then these subnets can be inserted into the project-updated schedules in each relevant time-period. In the final time-period, there will be a fully impacted schedule containing all delay events and considering all as built data (SCL, 2002). SCL (2002) considers TIA as the preferred method but not when the case of analysis is distant from the events (SCL, 2015). It considers project delays regardless of the originator or the type of the delay and encourages the parties to keep good records and to update the project schedule on regular basis. However, is that the method requires complex analysis and effort and a substantial time to perform. As such, its use will be highly depended on the availability and the quality of the project records (Arditi & Pattanakitchamroon, 2006). Williams (2003) described three other methods in a way similar to the TIA, which are the windows analysis, snapshot analysis and the time impact technique. They are effectively the same but with different ways of looking at the delay events, delay effect, window periods and project progress. The TIA, however, differs from the Contemporaneous Windows Analysis method in that the latter is observational method that does not require modelling or impacting the delay events as it follows the “effect and cause” approach rather than the “Cause and effect” approach. In summary, the review of the literature recommendations (table 1) supports the use of TIA except when projects have poor records or when there are limitations on time and budget for the analysis.

Table 1: Summary of delay analysis methods

Nr.	Method	Brief Description
1	As-Planned vs. As-Built (APvAB)	Observation of the difference between an as-planned and an as built schedule
2	Impact As-Planned (IAP)	It is based on the theory that the completion date can be determined by adding the delays into the as-planned schedule.
3	Collapsed As-Built (CAP)	Effects of delays are “subtracted” from an as-built schedule to determine what would have occurred but for the delay events.
4	Time Impact Analysis (TIA)	Assumes that delay impacts to a project can be assessed by running a series of analyses on schedule updates.

3. Main Selection Factors

Before selecting a DAM, questions should be asked as to which DAM can produce the desired outcome and whether the project circumstances are suitable for performing such method (Williams, 2003). Braimah and Ndekugri (2008), SCL (2002) and AACEI (2011) identified several factors affecting the selection of the appropriate DAM by delay analysts.

Data, Information and Records Available focus attention on the type and level of available project data that could heavily affect the selection and application of a DAM. However, the reliance on the project records varies between the DAMs. Records may include correspondence, progress reports, meeting minutes, site inspection records, transmittal sheets, videos, photos and others (Braimah & Ndekugri, 2008). None of the DAMs would give valid results if the project records were incorrect or invalid. Not surprising that more than 70% of the delay analysis effort is usually exerted in gathering and organizing the information (Arditi & Pattanakitchamroon, 2006). ***Baseline, Availability Quality and Features*** is the second in importance after the availability of proper records. Having a proper baseline schedule reflecting the original intentions of how and when to perform the works is essential to perform the delay analysis, regardless of the selected method (Arditi & Pattanakitchamroon, 2006). ***Contractual Obligations and the Attitude of the Opponent Party***; a DAM might be specified in the Contract documents or agreed by the parties. It may also be influenced by the applicable legislation. This may limit the analyst choices as to the selection of the DAM (Braimah & Ndekugri, 2008 and SCL, 2002). The attitude of the opponent party may not affect the application of the DAM, but it must be considered by delay analysts before selecting a DAM. If the opponent party, for example Is willing to accept liability, a fair and simple method maybe sufficient (Braimah & Ndekugri, 2008). ***Project Nature, Complexity and Circumstances***; the characteristics of the projects such as the size, design, duration, cost and complexity will heavily influence the selection of the DAM. However, the effect in two different ways. Complex and large projects may require a complex DAM to be able to analyse the delays. However, in some cases, the project might be too complex or has unnecessary complex information which may require a less sophisticated method to analyse the delay (Braimah & Ndekugri, 2008). ***Nature, Type and Number of the Delay Events***; Delays are usually categorised based on liability to Compensable, Excusable and non-excusable delays. The type of project delay affects the selection of the DAM as some methods are unable to analyse multiple liability events (SCL, 2002). ***Skills of the Analysts*** and abilities could influence the selection of the DAM as some methods require complex analysis and certain level of experience, particularly when it comes to making reasonable assumptions, subjective views, interpretations and understandings (SCL 2002; 2014, AACEI, 2011). ***Time, cost and Resource Constrains for Performing the Analysis***; claims are usually governed by certain resources,

budget, time and milestones. This must be taken into account before selecting the DAM. There is a huge variance on the level effort required to perform each of the DAMs Cost proportionality should be considered when selecting the DAM. The more complex the DAM is, the more effort is required and the more expensive it will be. (Arditi & Pattanakitchamroon, 2006). ***Capabilities, Shortcomings and Strength Points of the Method***; depending on the project circumstances, the analysis will have to choose a Dam that is capable of producing the desired results. For example, the IAP method cannot deal with concurrency issues while the TIA can (Arditi & Pattanakitchamroon, 2006). ***Status of Project and Point of Time***; delay analysis can be performed at any point of time before, during or after completion of the project. However, this will heavily influence the section of the DAM. For example, if a forecast of a prospective delay is required, then the IAP method may be appropriate. However, if a retrospective analysis is required and the as built data is available then the other methods such as the CAP or the ABvAP methods would more appropriate. In cases where the project is still running and a real time delay analysis is required, then the TIA method may be the best (SCL, 2015). ***Concurrent delays, Disruption and Acceleration Issues***; when multiple delay events with multiple potential liabilities for the delay exist in a project, complex analysis might be required. This would affect the analyst's selection of the DAM as, for example, simple methods such as the IAP cannot delay with such complex issues (Williams, 2003). ***Purpose and Reasons for Delay Analysis***; Braimah and Ndekugri (2008) note that the purpose of the delay analysis will influence the selection of the delay analysis methodologies. Purposes of analysis are usually extension of time, prolongation cost, and acceleration and disruption entitlements. Depending on each method capabilities, the selection should then be made. For example, if acceleration entitlement is the purpose of the analysis, methods such as the impacted as planned or the collapsed as built may not serve the purpose. However, methods such as the TIA may effectively present the acceleration measures. ***Ownership of the Float, Software Used and Scheduling Settings***; the ownership of the project float affects the criticality of the activities. While the float is commonly owned by the project, sometimes this is not the case. It is therefore essential that the delay analysis gets this cleared out and even try to get the consent of the parties on the ownership of the project float before selecting the DAM (Arditi & Pattanakitchamroon, 2006). Various scheduling software programmes in the market allow for scheduling large number of tasks and activities using the CPM logic. Such software contains various options that affect the calculation and determination of the critical path. Specific attention to software settings such as the scheduling options: retained logic and progress override is needed. In-progress updates, such scheduling option would make huge difference on the critical path as it would allow activities to schedule out of sequence (Arditi & Pattanakitchamroon, 2006).

4. Research Method

The research analyzed five case studies of construction projects in UAE. The decision to use case studies approach is driven by the need to engage the key actors, mainly delay analysts, and develop a detail understanding of the dynamics of the decision making process that determines the method as well as the process adopted for delay analysis. The projects were selected using the researcher contacts to ensure cooperation and overcome sensitivity about disclosing details of what many organizations consider confidential. A wide range of similarities and differences were identified between the analyzed case studies. The case studies were driven by three main questions; how the decision was made on the method to assess delays, what were the key factors that have influenced this choice and in what way has the selected method enabled or impeded the effort to assess delays more effectively and achieve the desired results. Table 2 is a brief summary of the case studies, interviewees and the used DAM.

Table 2: Summary of case studies

Project	Interviewee	Used Method(s)
A (5 Stars Hotel)(65M US\$)	A1 (Project Planner)	IAP
	A2 (External Consultant)	Float Mapping
	A3 (External Consultant)	TIA
B (International High School) (120M US\$)	B1 (Project Planner)	IAP
	B2 (Project Planner)	TIA
C (Highway Road) (113M US\$)	C1 (Project Planner)	TIA
D (Sewage Treatment Plant) (1.5B US\$)	D1 (External Consultant)	ABvAP
E (Residential Tower) (25M US\$)	F1(Project Planner)	IAP

In terms of the common DAMs, the TIA method is more common in the sample. The interesting fact is that the IAP method, although criticized by the researchers, according to the case studies, it is still commonly used. The float mapping method was used in one of the projects but did not deliver the desired results due to its over-complexity and lack of ability to deal with concurrent delays. Similarly, the As Built vs As Planned method was used in one of the case studies and, exactly as suggested by Arditi and Pattanakitchamroon (2006), was not successful because it is not yet popular and clients seems to have doubts about its abilities and results.

Figure 1, shows the research developed selection process for the DAMs. The process is dependent on the selection of a delay analyst having the appropriate experience which would influence the choice DAM. The process addresses all the relevant factors and the potential effects of such factors; however, it does not provide specific instruction for the selection of the DAM as such decision requires the analyst's subjective view.

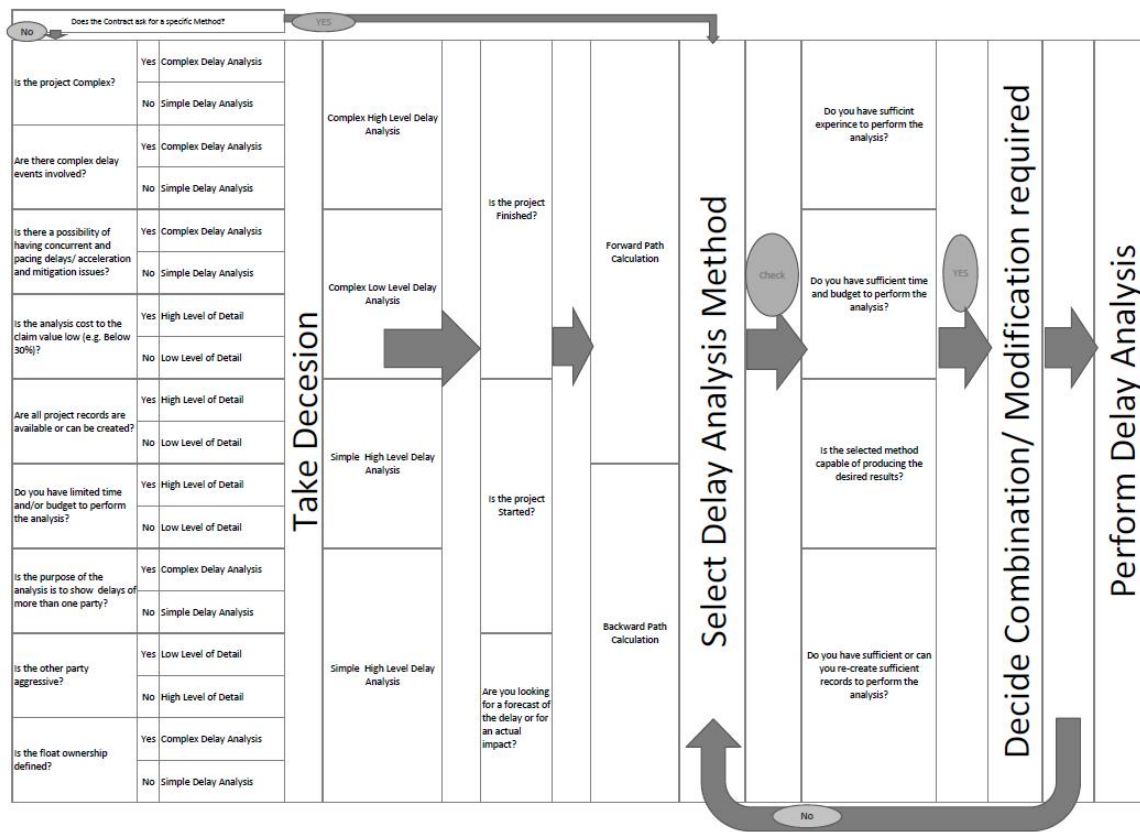


Figure 1: Selection process of delay analysis methods

5. Analysis and Discussion

The analysis of the case studies has shown that the main factors influencing selection of DAMs were the availability of records, the time available to perform the analysis, the attitude of the other party, the contractual requirements and the actual status of the project at the time of performing the analysis. The main factors that were found to be influencing the acceptance of the method were the attitude of opponent party and the purpose of the delay analysis which were highlighted by Braimah and Ndekugri (2008). An important finding however was that the selection of the method itself is a subjective decision of analysts based on their own understanding, interpretation and appreciation of the various factors. Interestingly, the reputation and the impartiality of delay analysts were found to be the main driver for accepting the delay analysis. Such factor was not directly addressed in the literature review although clients seem to be strongly influenced by such factor when making their decision.

There is an agreement that the first factor to check is that if the contract documents specify which DAM should be used. Although SCL (2002) suggests that new forms of contract nowadays specify the DAM, this was not the case in any of the projects examined in this study. The primary factors for the selection

of the DAM were the availability of project records, the time available for performing the analysis and the point of time of the analysis. The interviewees also viewed the availability of an adequate baseline schedule, as part of the project records, as an essential element for performing the delay analysis.

Only one of the interviewees gave great importance to the experience of the delay analyst while others viewed it as a secondary factor. This could be because he was performing the float mapping method which is not a common method and may require special experience. SCL (2002)) emphasize on the importance of this factor as it may affect both the decision of selection of the method and the results of the analysis. Cost and time limitations are viewed as a constraint for both the selection of the delay analysis method and the level of detail of the analysis. Contractors seem to tend to utilize IAP Method, not only because it gives them favorable results, but also because it requires the least time and effort. Although SCL (2015) notes that the actual status of the project and the time of performing the analysis are the main factors, it appears that in practice they are secondary. Table 3 below, however, provides a summary recommendations, based on the reviewed literature and conducted interviews, that may assist delay analysts while deciding which DAM to utilize.

Table 3: Summary of recommendations (1-2)

<i>Factor</i>	<i>Conditions/ Circumstances</i>	<i>Recommended Method(s), listed on priority basis</i>
Records availability, accessibility and Quality	Baseline only	IAP
	As Built only	CAB
	Baseline and As Built	CAB OR ABvAP
	Baseline, periodic updates and As	TIA OR CAB OR ABvAP
Contractual Requirements	Specific Method	Specified Method OR Challenge with Justifications
Complexity of Project and Delay Events	Simple	TIA/ low level of detail (LD) OR Any Method/ LD
	Complex	TIA/ High level of detail (HD) OR Complex Method/ HD
Skills of the Analyst	Expert	Perform Analysis
	Intermediate/Beginner	Get Support OR Refuse Job
The attitude of the opponent party	Lean	TIA/ LD OR Any Method/ LD
	Aggressive	TIA / HD OR Any Method/ HD
Time, Resource and Budget Constrains	High	TIA / LD OR Any Method/ LD OR Challenge Constrain(s)
	Low	TIA / HD OR Any Method/HD
	Complex	Complex/ HD

<i>Factor</i>	<i>Conditions/ Circumstances</i>	<i>Recommended Method(s), listed on priority basis</i>
Capabilities of the	Simple	Simple/ LD
Time of Performing	Before Start	IAP OR forward calculation method
Analysis	During Construction	TIA OR dynamic method
	After Completion	TIA OR CAB Or ABvAP OR dynamic
Concurrency,	Present	TIA OR Factual Based / HD
disruption and	Not Present	TIA /LD OR other simple method
Purpose of the Delay	Complex	TIA /HD OR modified version
Analysis	Simple	TIA /LD OR other simple method
Ownership of Project	Disagreed/Complex Apportionment	TIA /HD OR any complex method
Float	Agreed/Simple Apportionment	TIA / LD OR other simple method
Scheduling Settings	Special Settings/Constrains	TIA /HD OR complex method
	Common Settings/Constrains	TIA/LD OR other simple method

6. Conclusions

The challenge that most construction projects face is to deal with delays when they appear efficiently and effectively to be able to put the project back on track. This research reviewed the key literature on the topic and set case studies of the projects in the UAE to examine how the decisions to select a DAM and the factors influencing such a decision. The main finding of the research is that two DAMs, IAP and TIA, are dominant in the UAE construction industry with evidence that TIA is the most favoured by Clients. The availability of project records, the availability and quality of the baseline schedule, the actual status of the project and the time of performing the analysis are the primary factors that analysts consider when selecting a DAM. The results also showed that the selection of the DAM is subjective influenced by the delay analyst experience, knowledge and understanding. This is a new factor that can be aligned with the ‘skills of the analyst’ factor. Time and budget limitation are important factors. That would limit the work of the delay analyst who will have resist the pressure to compromise on quality and details as this may affect the accuracy, fairness and reasonableness of the delay analysis results. In summary, the research demonstrated that although the advantages and disadvantages of each of the DAMs are clear, the appropriateness of using any method remains influenced by the analysts personal views and judgment of the project events and their understanding of the appropriateness of the different DAMS.

The ability of the research to generalize its findings may be argued to be limited to the selected case studies. However, the depth of analysis and established trust between the researcher and the

interviewees would give credit to the findings that provide a useful insight in such important and sensitive issues.

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Statutory Adjudication of Payment Claim Disputes in Australia Affected by On-Going Scrutiny by Courts and Changes to the Legislation

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Abstract

The object of statutory adjudication in NSW and Queensland is to ensure that a party, who performed construction work for another party, is able to recover payment. It is intended that payment would be made on an interim basis, pending final resolution. However, the NSW Supreme Court has viewed adjudicators as tribunals, proceeded to judicially review adjudication determinations and provided relief in the nature of *certiorari* to quash an adjudication determination where there has been jurisdictional error. This power to quash an adjudication determination was initially rejected but subsequently re-confirmed by the NSW Court of Appeal.

The recent amendments of the NSW and Queensland security of payment legislation have significantly modified the operation of the adjudication process. The main purpose of the amendments in NSW was to put in place an orderly regime of cash flow from principals, through to head contractors and subcontractors, and to create retention trusts in high value projects, to improve security of payment to parties who carry out construction work. In contrast, the purpose of the Queensland amendments was firstly to improve efficiency of distributing adjudication applications to qualified adjudicators through an office of the Adjudication Registrar of the Queensland Building and Construction Commission (QBCC) and secondly, to correct the perceived bias that adjudication of large payment claims within the short statutory time lines, disadvantaged respondents. To that end, the amendments introduced a two tier adjudication process for 'simple' claims of \$750,000.00 or less and for 'complex' claims of over \$750,000.00. Respondents are now able to raise further reasons for withholding payment during the adjudication process and the parties to an adjudication have more time to make submissions to the adjudicator.

The main objective of this paper is to critically assess, based on the published information, the case law, and the data obtained from the QBCC Registrar, the NSW Government and the Adjudication Research and Reporting Unit (ARRU) of the University of NSW, the performance of the recent amendments of the NSW and Queensland security of payment legislation.

Keywords: Adjudication, payment claims, amendments, NSW, Queensland

1. Introduction

In the first part of this paper, the brief history of the security of payment legislation in the Australian construction industry will be outlined, with a particular emphasis placed on the NSW Act, in relation to the evolution of the adjudication law. In the following parts, the recent amendments to the NSW and Queensland Acts will be outlined and the authors will attempt to assess the impact of the amendments on the performance of the adjudication process.

2. History of statutory adjudication in Australia

The *Building and Construction Industry Security of Payment Act 1999*, which commenced in New South Wales on 26 March 2000 (the NSW Act or the Act), was an outcome of the Cole Royal Commission into the conduct and practice of the construction industry in the late 1990's. The objective of the Cole Royal Commission was to review the conduct and practices employed in the Australian construction industry in view of a high rate of insolvencies, particularly among subcontractors, who are the main source of labour and who undertake work, which represents 75% of the total project value (Cole, 2003).

The NSW Act was the first legislation in Australia, which aimed at providing security of payment for parties who carry out construction work or supply related goods and services under a construction contract by way of a rapid statutory adjudication process. It followed the introduction of the *Housing Grants, Construction and Regeneration Act 1996* (UK) (the UK model) but it adopted a different path to the UK model. The NSW Act was taken up by Victoria in its *Building and Construction Industry Security of Payment Act 2002*. Significant amendments were made to the NSW and the Victorian Acts in 2002 and 2007 respectively to remove the option of respondents providing security in lieu of paying the adjudicated amount. Under the amended Victorian Act, claims for damages and delay damages are expressly excluded as are some disputed variations.

Queensland, in 2004, and South Australia, Tasmania and Australian Capital Territory, in 2009, adopted the amended NSW Act with minor changes. This became known as the eastern model as it generally operates in the eastern States of Australia. The eastern model is characterised by the rapid adjudication of payment claim disputes, where only a party (a claimant), who carried out construction work, may apply for adjudication.

Western Australia and the Northern Territory introduced their own security of payment legislation under *Construction Contracts Act 2004* and *Construction Contracts (Security of Payments) Act 2004* respectively. These Acts were based on the UK model and are commonly referred to as the western model, under which either party to a dispute may apply for adjudication. Timelines for submissions are longer than in the eastern model. The reason for narrowing down the scope of this paper to the eastern model and in particular, to the recently amended legislation in NSW and Queensland, is that data on the performance of the adjudication process in these two States is more readily available.

The intent of the original NSW Act was to ensure that a party, who carried out construction work or supplied related goods and services under a construction contract, received payment by way of a rapid adjudication process, pending the final resolution of the dispute by arbitration or litigation. However, the Act was found not to provide security of payment, as intended, as the respondent, instead of making payment of the adjudicated amount, could provide security for payment in the form of a bank guarantee or a deposit into a trust account pending the final resolution of the dispute. The outcome of this was that despite being successful in adjudication, the subcontractor received no payment and its cash flow was adversely affected.

The amendments introduced in 2002 re-affirmed the original intent of the Act and made it much more effective in providing security of payment by:

- empowering Authorised Nominating Authorities (ANAs), who collect adjudication applications and appoint adjudicators, to issue an adjudication certificate, which, when filed in a Court of competent jurisdiction, becomes an enforceable judgment for debt;
- preventing the respondent, in challenging an adjudication determination in a Court, to raise any cross-claims or any defence in relation to matters arising under the construction contract; and
- requiring the respondent to pay the adjudicated amount.

The effectiveness of the amendments was reflected in a sharp increase in a number of adjudication application, as reported by Uher & Brand (2005a). However, this period is also characterised by an increase in challenges to adjudication determinations in the NSW Supreme Court. In *Musico & Ors v Davenport & Ors* [2003] NSWSC 977 (*'Musico'*), McDougall J viewed the adjudicator as a tribunal with power to make determinations that, although not final, are binding on the parties. On that basis, in paragraph [54] in *Musico*, McDougall J held that the Court had power under s.69 of the *Supreme Court Act 1970* to provide relief in the nature of *certiorari* to quash an adjudication determination where jurisdictional error is shown. This was contrary to the object of the Act in that the intended role of an adjudicator was that of a mere certifier.

Subsequently, in *Brodyn Pty Ltd trading as Time Cost and Quality v Philip Davenport & Ors* [2004] NSWCA 394 (*'Brodyn'*) the Court of Appeal reversed the decision in *Musico*, to the extent that relief in the nature of *certiorari* to quash an adjudication determination that is not void, is not available, and that the only relief available was by declaration and injunction if a determination is void. The Court of Appeal provided guidelines as to the basic and essential requirements for a valid adjudication determination. These were: the existence of a construction contract, valid service of a payment claim and an adjudication application, and the adjudicator determining the adjudication application in accordance with the Act. The Court of Appeal held that a determination is void where the adjudicator acts outside its jurisdiction, including where the adjudicator does not exercise its power under the Act in a 'bona fide' manner and where it denies natural justice to a party.

The period post *Brodyn* is characterised by a further increase in the number of adjudication applications as reported by Uher & Brand (2005a), which reached the peak in or around 2005. This is verified by empirical studies by Brand & Uher (2004) and Uher & Brand (2005b), and by reports issued by the NSW Government and the ARRU. While generally complying with the principles decided in *Brodyn*, the Courts set aside many determinations for a variety of jurisdiction related reasons including denial of natural justice, abuse of process, issue estoppel, a payment claim being related to multiple contracts, not satisfying the contract pre-conditions of payment or not being referable to a valid reference date, invalid service of documents and an adjudicator failing to apply an active process of intellectual engagement.

In *Chase Oyster Bar v Hamo Industries* [2010] NSWCA 190 [*Chase Oyster Bar*], the NSW Court of Appeal revised the decision in *Brodyn*. The Court, found that the adjudicator was a tribunal, and the NSW Supreme Court had power to provide relief in the nature of *certiorari* to quash an adjudication determination. As the laws now stands, adjudication determinations may be quashed by the NSW Supreme Court, where there has been a jurisdictional error of law and where an adjudicator denies natural justice to a party. However, this decision did not change the finding in *Musico* that judicial review of an adjudicator's decision is not available on basis of non-jurisdictional error of law.

The decisions of the NSW Courts have, to a large extent, been persuasive in Queensland Courts, nevertheless, the Queensland Supreme Court and the Court of Appeal have, in some instances, handed out decisions, which are contrary to the decisions of the NSW Courts.

3. The 2010 Amendments of the NSW Act and their impact on the operation of the Act

Upon a review of the operation of the Act, in 2010 the NSW Government inserted a new Division 2A into the Act to give greater protection to subcontractors. Prior to this amendment, a claimant (a subcontractor), upon filing an adjudication certificate in a Court, could request the Court to issue a debt certificate under s.7(1A) of the *Contractors' Debts Act*. If served upon the principal, the principal would be required to action the debt certificate by deducting an adjudicated amount from payment to the respondent (a head contractor). The shortcoming of this mechanism was that upon the conclusion of an adjudication process, the principal may have already paid the respondent the full amount of its entitlement so the debt certificate was of no utility.

The new Division 2A of the Act provided, in sections 26A–26F, that a claimant (a subcontractor), who has made an adjudication application, may serve a 'payment withholding request' upon the principal. The principal is then required to retain sufficient money due to the respondent (a head contractor) to cover the claimant's payment claim. This new mechanism, while allowing a subcontractor to issue a payment withholding notice much earlier than under the *Contractors' Debts Act*, does not guarantee payment to the subcontractor in circumstances where the principal has already paid the respondent its payment entitlement. This may well be the reason, why

subcontractors, in the authors' personal experience as adjudicators, only infrequently rely upon sections 26A–26F of the Act.

4. The 2013 Amendments of the NSW Act and their impact on the operation of the Act

4.1 Introduction to 2013 amendments

On 9 August 2012, the NSW Government established an inquiry into Construction Industry Insolvency in NSW, headed by Bruce Collins, a Queens Counsel. The impetus was the financial collapse of a number of established building/construction companies. The purpose of the inquiry was to recommend measures to better protect subcontractors from the effects of insolvency of head contractors.

The Final Report was published on 28 January 2013 (Collins, 2003). It made a number of recommendations, some of which were adopted by the NSW Government as the 2013 Amendments of the Act. The most notable amendments will now be briefly discussed.

4.2 Definition of subcontractor, head contractor and principal

Superseded section 4 of the Act provided definitions of various terms including the definition of *claimant* and *respondent*. Amended section 4 introduces, for the first time, definitions of *subcontractor*, *head contractor* and *principal*. This was necessary for the proper interpretation of a new regime for the due date for payment outlined in amended sections 11(1A–1C), trust accounts for retention in section 12A and the supporting statement in section 13(9) of the Act.

A head contractor is defined as “the person who is to carry out construction work or supply related goods and services for the principal under a construction contract (the main contract) and for whom construction work is to be carried out or related goods and services supplied under a construction contract as part of or incidental to the work or goods and services carried out or supplied under the main contract”.

It emerges from this definition that a party cannot be a *head contractor* unless the party enters a construction contract that requires another party to carry out part of the *head contractor's* obligations under the main contract. A *head contractor* must also have at least two construction contracts, one with the *principal* and one with a *subcontractor*. A *head contractor*, whose construction contract bars sub-letting of any part of the contract works, is not a *head contractor* but a *subcontractor*.

While there will always be a subcontractor, given the varied nature of contractual arrangements associated with building/construction projects and the varied nature of roles played by participants to construction contract, Davenport (2014, pp. 2–4) observed that “*in the course of a contract, a*

principal can mutate and cease to be a principal and a subcontractor can mutate and become a head contractor. On any day, you may not know whether a party to a construction contract is a principal, a head contractor, a subcontractor or something else”.

In circumstances, where a subcontractor or a head contractor can both be a claimant, the parties' failure to correctly identify their status could lead to confusion as to whether the claimant is a subcontractor or a head contractor and whether the respondent is a principal, a head contractor or a subcontractor. Although the authors are unaware of any adjudication application falling over due to the failure to properly identify the status of the parties in relation to a construction contract, as noted by Davenport [2014], Rippon & Smiley [2014] and Davenport et al (2015), these new definitions may bring about a real problem for adjudicators to interpret the proper status of the parties.

4.3 Due date for payment

Prior to the 2013 Amendments, the due date for payment was, according to section 11 of the Act, 10 business days after a payment claim was made if a construction contract made no express provision thereof.

The amended section 11 now differentiates between payment by a principal to a head contractor and payment to a subcontractor. Under s.11(1A), the maximum period for payment to a head contractor is 15 business days after a payment claim is made and under s.11(1B), the maximum period for payment to a subcontractor is 30 business days after a payment claim is made.

The rationale for mandating the maximum period of 15 business days for payment to a head contractor is to improve the flow of cash from top of the contractual chain down through the supply chain. This amendment clearly benefits head contractors' cash flow but it may impair the principals' ability to source funds from lenders within the prescribed time frame.

The statutory maximum period of 30 business days for payment to subcontractors is likely to adversely affect the cash flow of subcontractors involved in small value subcontracts, who often enter into subcontracts with no express terms of payment. Prior to the 2013 Amendments, payment was, in those circumstances, due within 10 business days of the date of service of a payment claim. Under the amended section 11(1B), payment is now due some 20 business days later. This amendment may also compel subcontractors to rely on other than the adjudication process to recover payments. While no statistical data is available from either the NSW Government or the ARRU on the impact of this amendment on subcontractors and the adjudication process, the information obtained from one ANA indicates that in the period after the amendment to June 2015, the number of adjudication applications declined by 28%. However, whether this is entirely related to the amendment or to some other factors, is not clear.

Only subcontractors, who may benefit from the amendment, are those, involved in high value subcontracts, where they traditionally receive payment well after the new mandatory period of 30 business days.

4.4 Removal of a notice that a payment claim is made under the Act

Prior to the 2013 Amendments, a payment claim required to be endorsed as a claim under the Act. This ensured that the Act only applied to such endorsed payment claims.

Under the 2013 Amendments, a payment claim under a construction (non-residential) contract is no longer required to state that it is made under the Act.

Facts Sheet 4 (2014), issued by the NSW Government, explains the rationale for this change by asserting that the mandatory endorsement of a payment claim as a claim under the Act, made subcontractors reluctant to use the adjudication process for fear of losing future work. This issue was identified by Brand & Uher (2004) and Uher & Brand (2005b), in analysing the performance of the Act in the first few years, as a potential problem for subcontractors. However, contrary to Facts Sheet 4 (2014), there is no evidence whatsoever that in the past 10 or more years, the endorsement requirement had the effect of intimidating subcontractors.

An unintended side effect of this amendment is that any document may be a valid payment claim under the Act if it satisfies the requirements of section 13(2) of the Act. This will require a respondent to be vigilant and issue a payment schedule in respect of each document, which may be or may appear to be a valid payment claim and which is referable to a reference date. The failure to do so may expose the respondent to the risk that the claimant would proceed to recover payment as a debt due in any court of competent jurisdiction.

This amendment could also cause a problem for a claimant. This is demonstrated in the following example. In a day to day communication with a respondent, the claimant may issue an email in which it identifies construction work and indicates the amount that the claimant claims to be due. The respondent may construe this email to be a payment claim. Prior to issuing a payment schedule within 10 business days of receiving the email, the claimant issues a regular monthly payment claim. Provided the email satisfies the requirements of section 13(2) of the Act, it would be found to be a valid payment claim. Accordingly, a subsequent monthly payment claim could be a second payment claim referable to the same reference date. As such, it would be invalid under the Act.

Although no statistical data is available on whether or not this amendment has caused adjudication applications to fall over, the authors have, in their practice as adjudicators, become aware of adjudication applications being found to be invalid due to this issue.

4.5 Mandatory head contractor statement

The 2013 Amendments include, in sections 13(7) and 13(9) of the Act and in section 10 of the Building and Construction Industry Security of Payment Regulation 2008 (amended on 1 May 2015), a new provision, which requires a head contractor to include, with a payment claim served upon the principal, a supporting statement in the form of a declaration to the effect that all subcontractors have been paid all amounts that have become due and payable in relation to the construction work the subject of the payment claim. No such requirement has been placed upon subcontractors making a payment claim against head contractors and no rationale for this has been provided by the NSW Government.

This new provision has, according to Facts Sheet 3 (2014), issued by the NSW Government, further improved subcontractors' security of payment by requiring head contractors to make a required declaration of payment to subcontractors at the time of making a payment claim to the principal. Section 13(7) of the Act provides a maximum penalty of \$22,000.00 for failure by a head contractor to provide a declaration with a payment claim. Section 13(8) of the Act provides a similar monetary penalty and/or 3 months imprisonment for knowingly providing false or misleading information in a declaration.

No statistics are available at present as to the impact of this new provision on the operation of the Act. However, the authors are of the view that while this provision may improve security of payment of subcontractors, it is less likely to improve the position of sub-subcontractors of a subcontractor who makes a payment claim on the head contractor.

4.5 Trust account for retention moneys

The 2013 Amendments include a new section 12A relating to retention money being held by a head contractor in trust for a subcontractor. It was enlivened by the proclamation on 1 May 2015 of the Building and Construction Industry Security of Payment Regulation 2008. The regulation in section 5 requires head contractors to hold retention money in a trust account for subcontractors, where the head contract value reaches a threshold of \$20 million, either at the time when the head contractor entered into a main contract with the principal or when the original main contract value reaches the threshold.

The retention trust created in section 12A of the Act, is not the statutory construction trust recommended in the Collins Inquiry Final Report. The Final Report recommended that any payment by a principal to a head contractor, or by a head contractor to a subcontractor, or by a subcontractor to a sub-subcontractor, for work done or materials supplied by the head contractor, subcontractor or sub-subcontractor, be held on trust where the value of the building project exceeds \$1,000,000. This recommendation was to ensure that in case of insolvency of a head contractor or subcontractor, money paid for work done or materials supplied would be protected. The NSW Government's reason for limiting the statutory trust to retention, managed by a head contractor for contracts greater than \$20 million in value, is unclear.

This amendment was criticised by the Housing Industry Association (HIA, 2015) on many grounds, including that no reciprocal proposal has been created to quarantine head contractors' retentions held by principals, and that the trust creating, managing and reporting requirements are overly onerous and anticompetitive.

While this new amendment recognises the importance of protecting subcontractors' retention money, it only operates on projects with a value of at least \$20 million and in any event, the only guarantee that the retained amount is secured in case of insolvency of a head contractor is that provided by the laws governing trusts. Subcontractors engaged on small value contracts will continue to have their retention money unprotected.

This new amendment has no impact on head contractors if the contract value does not reach \$20 million. However, when it is reached, which could occur any time during the execution of the works, head contractors will assume an additional administrative burden in establishing and managing a trust fund in respect of subcontracts entered into after the threshold is reached, and in complying with the reporting requirements. It is likely that at least some head contractors will attempt to negate the impact of amended section 12A of the Act by moving away from cash retention in favour of a bank guarantee. While no empirical data is available at present to verify this, the authors have already experienced, as adjudicators, a shift away from cash retention to bank guarantees in high value contracts between head contractors and subcontractors.

5. Recent amendments to the Queensland Act and their impact on the adjudication process

5.1 Introduction to recent amendments

The intent of a discussion paper titled 'Payment dispute resolution in the Queensland building and construction industry', issued by the Queensland Government in December 2012, was to obtain feedback on the operation of the Building and Construction Industry Payment Act (the BCIPA Act or the Act). It resulted in the release of a Final Report, prepared by Andrew Wallace, on 24 May 2013 (Wallace, 2013). The main recommendations of the Final Report were accepted by the Queensland Government in the form of the 2014 Amendments of the Act. The two most prominent amendments will now be briefly discussed.

5.2 Appointments of adjudicators by the Adjudication Registrar only

Prior to the 2014 Amendments, claimants lodged adjudication applications with privately operated ANAs, who in turn referred the applications to adjudicators on their respective panels.

Under the 2014 Amendments, the responsibility for receiving adjudication applications and for appointing adjudicators now lies with the Adjudication Registrar of the QBCC. The 2014 Amendment in effect abolished the ANAs and centralised the administration of the Act within the

QBCC. This was intended to improve efficiency and effectiveness of the adjudication process, improve the quality of adjudicators through mandatory transitional training and through on-going professional development, and remove perception that some adjudicators and some ANAs were claimant friendly.

While the Wallace Final Report provided no verifiable evidence of inadequate training of adjudicators, the requirement for on-going professional development of adjudicators under the new regime must be viewed a step in the right direction.

It is commonly accepted that greater efficiency of public services can be realised through privatisation. In that context, the decision of the Queensland Government to abolish the ANAs and administer the Act through the QBCC, is a revolutionary step.

The Adjudication Registrar of the QBCC provides, on its website, comprehensive monthly statistics of adjudication applications submitted, adjudication decisions released, certificates issued and adjudication fees charged. In the period from July 2015 to November 2015, 44% of adjudication applications, made under the 2014 Amendments, did not proceed to adjudication for the reason of withdrawal due to invalidity of applications or settlement. In comparison to the same period under the original Act (from July 2014 to November 2014), 26% of adjudication applications did not proceed to adjudication. Whether this indicates that there are gaps in information that the Adjudication Registrar provides to claimants on how to prepare valid applications or the high rate of failed applications is a short term issue related to the transition from the original to the Amended Act, is not clear.

5.2 Dual system of adjudication

Perhaps the most significant change to the Act was the creation of a dual system of adjudication. A claimant must now identify in a payment claim whether the claim is a standard or a complex claim.

A standard claim is a claim with a monetary value of \$750,000.00 or less. The time frame for providing a payment schedule and an adjudication application has not changed. However, the time frame for the lodgement of an adjudication response has doubled from 5 to 10 business days. Otherwise, adjudication of payment claims follows much the same path as under the original, unamended Act.

A complex claim is a claim with a monetary value of more than \$750,000.00. It is worth noting that it is not necessarily a claim involving complex issues. The only parameter for a claim to be classified as a complex claim is its monetary value.

An adjudication response, issued in response to a complex claim, may include new reasons for withholding payment not previously included in the payment schedule and the claimant has a right of reply to such new reasons. In order to accommodate the claimant's additional submission and

by assuming that a complex claim is multifaceted and wide ranging, the amendment provides a significantly longer time lines for adjudicating a complex claim, which could be in the order of many months. In comparison, the time frame for adjudicating a standard claim is only 30 business days from the day of service of the claim.

Given the significantly different time lines between complex and standard claims, it is likely that claimants would prefer to make standard rather than complex claims in order to secure payment in the shortest possible period. The statistics provided by the Adjudication Registrar indicate that in the period from July 2015 to November 2015, only 12 complex claims or 7.1% of all claims, have been made. It is not possible to directly compare the number of complex claims of over \$750,000.00, made under the Amended Act to the same value claims made under the original Act as the Adjudication Registrar's previous statistics classified large claims as claims in excess of \$500,000.00. Notwithstanding, it is to be noted that in the period from July 2014 to December 2014, just prior to the introduction of the Amended Act, there were 35 or 16.3% of all adjudication decisions related to claims in excess of \$500,000.00. While the value of some of these claims would have been below \$750,000.00, the difference in the percentages is sufficiently large to suggest that high value claims had more frequently been made under the original Act than under the Amended Act.

6. Conclusions

Wide ranging amendments were made to the NSW Act in 2010 and 2013. New provisions were introduced in the form of a payment withholding request, a head contractor's statement and a retention trust to further enhance security of payment of subcontractors. Of these provisions, only a head contractor's statement is likely to achieve the desired objective as a payment withholding request would only provide security of payment in circumstances, where the principal is yet to make payment to the head contractor. The establishment of a retention trust will not enhance security of payment of small subcontractors or those engaged on a project of less than \$20 million.

The impact of the amendments on the operation of the adjudication process is not possible to assess objectively for lack of statistical data. In the authors' view, while the amendments are likely to further improve security of payment of claimants and subcontractors in particular, compliance with the new provisions, such as a head contractor's statement and a retention trust, will increase the administration cost of construction contracts.

An unintentional consequence of the removal of the requirement to endorse payment claims as claims under the Act is that documents not intended to be payment claims may in fact qualify to be valid payment claims under the Act. This has already resulted in an intended payment claim being invalid as it was referable to the same reference date as a valid but unintended payment claim.

The new maximum mandatory date for payment of subcontractors of 30 business days is contrary to the original intent of the Act to provide payment within 10 business days, unless a construction contract allowed for a longer period. This will impact adversely on the cash flow of subcontractors who enter contracts with no payment terms. The data available from one ANA indicates that this amendment may have caused the reduction in the number of adjudication applications made in the post-amendment period.

The 2014 Amendment of the Queensland Act, which abolished privately operated ANAs in favour of having adjudication applications submitted to the Adjudication Registrar of the QBCC, who in turn appoints adjudicators, runs contrary to an established trend of achieving greater efficiency through privatisation. It is much too early to draw conclusions as to whether or not this amendment has achieved any efficiency. The data provided by the Adjudication Registrar indicate that at least, in the short term, more adjudication applications have not proceeded to adjudication for the reasons of either being non-compliant or withdrawn. This may indicate that the Adjudication Registrar does not advise claimants on the process of making valid adjudication applications to the same extent as now abolished privately operated ANAs. Another significant 2014 Amendment of the Queensland Act was the creation of a dual system of adjudication, which provides for claims in excess of \$750,000.00 to be adjudicated over a significantly extended period. This will undoubtedly result in an increased cost of adjudicating such claims. The present trend indicates that claimants are averse to making complex claims in excess of \$750,000.00.

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Designing Project Management

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Abstract

In this paper we introduce the concept of Designing Project Management. On the basis of our earlier work, we suggest that there is still a gap between what is known from recent project management literature and what project managers can structurally help in the effectiveness of their work. Assuming that project management is a form of solving wicked problems, we propose a designerly way to solve these problems. To this end, we introduce the Project Design Cycle, consisting of the elements Awareness, Design, Performance and Reflection. This cycle has been studied in a purely exploratory study. Result of the study is that these elements are sometimes recognized, sometimes not, that the order of these elements has been hardly recognized, that the difference between Reflection-in-action and Reflection-after-Action has been recognized and a distinction seems to occur between a 'large' Project Design Cycle through the overall project management and a 'small' Project Design Cycle in the daily management. We finally conclude that more training in the cycle is necessary because this will possibly lead to a more effective project management.

Keywords: Project management theory, managing, designing, project management education

1. Introduction

In this paper we introduce the concept of Designing Project Management as a domain specific approach to the management of architectural design and construction projects in an ever changing environment. Much recent research points to the importance of understanding projects, and building projects in particular (Svejvig, 2015), as social systems in which there is a complex interplay and alignment of different goals, meanings, and perspectives (O'leary, 2013). This research suggests that it is important to take the personal, professional and business situations of project partners, commissioners and stakeholders into account when attempting to manage project teams [citation]. Many of the leaders in the rethinking project management (Cicmil, 2006; Hodgson, 2006; Morris, 2013) have come to the conclusion that as yet little of this research has led to significant advances in project management tools, practice, or education. Nor does the so-called classical approach address issues of daily practice or career development of project managers structurally do. In this we believe that current approaches to project management, while containing much essential material are not entirely adequate to the task of helping project managers to carry out their work (Heintz, 2015).

Our purpose is to refocus education from learning the systems of project management to learning how to be a project manager. To do this we propose an approach to project management that is based on the agency of the project manager rather than on the integrity of project management systems. It is not that we believe that the project management systems are irrelevant, but that we place the emphasis on the project manager's agency in selecting tools and actions from those systems and enacting courses of action using them. More specifically, we choose to see project management as a process of designing and enacting courses of action and "preferred situations". In doing so we are shifting attention from project management as an idea to project management "an ostensive (the idea) ... [to] a performative (the enactment of the idea) dimension" (Carlgren, 2016).

We call this approach Designing Project Management. The research intention is as much to provide a lens through which to view project management action as to confirm the use of designerly approaches to problem solving by project managers. The educational intention is to offer a model for and an approach to training students in management of design and construction projects in how to enact the systems and theory of project management in the management of complex building projects. Further we believe that this approach will support young project managers in developing their professional capabilities.

This paper discusses the results of a preliminary explorative research project attempting to determine if the elements of the project design cycle can be recognised in the practice of project managers, and to what extent these elements function together as a cycle. The data consists of an interview based case study, and four semi-structured interviews of project managers. We found that the elements were observable, and that while not structured as a formal cycle, a regularity and interdependency between the elements could be observed.

2. Designing project management

2.1 Design in project management

By focussing on the action of the individual project manager we shift the interest from the validity and robustness of project management systems, many of which are aimed at monitoring and enforcement, to the interventions project managers make in steering projects towards successful completion. Such interventions occur at a range of scales from major problems such as development of project organizations to 'smaller' daily problems such as conflicts between project team members. Seen this way, project management is a form of problem solving (Ahern, 2014). These problems may be planning problems, or they may be problems requiring interventions in already ongoing events. Anticipating the current interest in design thinking Herbert Simon connected problem solving in areas such as management with design in areas such as architecture (Simon, 1969) He proposed that design was a approach to general problem solving across a wide range of fields, and defined design as itself "defin[ing] courses of action aimed at changing existing situations into preferred ones." (Simon, 1969) A more recent and more specific definition is: "A design can be defined as a model of an entity-to-be-realized, as an instruction for the next step in the creation process." (Aken, 2007). Indeed project management can be seen as a process of situated inquiry in which the project manager must interrogate the situation he or she finds themselves in, and through processes of sense-making arrive at judgements about, or design, what to do. (Lalonde, 2012)

The recent interest in the application of design thinking to management (Boland, 2004; Martin, 2009; Brown, 2008) has been based on the belief that because of its “liquid and open character” (Boland, 2004), design is an excellent way to approach the more general types of problems encountered in management. Although much of the literature on design thinking in management has drifted away from the earlier work on what Carlgren et al (2016) call designerly thinking, we believe that the distinction will be more limiting than empowering of research and practice in this area.

We therefore draw our inspiration from both the contemporary work on Design Thinking, and the older work on how designers think (Dorst, 1997; Cross, 2006; Lawson, 1997).

Design problems facing design and construction project managers include developing briefs and budgets, composing the design teams, specifying tendering approach and project organization, and creating construction schedules. However, design is also required in order to solve the day-to-day problems that face building project managers. Determining how cope with conflicts between stakeholders or actors, deciding how to bring a jury’s deliberations to a close and choose the architect. In each case the project manager must inform him or herself about the current situation, and determine a course of action that is very likely to lead to the desired result. Both kinds of design problems, the mapping out of the future course of the project, and the resolution of day-to-day problems occur under a high level of uncertainty, and in dynamic situations where hidden and exogenous factors will likely play a significant role in driving the project off the current plan. Design thinking is required to find courses of action that will yield the desired results but will be robust across a large range of possible futures.

2.2 The Project Design Cycle

Design whether in the more generalized sense described by Simon, or in the more specific architectural sense, is a cyclical process. In the simplest sense this is a cycle of generate and test (Simon, 1969), but the design cycle also bears similarity to Deming’s Plan-Do-Check-Act cycle (Deming, 1952) and the Kolb Learning Cycle: Concrete Experience – Reflective Observation – Abstract Conceptualization – Active Experimentation (Kolb, 2000). These similarities are not coincidental, design and management both rely on learning and feedback from the situation to arrive at better outcomes than might otherwise be realized. For the purposes of illuminating the role of design in building project management the following formulation of the cycle may be most helpful:

Awareness – Design – Performance – Reflection

2.2.1 Awareness

The cycle begins with establishing awareness of the current situation. This awareness encompasses not only the formal project as captured in so called “project information”, but also, and importantly, the social situation (situational awareness), including the status and state of the various actors and stakeholders in the project. Awareness of what is going on, who is doing what, etc. Also of intentions, goals, and plans. Awareness also encompasses the determination that ‘something needs to be done’ i.e. deviation from the intended course of the project in some way. Awareness has a very significant component of sense-making.

2.2.2 Design

Out of awareness flows an understanding of both the current state, a need for change and perhaps a desired outcome. Having determined that action is required, design refers to the shaping of a course of action. Design thinking here is important in its open and free approach to generating alternatives and possibilities. But Design should include both generate and test. A designed course of action is also one that has been in some sense tested.

2.2.3 Performance

The designed course of action must be performed by the project manager. The choice of the word performance refers to the performative aspect of management. It is not just a matter of carrying out the design. A performance is required in that project management requires that one changes people's minds and actions. This requires that one reach them in the same way an actor does. Here we define performance as acting/ putting on a mask to change behaviour.

2.2.4 Reflection

Finally, there is a reflection upon the outcome, attempting to draw any lessons about the designed course of action or its performance that may be useful in the future. We use Reflection in two different senses. In the first sense reflection refers to reflecting in a separate moment after the performance is completed, reflection-after-action. This type of reflection is used by e.g. Deming's (quality) management cycle and Kolb's Experiential Learning cycle (Kolb, 2000). The second sense in which we use reflection is reflection while performing, referring to reflection-in-action, introduced by Schön and defined as thinking about doing something while doing it (Schön, 1983). It is precisely these two approaches of reflection-after-action like Deming and Kolb and reflection-in-action as described by Schön that seem to come forward in the next case.

3. Case: the Vondelpark Pavilion in Amsterdam

3.1 Introducing the case and methodology

The Vondelpark Pavilion is at a magnificent location in the Vondelpark in Amsterdam. Previously, the Pavilion housed a Film Museum, and a café (always packed in the summer), giving the location the reputation of 'a cultural media house', a platform where the creators of art and culture programmes could find a varied audience. The departure of the Film Museum meant that new tenants had to be found – and a second media organization agreed to lease the building. A new restaurant tenant was also found at this time. Due to the change in tenancy and a substantial backlog of maintenance issues, the building had to be substantially rebuilt. The new lease agreements left a very limited time for the renovation. The project management was in the hands of the Project Management Office of the municipality of Amsterdam and consisted of a project manager, assisted by an assistant and a quantity surveyor.

To explore to what extent the Project Design Cycle described above could be recognized in the daily practice of a project manager, a pilot interview covering the Vondelpark Pavilion project was held with the project manager. The data were analysed on four topics: 1. the identification of the elements of the Project Design Cycle, namely Awareness, Design, Performance and Reflection, 2. the sequencing of

the elements of the cycle, 3. the difference between Reflection-after-action and Reflection-in-action and 4. the identification of large and small scale cycles during the project. The interviewee was already aware of our work, and for this reason a document was provided ahead of the interview clarifying our then current understanding of the project design cycle. The interview was conducted in Dutch, and translated by the authors.

3.2 Data and Findings

When asked if he could recognize the elements of the PDS in his work for the Vondelpark pavilion, he replied: ‘the funny thing about the [PDS] model is that in the last few years with the complex projects I have managed, you start with setting up the project on a rather systemic way – I mean: the money should be okay, planning, organization etc. etc. – then you go along, and things prove to be quite different than you expected. This is not about, for example, whether the schedule is right, but it is about the peoples’ perception, what their roles are, and whether they feel good about the objectives; because if [they do] not, they will object or start acting in complicated ways. In the latter case people just don’t go along with you, do not act as agreed upon and then you must analyse, you must repair, you must change.’

In the Vondelpark project, at a certain moment different actors had different perceptions of the importance of keeping to the schedule. The schedule was accepted as such, but without sufficient commitment. It was only during the course of the project that the project manager became aware of this problem. Once he became aware of this issue, the project manager attempted several different approaches to getting the team to accept and implement the schedule. Including a ‘hard line’ strategy developed in consultation with the project manager’s employer. All without success. Finally, the project manager determined to approach the issue by trying to understand what the schedule meant to the other actors, he spent two months in conversations between the various actors: *“my question remained; how do I get my team really involved in the plan? For a few months, at the start of a construction meeting, I began to ask every time: how are you? We were able to talk about our concerns, the opportunities we saw and the threats, about how the project was accepted in their organization. Further, a study of sense making¹ in the project seemed to start to bear fruit. People came as reborn out of the conversations that were held in the context of that research. In these conversations they had it made clear for themselves and others what this project was about. Hence they behaved differently during the regular project meetings and the schedule was actually no longer an issue.”*

Reflective discussions by the group members during the regular meetings were uncomfortable, but there definitely was reflection during the ‘sense making’ conversations.

The episode outlined above displays the elements of the Project Design Cycle, but not in a clear sequence. There were Conscious moments of trying to make sense of the situation and then designing a course of action to remedy it. Also smaller cycles imbedded in a large cycle. Trial and error, but with intention. We see the project manager actively expanding his awareness, designing a strategy, trying, and then starting again. There was a ‘large’ Project Design Cycle from the fuzzy beginning, to the eventual implementation and confirmation of the overall schedule. But there were also ‘small’ daily

¹ This was a research project conducted by the second author, Louis Lousberg (Lousberg & Pikker, 2015)

cycles in, for example, meetings, in which following daily ‘surprises’ actions are planned, undertaken and given feedback to support the 'large' cycle.

The project manager had the awareness in advance that things could go wrong due to lack of clarity regarding the contract and designed an arrangement on this issue. In the everyday project management however, it seemed different: *“during the construction process, you're more reactive as manager, sometimes the phone rings and you have to solve a problem. However, you notice that there is not only a construction problem, but also from the angry call from the contractor that the structural engineer is not cooperating. And then when I check with the structural engineer it appears that he does not do so because he did not receive an order to do additional work. But, that's pretty standard, I have subsequently called the managing director of the structural engineer to have a coffee and asked him: why do you react so unprofessionally?”*

In this episode, the project manager saw *“no design here: it is a matter of just keep asking questions. Especially during the construction phase you can be direct, because there are simply agreements and everyone should keep them, so you can just say to someone: you're not doing your job, why is that? It does not really require social skills, it's just being direct and directive. But sometimes you also have to be diplomatic, as in: how do we fix this?”* There appears to be a conscious dealing with problems on the one hand, but otherwise a fairly routine resolution is shown in which, at least not consciously, is designed and performed. It is, one might say, classical project management. Though there seems to be consciously reflecting-in-action.

This was completely different regarding a large ‘surprise’ in the project. *“The surprise with the hotel and catering industry entrepreneur was an exciting one. We had designed a kitchen with a catering consultant and tendered a hotel and catering entrepreneur as a tenant of the restaurant. After which this entrepreneur said: I can't work in that kitchen. His design for the kitchen which cost not only a 100.000 euro's more but also had all sorts of consequences for the rest of the construction work. I initially approached this in a hard way: 'you pay it all by yourself, because you had to say this in the tender procedure' but finally we settled it on each a half of that amount.”*

In this episode the project manager described his role as: *“first analysing what happens when we would accept this, what impact will this have not only on the building, but also on the costs on the basis of current contracts with e.g. the architect or the consequence for the penalty clause with the contractor at time overrun, in that sense it was complex. I eventually had to talk to the clients. Client B agreed because of the entrepreneurship and employment of this hotel and catering entrepreneur. But before that he summoned them to appear and informed them that this was the last time, otherwise he could leave. Client B picked this up beautifully: the entrepreneur sat shivering on his chair, because first the client made clear that this was the very last time and only finally he presented the deal.”* That was a moment of performance as we have defined in this paper.

Finally, we asked for moments of reflection e.g. at the end of the day. The project manager: *“I have a lot of those moments, especially when things have clashed. Then I ask myself: was this smart or tactical enough by me? I also discuss this often with my colleagues, of which the most important result is that you become aware of things and try out your thoughts. By talking about it, it becomes a kind of reality.”* With the observation that this turns out to be about Reflection-after-action the interview is closed.

4. Interviews with project managers

4.1 Introducing the interviews

After reviewing the pilot interview/case, semi-structured interviews were carried out with four project managers. For these interviews we did not explain the Project Management Design Cycle in advance. Nor were these interviews restricted to a single project. At the beginning of an interview we explained that the research was concerned with establishing what project managers actually do, that we had created a model on the basis of what is known in the literature and that we are now investigating whether the model is adequate. Also, we distinguish between strategic and daily management and that the model might be applicable to both. Interviewees were asked to tell us what they did. Questions followed where necessary to encourage the interviewee to address aspects of the PDS, but without using any of the terminology of the model. Extensive notes were taken from the recordings of the interviews, and the analysis based on these notes.

4.2 The four elements of the cycle

Our opening question at all four project managers was: "what do you do as a project manager?". One of them replied, *"I start with identifying ... the program of requirements [including] the environmental factors i.e. stake-holders who can influence the project, feasibility studies, risk analysis, ... and then I walk through all management elements. ... [then] I start with a Plan of action."* Another project manager described his role as *"determining frames ... My role in this is: making it a project. ... I look at it from the point of view of project hygiene. My role is very much to agree, capture and make people stuck to their role. ... I'm not going to start with a project if I don't have written my own project plan. You need to formulate your own assignment as it were. This includes explicit creation of what I do not. ... First you focus the project on what do you want to achieve, then you need to set it up and then you go do."* Just like the project manager of the Vondelpark case, both project managers start with gaining awareness of the project and environment, and then create a Plan of action or determine and establish the frameworks within which the project can be carried out; the first steps in a large project design cycle.

Further, one of the project managers describes how she treats a 'surprise' in the daily work: *"I try to advise the client as well as possible, because in the end it is not my risk, but that of the client. I draw up scenarios, and the client then asks me 'what do you think?'. First, there is a problem signalled, that problem is extensively unravelled on what risks we actually have and there are possible measures (Design), where each choice has all kinds of consequences, up to and including the procurement strategy. So you will have to think about very well."* And another says about 'surprises': *"I manage decision making, by my client, but also by myself. However, if something happens, I always ask myself: 'is this bad, is it an issue?', because what everyone does when something is an issue – especially in a meeting with techies – is to solve, without thinking at all whether it is necessary. I sharpen the problem in terms of consequences, I see that as my role compared to other team members."* To which another project manager adds: *"Actions such as letting clients choose where the paintings may hang – together with the architect – are deliberately designed [to create support for the project]."*

When asked to elaborate on acting out his role as project manager, one interviewee responded: *"I have been trained to think of yourself as a tool. That is, to be aware of what you can do and what you can't,*

also of how you look, what you're wearing, for example, a suit and sometimes a tie. The rule is that you never are underdressed. " Another: "Yes. I act absolutely. For instance, in a meeting where I enter and think about the place where I sit down, and meetings where I say nothing or only two things. What I'm going to do, mainly depends on the others." And another: "Sometimes you need some sort of decisiveness. This has to be called a form of bluff sometimes, because you still do not know exactly what's going on."

Regarding Reflection one interviewee said: *"I think about work when I'm in bed at night. It's about responsibility. Whether did you do things well as a team, or did you have enough control ..., did we do things well – you always doubt of course – did we make the right choice, could we have done it not better in another way?"* All four project managers said they think it's important to reflect with colleagues: *"Often this is in conversations with colleagues who were there. We discuss how it went, what the next steps are that we need to take, what those are in six weeks. ... It is sharing what you are going through, that mutual collegiality, that reflection is very important to be able to grow. That you should do as much as possible."* Or: *"Moments of reflection are those in which I am away with my assistant on to or off from a meeting. We also here internally with colleagues do very much to exchange knowledge, both structurally at meetings every month as it happens to come across or look for each other, with us is that essential."*

In the interviews all four elements of the Project Design Cycle can be recognized both in large design cycles and in 'surprises' in everyday work. As in the Vondelpark case that they are not always seen by the interviewees to constitute a formal or explicit cycle.

4.3 Content and Support

In addition to the recognition of the PM Design Cycle, the analysis of the data from the four interviews resulted in two additional findings.

1. There seems to be an awareness of two distinct issues: content and support. All project managers report that they have a strategy or plan of action which they enact and against which they measure progress. This was often referred to as [project management] content. In addition to this, three of the interviewees emphasized their work on generating support or enthusiasm (*draagvlak*) for the project: "For one of our projects we let the Board take a decision on our proposals for their wing. We have lots of support, since we have put a lot of time in it in recent months. So that decision will certainly succeed", as with the user "Our added value is the creation of support [for the project]. By making people feel that they are heard, making them feel that something is done with the comments they make, even if you do nothing with it, explain why you do nothing, give feedback and as much as possible make them understand that it is going to work." For example let the architect have a say in the selection of technical advisers to have a good click because otherwise everyone sits on his small island" or "to make sure that everyone is heard, for example, despite differences in dominance in terms of personality. And I'm steering in the sense that I always say ' what are we going to do now, how will we approach this? (-) It is really people work, I'm aware of this increasingly." The latter is typical, there seems to be a dual consciousness in the way project managers look at their work. This dual consciousness seems to consist of content and support. Based on that Plans of approach are made (content) and captured (support) and meetings are led. "A junior project manager has in a great deal of difficulty in following the rhythm of a meeting. A senior project manager actually looks at what happens in a meeting, by which I mean how

people respond, whether they are involved, or what they say, or not. A junior project manager has no time to think about how he should steer a meeting. ... If it's in a meeting about an ICT-issue and the ICT-man says nothing, then you should think: 'That is not ok'. The way someone says something, or doesn't say, is almost more important than what he or she says. "

2. That dual awareness has to do with the professional growth as a project manager. In the previous paragraph, a relation was established between the project managers focus on generation of support and the development of a project manager in his or her career. All four interviewees supported this relation. For example: "there comes a time in your career that you come out of the shadow of an experienced project manager into full exposure. ... It is important that you gradually develop your soft skills more and more, that you observe how people are most effective." And: "you can be promoted from assistant manager to senior manager if you can look further than just facilitating, if you have an eye for the interests at stake. If you have a kind of independence, and are aware of the risks out there It also has to do with your attitude, you shouldn't be an uncertain little mouse." And again: "Self-reflection and feedback (Reflection) of your surroundings is an important part in order to grow. If you always make others responsible, you can't grow. ... You have to dare to experiment with management styles to see what work, therefore you need self-reflection." Beside that dual awareness has to do with professional growth, the last quoted project manager seems to indicate that even in that there is a cycle.

4.4 Education

The interviewees were explicitly asked which characteristics or capabilities distinguished a senior project manager (capable of leading projects independently) from a junior project manager (capable only to assist a senior project manager). In addition to the dual awareness described in the previous section, they consistently identified two things that were key in this distinction 1) the ability to conceive of and enact courses of action independently, 2) the ability to lead or carry a team – to perform with authority. Thus, while the knowledge of project management systems is an important pre-requisite to working as a project manager, it seems to be that it is precisely those capabilities highlighted it in the Project Design Cycle which are key to career development and success as a fully fledged project manager. Indeed, many of the interviewees indicated that as a senior project manager they no longer concerned themselves with monitoring daily progress or operating project management systems.

This points to the importance of preparing young project managers not only for their immediate employment as junior project managers, but also to be able to successfully grow into more senior roles. To do this, we believe that project management education should address issues of design, performance and reflection as integral to project management. We do not necessarily think that project managers trained through the use of the PDS will always follow these steps in practice, rather that by incorporating the PDS into their practice, they will approach the issues of awareness, design, performance, and reflection in a more considered and professional manner.

5. Discussion

The results reported here are only exploratory, and both additional data and analysis will be required to put the findings on a surer footing. What we have tried to do, is determine if the elements of the project design cycle could be identified in the daily practice of project managers, and if these elements occurred

in the expected cyclical pattern. This has been done by investigating a pilot case and four comparable interviews with project managers.

The interviews have yielded evidence of all four elements of the Project Design Cycle. However, the complete cycle itself was not observed. Rather groups of elements were reported together, and in the order described in the model, but not the whole cycle. These fragmentary cycles occurred at both large scales and smaller day-to-day scales. There is too little data to show more than the possibility of recognizing these elements and the possibility of consistent relationships between them. Further research will be needed to both firmly establish the ubiquity of the Project Design Cycle elements, their cyclic relationship, and the degree to which project managers use these elements as an explicit method. However, we might speculate that the Project Design Cycle will not be observable 'in the wild' as an explicit method. Rather we believe that further research will show that the Project Design Cycle is a formalization of habits of thought and action common among experienced project managers.

Both the literature upon which the Project Design Cycle was based, and the interview results here have suggested that the Project Design Cycle and the behaviour it attempts to capture and (eventually) reinforce are strongly related to a number of important areas of management research – sense-making, methodological pluralism, design thinking and leadership. Further research will be needed, both in the literature and in the field, to explore how each of these processes manifest themselves in the behaviour of project managers and in the Project Design Cycle.

6. Conclusions

In this paper a first exploratory research is conducted into the recognition of the Project Design Cycle in managing building projects. Drawing from literature, the proposed Project Design Cycle consists of Awareness, Design, Performance and Reflection. Subsequently, in an interview with the manager of a complex project followed by comparable interviews with four different project managers we looked for moments in the management of the project to which one or more elements of the cycle may be attributed. The research reveals that: 1) the elements sometimes are and sometimes are not recognized. 2) The sequencing of the elements is barely recognizable. 3) In some moments there is reflection-in-action and sometimes reflection-after-action. 4) In everyday work sometimes management can be described as elements of a 'small' Project Design Cycle and sometimes as elements of a 'large' Project Design Cycle. 5) There seems to be a dual awareness: content and support and 6) That dual awareness has to do with the professional growth as a project manager. Follow-up research will reveal to what extent this can be confirmed and deepened.

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Stakeholder Management Practices to Boost Outcomes of Construction Projects

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Abstract

The role of project managers (PMs) in stakeholder management to boost project outcomes is investigated, by examining the practices that PMs adopt which lead to effective stakeholder management and studying the extent to which effective stakeholder management contributes to better project outcomes. Based on the literature review, a questionnaire containing 39 practices were identified and grouped into 8 categories. Using a survey questionnaire, data were collected from PMs in Singapore's construction industry. Adopting 11 stakeholder management practices could significantly improve the level of effectiveness in managing clients, consultants and/or main contractors, especially those that take into account stakeholders' power. It is also found that managing project stakeholders effectively can improve time performance, quality performance and owner satisfaction. It is recommended that PMs need to set and communicate common goals and objectives, understand stakeholders' interests and consider their power and influence on the project. To manage clients better, PMs need to prioritize stakeholders and develop a stakeholder interest list. The study found that clients prefer to be the sole winner in project disputes, but PMs need to strive for a multi-win solution. PMs need to cultivate skills and methods in managing stakeholders so that conflicts can be resolved in a collaborative and constructive fashion.

Keywords: Project management, stakeholder management, project outcome, construction projects, Singapore

1. Introduction

In a construction project, the stakeholders include the owners and users of facilities, project managers (PMs), facilities managers, designers, shareholders, legal authorities, employees, subcontractors, suppliers, process and service providers, competitors, banks, insurance companies, media, community representatives, neighbours, general public, government establishments, visitors, customers, regional development agencies, the natural environment, the press, pressure groups and civic institutions (Smith and Love, 2004). Leung and Olomolaiye (2010) stated that internal stakeholders, mainly the client, consultants and contractors, are key decision makers who are linked via legal contracts. As stakeholders can influence a project either positively or negatively, their rights, needs and expectations must not be taken lightly (Carroll and Buchholtz, 2006). If stakeholder management is not in place, it may bring about uncertainty and unexpected problems, where stakeholders' disparate actions can harm the project outcome (Aladpoosh et al., 2012).

The aim of the research is to investigate the role of PMs in stakeholder management to boost construction project outcomes. The specific objectives are to: (i) investigate the extent to which PMs practise stakeholder management; (ii) study the extent to which PMs' effectiveness in stakeholder management contributes to better project outcomes; and (iii) examine the practices that PMs adopt which lead to effective stakeholder management.

The scope of research is limited to PMs who work for clients (either as employees or project management consultants) who have managed construction projects in Singapore. These PMs may be working for project clients, architectural, engineering or project management consultancy firms.

2. Brief literature review

Taking into consideration that internal stakeholders are the key decision makers, this research focuses on internal stakeholders that PMs need to manage, namely clients, consultants and main contractors. PMs' effectiveness in managing stakeholders in a construction project is operationalized into effectiveness level in managing clients (Y1); consultants (Y2); and main contractors (Y3). The aim of stakeholder management is to achieve a successful project outcome (McElroy and Mills, 2003). The following variables relating to project outcomes are operationalized following Ling et al. (2009): cost performance (Z1); time performance (Z2); quality performance (Z3); and owner satisfaction (Z4).

Based on the literature review, the possible actions of PMs (X variables, numbered as X1 to X39), and how projects are managed to achieve effective stakeholder management (Y1 to Y3) are identified. It also uses the instrumental approach to identify the connections that exist between the management of stakeholder groups (Y1 to Y3) and the achievement of project goals (Z1 to Z4). The relevant actions that PMs can take in stakeholder management include: defining project missions, goals and milestones (Jergeas et al., 2000); understanding stakeholders' characteristics and exploring their circumstances (Chinyio and Olomolaiye, 2010); assessing stakeholders'

behaviour (Freeman et al., 2007); understanding stakeholders' power (Bourne and Walker, 2005); engaging stakeholders (Leung and Olomolaiye, 2010); managing conflicts (Ogunbayo, 2013); and managing corporate social responsibility (Yang et al., 2009).

The literature review has revealed many practices in stakeholder management. The gaps in knowledge are that it is hitherto not known if: PMs are managing stakeholders effectively; adopting certain practices would lead to more effective stakeholder management; and better stakeholder management leads to project success in terms of time, cost, quality and owner satisfaction.

3. Research method

The research design was based on a questionnaire survey. A structured questionnaire was designed as the primary data collection instrument. The questionnaire was divided into three sections. Section A comprised questions to find out the characteristics of the construction project and project outcomes. Cost performance (Z1) was rated on a 5-point scale, anchored as: 1 = overrun budget by > 5%; 3 = cost same as budget; 5 = below budget by > 5%. Time performance (Z2) was also rated on a 5-point scale, anchored as: 1 = late finish by > 5%; 3 = finish on time; and 5 = early finish by > 5%. Product/output quality (Z3) was measured on a 5-point scale, where 1 = expectations not met; 3 = expectations met; and 5 = exceed expectations. Owner satisfaction (Z4) was measured on the 5-point scale where 1 = very low; 3 = neutral and 5 = very high. Respondents were also required to evaluate their level of effectiveness in managing three main stakeholders (clients (Y1), consultants (Y2) and main contractors (Y3)) on a 5-point scale similar to Z4. Section B requested respondents to rate extent to which stakeholder management practices were implemented for the project identified in Section A. These were derived from the literature review on stakeholder management practices, and rated on a 5-point scale, where 1 = not adopted, 3 = adopted about half the time, and 5 = adopted almost all the time. Section C sought information on respondents and their firms.

The population comprised PMs working for clients, or as consultant PMs in project management, architectural or engineering consultancy firms. In Singapore, there is no national registry of PMs, so the size of the population is not known. Random sampling was used to identify PMs from architectural, engineering and project management consultancy firms registered with the Building and Construction Authority's Public Sector Panels of Consultants. A search was also done on GOV.sg and Asiabuilders.com to identify PMs in the government sector and developer firms respectively. To increase the sample size, convenience and snowball sampling methods were also employed. E-mails were sent to firms and individual PMs, with follow-up calls made to these companies requesting for relevant PMs to participate in the survey.

4. Results

A total of 352 surveys were sent out and 43 responses were received. 35 questionnaires were completed comprehensively and used for data analysis. The majority of the respondents are PMs and senior PMs from middle management. They have worked in the construction industry for

between 1.5 and 28 years, with an average of 15 years. The majority have more than 15 years of practice. The PMs work in client (public and private) organizations and consultancy firms, with the majority working in the private sector. The PM-respondents reported mainly building projects. The projects range from 415 m² to 250,000 m², with the average at 44,377 m². The majority of the projects cost above S\$50 million (S\$1 \approx US\$0.72), with a mean of S\$106.5 million. Most of the projects took more than two years to be completed. Table 1 shows the projects had significantly poor cost and time performance indicating budget and schedule overruns. The projects had significantly good quality performance (Z3) and owner satisfaction (Z4) In addition, the PMs reported that they were significantly effective in managing clients (Y1), consultants (Y2) and main contractors (Y3).

Table 1: Outcomes of projects and stakeholder management

Code	Variable	Mean	T-test		Y1		Y2		Y3	
			t	Sig	r _s	Sig	r _s	Sig	r _s	Sig
Z1	Cost Performance	2.600	-1.983	.028*	.211	.223	.073	.677	.030	.865
Z2	Time Performance	2.171	-5.964	.000**	.394*	.019	.140	.422	.244	.157
Z3	Quality Performance	3.229	2.095	.022*	.409*	.015	.393*	.019	.308	.072
Z4	Owner Satisfaction	3.743	5.380	.000**	.344*	.043	.409*	.015	.455**	.006
Y1	Effectiveness in managing Client	3.686	5.096	.000**						
Y2	Effectiveness in managing Consultants	3.771	7.069	.000**						
Y3	Effectiveness in managing Main Contractor	3.771	4.552	.000**						

Notes: ** $p < 0.01$; * $p < 0.05$. r_s is Correlation coefficient, and sig is 2-tail. Sig for t-test is 1-tail.

Objective 1 was to investigate the extent to which PMs practised stakeholder management in construction projects. Statistical t-test of the mean was carried out to check whether the population would adopt the practices to a significant extent or otherwise. The t-test results in Table 2 show that among the 39 practices, 34 have been adopted by PMs to a significant extent (mean > 3; t-value positive; and $p < 0.05$), indicating that PMs do actively adopt stakeholder management.

Objective 2 was to study the extent to which PMs' effectiveness in stakeholder management (Y) contributes to better project outcomes (Z). Table 1 shows that time performance (Z2) is significantly correlated with the effectiveness level in managing clients (Y1). When clients are managed more effectively, the project is less likely to have schedule overrun. Table 1 also shows that the effectiveness levels of managing clients (Y1) and consultants (Y2) have significant

positive correlations with the output quality of the project (Z3) and owner satisfaction (Z4). This suggests that when PMs manage clients and consultants more effectively, project quality and owner satisfaction may be higher. There are significant positive correlations between owner satisfaction (Z4) and the level of effectiveness in managing project client (Y1), project consultants (Y2) and project main contractor (Y3) (see Table 1). This suggests that by managing all stakeholders more effectively, owners will be more satisfied.

Table 2: T-test and significant correlation results

Code	Management Practices	Mean	T-test		Y1 (Client)		Y2 (Consultants)		Y3 (Main contractors)	
			T-Value	Sig.	r _s	Sig	r _s	Sig	r _s	Sig
	Defining Project Missions, Goals and Milestones									
X1	PM set common goals, objectives and priorities	4.171	9.809	.000			.405*	.016	.457*	.006
X2	PM identified clear project missions at different stages	3.971	6.992	.000						
X3	PM set project milestones	4.114	10.445	.000						
X4	PM communicated intentions and goals effectively to all stakeholders	4.200	12.154	.000						
	Understanding Stakeholders' Characteristics									
X5	PM gathered information about stakeholders	3.914	5.883	.000					.505**	.002
X6	PM classified stakeholders into various criteria / groups	3.314	1.540	.067						
X7	PM prioritized stakeholders	2.257	-3.599	.000	.351*	.039				
X33	PM re-conducted stakeholder analysis when there is a change in stakeholders	3.943	7.691	.000						
	Exploring Stakeholders' Circumstances									
X8	PM developed a stakeholder interest list and discussed it with team members	3.000	0.000	.500	.352*	.038			.444**	.008
X9	PM assessed each stakeholder's needs and constraints to understand the stakeholder's interest	3.800	5.454	.000						

Code	Management Practices	Mean	T-test		Y1 (Client)		Y2 (Consultants)		Y3 (Main contractors)	
			T-Value	Sig.	r _s	Sig	r _s	Sig	r _s	Sig
X10	PM took stakeholder interests into account in decision making and operations	4.057	9.150	.000			.351*	.039	.335*	.049
X15	PM understood stakeholders' circumstances	3.943	8.728	.000						
X31	PM formulated different strategies to manage different groups of stakeholders	3.743	5.158	.000						
X34	PM understood demands of various stakeholders	3.743	4.231	.000						
Assessing Stakeholders' Behaviour										
X11	PM measured capacity of stakeholders to ascertain their willingness to cooperate with other team members	3.486	2.764	.005						
X12	PM understood the range of stakeholder reactions and behaviours	4.029	9.852	.000						
X32	PM predicted stakeholders' reaction to strategies and decisions before they are implemented	3.229	1.276	.105						
Understanding Stakeholders' Power										
X13	PM assessed stakeholders' strengths and weaknesses	3.600	3.340	.001						
X14	PM explored probable strategies that stakeholders could employ to realize their objectives	3.657	4.638	.000			.380*	.024	.369*	.029
X16	PM rated the impact of project strategies on each	3.400	2.119	.021					.374*	.027

Code	Management Practices	Mean	T-test		Y1 (Client)		Y2 (Consultants)		Y3 (Main contractors)	
			T-Value	Sig.	r _s	Sig	r _s	Sig	r _s	Sig
	<i>stakeholder</i>									
X17	<i>PM understood the power (influence, authority) of each stakeholder</i>	4.229	8.620	.000						
X18	<i>PM understood the urgency faced by stakeholders</i>	4.400	13.715	.000			.394*	.019		
X35	<i>PM implemented strategies depending on the demands of the stakeholders</i>	3.571	3.977	.000			.389*	.021		
	<i>Engaging Stakeholders</i>									
X19	<i>PM ensured effective, regular and planned communication</i>	4.171	10.444	.000						
X20	<i>PM exercised formal forms of communication</i>	4.514	12.766	.000						
X21	<i>PM exercised informal forms of communication</i>	2.657	-1.922	.032						
X22	<i>PM continued to engage with stakeholders when the project met with difficulties</i>	4.257	12.176	.000						
X29	<i>PM developed positive relationships with stakeholders</i>	4.171	11.220	.000						
X30	<i>PM built trust between stakeholders</i>	3.914	6.614	.000						
	<i>Managing Conflicts</i>									
X23	<i>PM identified potential conflicts between stakeholders</i>	3.543	3.932	.000						
X24	<i>PM identified types of conflicts and their causes</i>	3.429	2.983	.003						
X25	<i>PM identified possible coalitions between stakeholders</i>	3.771	5.413	.000						
X26	<i>PM took into account stakeholders' influence before resolving conflicts</i>	3.714	5.122	.000			.354*	.042		

Code	Management Practices	Mean	T-test		Y1 (Client)		Y2 (Consultants)		Y3 (Main contractors)	
			T-Value	Sig.	r_s	Sig	r_s	Sig	r_s	Sig
X27	PM employed suitable conflict resolution strategy	4.086	8.223	.000	-.391*	.020				
X28	PM implemented a multi-win solution	4.143	7.690	.000	-.336*	.048				
Managing Corporate Social Responsibility										
X36	PM undertook project with a sense of social responsibility	4.086	9.153	.000						
X37	PM exercised utilitarianism – chose actions based on what was best for as many stakeholders as possible	3.943	6.159	.000						
X38	PM managed projects with a sense of duty and in accordance with the law	4.457	11.628	.000			.349*	0.04		
X39	PM implemented stakeholder management with strong awareness of firms' CSR (corporate social responsibility) policies	3.800	4.625	.000						

Notes: ** $p < 0.01$; * $p < 0.05$. Sig for t-test is 1-tail. r_s is Correlation coefficient, and sig is 2-tail.

5. Discussion

Objective 3 was to examine the practices that lead to effective stakeholder management. The results in Table 2 show that there would be significantly more effective management of clients (Y1), consultants (Y2) and main contractors (Y3) when some of the practices are adopted to a higher extent respectively.

Results from Table 4 show that PMs setting common goals, objectives and priorities (X1) is significantly correlated with higher effectiveness in managing consultants (Y2) and main contractors (Y3). Clear indications and directions are necessary to ensure that consultants and main contractors fully understand project requirements, which will safeguard the quality and performance of project deliverables, and improve confidence among project stakeholders (Karlsen et al., 2008).

Table 4 shows a significant positive correlation between PMs gathering information about stakeholders (X5) and the level of effectiveness in managing main contractors (Y3). The result

is consistent with Carroll and Buchholtz's (2006) finding on the importance of gathering information on stakeholders' background and role in the project. PMs should embark on aggressive information-gathering of stakeholders, such as their stake, power and influence on the project, as well as any opportunities, challenges and threats that the stakeholders face.

The t-test result in Table 4 shows that PMs do not conduct prioritization of stakeholders (X7) to a significant extent (mean = 2.257, $t = -3.599$ and $p = 0.000$), yet this activity is significantly correlated with effectiveness in managing clients (Y1). PMs may not have done this because they took for granted that the client should be given the highest priority, rather than other stakeholders. Taking the t-test and correlation results together, it is recommended that PMs conduct more systematic prioritization of stakeholders. This is important because it allows PMs to deal with the different stakeholders appropriately according to their power and interest in the project. By knowing which stakeholder takes priority, PMs will be able to closely manage those who possess high power and high interest (Kolk and Pinkse, 2006).

Developing a stakeholder interest list and going through it with team members (X8) is not adopted by PMs to a significant extent, yet it is significantly correlated with Y1 and Y3 (see Table 4). PMs may not have consistently carried out X8 because they assumed that stakeholders' interests are similar to project goals. Developing the stakeholder interest list at the early stage of the project will allow the potential impact of stakeholders' vested interests on the project to be identified (Arian and Low, 2005). It is recommended that PMs develop a stakeholder interest list so that they know which stakeholder to pay attention to.

Taking stakeholder interests into account in decision making and operations (X10) was significantly adopted, and X10 also has a significant positive correlation with the level of effectiveness in managing consultants (Y2) and main contractors (Y3). Without considering stakeholders' interests, PMs may make decisions purely based on achieving project objectives (timely completion, within budget and acceptable quality). However, this may frustrate stakeholders who may not cooperate because their interests are not safeguarded.

Exploring probable strategies that stakeholders could employ to realize their objectives (X14) is significantly adopted by PMs, and also have significant positive correlation with the level of effectiveness in managing consultants (Y2) and main contractors (Y3) (see Table 4). As stakeholders may adopt strategies that can help or obstruct an on-going project, it is important for PMs to predict stakeholders' actions as these may have both direct and indirect effect to aid or obstruct the development of a project (Orndoff, 2005).

The result shows that PMs do rate the impact of project strategies on each stakeholder (X16) and this has a significant positive correlation with the level of effectiveness in managing main contractors (Y3). This supports Chinyio and Olomolaiye's (2010) finding that in developing strategies to manage construction projects, PMs have to make assumptions regarding the stakeholders and how project strategies implemented by PMs can impact the level of interest, influence and support of these stakeholders. Stakeholders with higher impact ratings should be handled more carefully.

Understanding the urgency faced by stakeholders (X18) is positively correlated with the level of effectiveness in managing consultants (Y2). Urgency influences the manner and extent to which power is exercised in stakeholder management (Chinyio and Olmolaiye, 2010). When stakeholder claims are given immediate attention it shows that PMs are conscious of a project's time sensitivity in relation to stakeholders (Mitchell et al., 1997).

The practice of implementing strategies which depends on the demands of stakeholders (X35) is positively correlated with managing consultants (Y2) (Table 4). Certain stakeholders may assert their demands and claims, which may not be in the best interest of the project or in line with the client's vision. PMs must be able to handle these stakeholders within project constraints, and devise and implement appropriate strategies to engage and manage them (Leung and Olomolaiye, 2010).

The practice of taking into account stakeholder influence on the project before resolving conflicts (X26) is significantly correlated with the level of effectiveness in managing consultants (Y2) (Table 4). If PMs do not take into account varied stakeholder influence, they may not accord the correct response, and be unable to mitigate any negative stakeholder influence on the project (Aladpoosh et al., 2012).

Table 4 shows that identifying suitable conflict resolution strategies (X27) and implementing a multi-win solution (X28) are negatively correlated with the effectiveness of managing clients (Y1). The results indicate that if PMs identify suitable conflict resolution strategies and/or implement multi-win compromise solutions, clients are not managed effectively. This may be because finding the right conflict resolution strategy requires time, which is a luxury that most projects can ill afford. A multi-win solution can pose a challenge to the project team (Yang et al., 2009), and cause clients to incur additional costs or suffer project delays. Notwithstanding the results, it is recommended that PMs adopt appropriate conflict resolution strategies and resolve conflicts in a collaborative and constructive manner (Moura and Teixeira, 2010) so that the conflict does not escalate to a greater dispute and lawsuit (Ogunbayo, 2013).

Managing projects with a sense of duty and in accordance with the law (X38) is positively correlated with the level of effectiveness in managing consultants (Y2). The results echo Turner and Muller's (2005) emphasis that PMs actions and decisions should be based on rightfulness and integrity. To manage the legal aspect of construction projects effectively, PMs should be familiar with the relevant and most current legislations, and the contractual agreements made between stakeholders.

6. Conclusions

The findings show that when PMs manage clients more effectively, projects will have significantly better time and quality performance and owner satisfaction. Managing consultants and contractors more effectively leads to better owner satisfaction. This study contributes to knowledge by showing specific practices that PMs adopt which are significantly correlated with effective management of stakeholders (see Table 2). Among the many practices, those relating

to assessing and taking into account stakeholders' power have the most instances of significant correlation with effective stakeholder management. It was found that consultants and contractors would be managed more effectively when PMs adopt these practices to a greater extent: set common goals, objectives and priorities; take stakeholders' interest into account in decision making; and explore probable strategies that stakeholders could employ to realize their objectives.

The implications of the findings are that PMs need to set clear goals, objectives and priorities so that all stakeholders have the same understanding throughout the whole life cycle of the construction project. As the interests of all stakeholders are of intrinsic value, it is important that the PM is able to reconcile the divergent interests of all stakeholders for the benefit of the project. To do this, PMs should endeavour to understand the different interests of stakeholders and what project success means to each stakeholder. Going through the stakeholder interest list with the project team allows all interests to be explored and understood, and should be done at the start of a project. Additionally, these interests should be well considered in decision making and operations throughout the life cycle of the construction project.

Another novel finding is that clients are perceived to be not well managed when PMs identified suitable conflict resolution strategies and implemented multi-win solutions. The finding suggests that clients prefer to be the sole winner in project disputes, thus putting PMs in a difficult position of having to manage other stakeholders and ensuring projects are completed successfully. Striving for a multi-win solution is challenging and PMs need to cultivate skills and methods in managing stakeholders so that conflicts can be resolved in a collaborative and constructive fashion. This is vital to ensure that any conflicts in the construction project will not be escalated.

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Design and Safety: From the EU Directives to the National Legislation

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Abstract

This contribution wants to examine the relationship between the role of the designer and the role of the safety coordinator in design and construction phase.

EU technical analysis say that the designer plays a key role in the design preparation stage, and is so important in preventing occupational risks on construction sites. In national codes the relationship between design and safety it is not so strong.

The chronological path of EU directives dealing with Health and Safety at work in temporary and mobile sites it is analysed, starting from 92/57/EEC till arriving to the later EEC communications on the subject. Contemporary, the national Italian legislation is analysed, from Decree 494/96 till Decree 81/08, with the specific aim to search the connection between the role of designer with respect to the safety in project development. This way it is possible to reconstruct the actual link among architectural design and safety design.

It is thus possible to individuate the weak points in this relationship that lead to a difficult safety management in construction phase; main finding is that the connection between design and safety has been transposed into national standards in very different ways and only through a cultural awareness of the designers on the issues of health and safety objectives of Directive 92/57/EEC will be reached.

Keywords: Safety, design, legislation

1. Introduction

Health and safety issue in construction industry has a great importance. The importance of the theme is ratified by the specific European health and safety on construction sites directives that dictate the guidelines for the state members regulations. All European states are then provided with health and safety legislation concerning construction sites that is related with the common European principles.

Therefore if we analyse the data of accidents in construction industry in the various Member States on the basis of annual Eurostat report, it is possible to note a particularly variable trend within the Member States. The data shared by all European countries is a general decline in accidents: between 2008 and 2012 (latest available consolidated data) accidents in the workplace, in construction industry, had a decrease of 46%. But the fact remains that the number of accidents in construction is considerably higher than that recorded in other economic activities

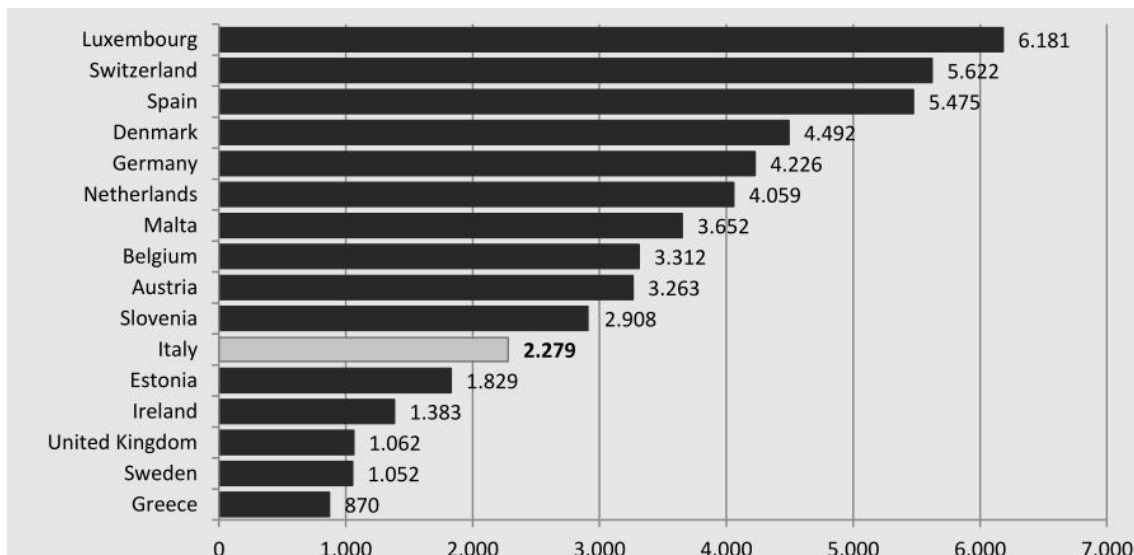


Figure 1: Accidents per 100.000 workers in construction in 2012 (Cresme Ricerche spa, 2014)

The international comparison shows that Italy, in 2012, was well below Germany (4,226) and Spain (5,475). However, considering the most serious accidents, i.e. fatal accidents, Italian ranking radically changes. This may partly be due to the vast spread of the informal economy and the specific entrepreneurial fabric (mainly made up of small and micro enterprises) can lead to under-reporting of less serious accidents.

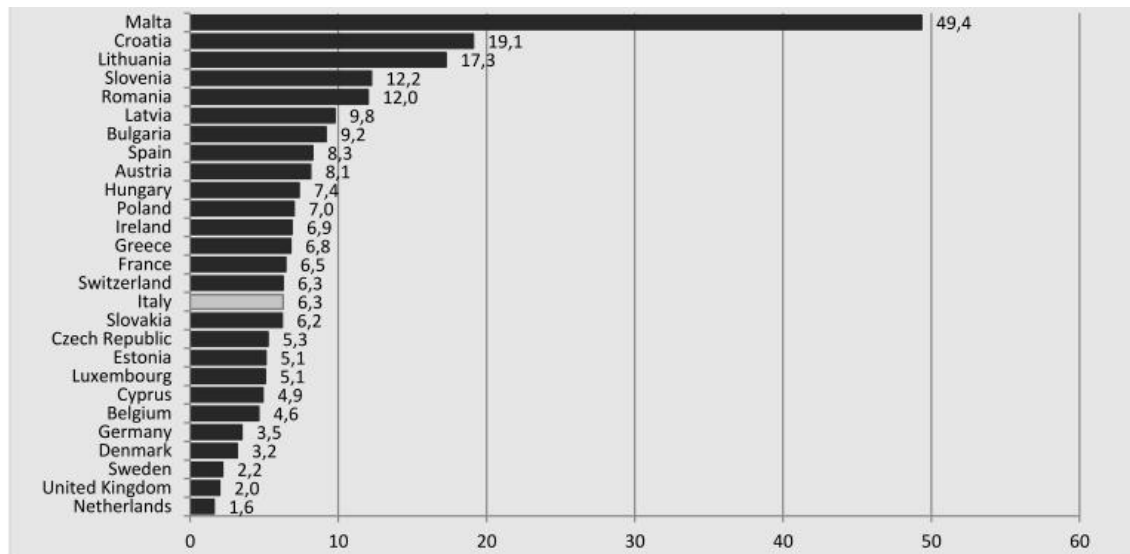


Figure 2: Deadly accidents per 100.000 workers in construction in 2012 (Cresme Ricerche spa, 2014)

The clear disparity in accidents that emerges from the European data, lead us to investigate the path that European directives have made at the moment of their implementation through national legislation. According to Capone et al. (2015), it is interesting to investigate how the European inspiring principles can be found in the texts of Member States laws.

In particular, the question we focus in this paper is on the relationship between the responsibility of the designers of the building and the project and health and safety management. This point of view comes from the importance that the European directives give to the design with respect to health and safety management in construction. EU directives clearly state the importance of the “safety awareness” during various stages of design and, for this reason, remark the Health and Safety Coordinator involvement in the design phase. Despite of it, in some European countries (i.e. Italy) the involvement of Safety Coordinator in design process is weak, even if national laws theoretically agree with EU directives. For this reason we examine how much national laws are in complete concordance with EU principles basing our analysis on the duties of Designer and Health and Safety Coordinator in Design phase. With the comparison we try to understand possible reasons for such differences in national legislations.

2. EU directive 92/57/CEE and UE Communication 06/11/08

2.1 EU directive 92/57/CEE

Directive 92/57/EEC concerning the minimum safety and health requirements at temporary or mobile constructions sites, since the initial considerations expresses the centrality of architectural choices in determining the safety during construction:

“[...] Whereas unsatisfactory architectural and/or organizational options or poor planning of the works at the project preparation stage have played a role in more than half of the occupational accidents occurring on construction sites in the Community [...] “

Right from the initial considerations, the Directive stipulates a direct relationship between the architectural choices and the occurrence of accidents in construction site. Stating that *“it is therefore necessary to improve coordination between the various parties concerned at the project preparation stage and also when the work is being carried out”*, it focuses on the design phase of the work.

Directive brings together again the connections between design and safety:

“Article 4 - Project preparation stage: general principles

The project supervisor, or where appropriate the client, shall take account of the general principles of prevention concerning safety and health [...] during the various stages of designing and preparing the project, in particular:

— when architectural, technical and/or organizational aspects are being decided [...]”.

The article 4 involves the client, empowering him, and asserts that he also must consider the principles of health and safety at the time of the architectural, technical and organizational choices. Complementing this, the article 5 stipulates the presence of specialized technicians in construction site safety (Health and Safety Coordinators), working since from the design stage.

All the European safety codes are therefore based on the above assumptions. It is interesting to investigate regulatory developments subsequent to 1992 to understand how the relationship between design and safety is inside in the current national standards.

2.2 EU Communication on the practical implementation of Health and Safety at Work Directives 92/57/EEC – 06/11/08

Communication is a European report about the practical implementation of Directive 92/57/EEC in the Member States; it is dated 06/11/08 and represents the state of the art 16 years after the enactment of the directive. Communication follows a Commission undertaking to assess the implementation of the regulatory framework with a view to improve it. It is based mainly on the national reports supplied by the Member States and an independent experts' report analysing implementation of the Directive 92/57/EEC.

The practical implementation of Directive 92/57/EEC

The implementation of the Directive is a complex issue in terms of technical and administrative staff. Member States regularly revise and update their legislation. This explains why in some States the directive has been transposed in a very fragmented of legislation that make it more difficult to assess. It is then revealed differences in national legislation deriving from the previous regulatory framework and from the fact that the Directive lays down minimum

requirements and leaves the Member States free to maintain or establish higher levels of protection.

Since the Directive gives all those active on a construction site key roles in prevention, its implementation was therefore assessed in terms of the influence that each group has on prevention of and protection from occupational risks. While the Directive does not refer explicitly to architects, engineers or consultancy firms, this group was evaluated because the designer plays a key role in the project preparation stage, and is so important in preventing occupational risks on construction sites.

It is clear from the report that architects and engineers know the health and safety requirements but do not totally agree with the measures imposed. Some designers are not in favour of the client appointing a coordinator for the design stage as, in their view, this hampers their creative freedom.

While stressing, in some ways, a lack of safety culture in the designers, on the other side it also notes that, when architects and engineers act as coordinators at the design stage, the working conditions on construction sites considerably improve. A specific education in the field of building design is a condition of absolute advantage for the health and safety coordinators. Communication also underlines that preventive health and safety is often not integrated into the project at the design stage because safety conditions during construction and subsequent use and maintenance are not a major factor in design/architectural choices. The designers are thus not adequately involved in health and safety process from national codes.

“There is a long way to go in all the Member States before the culture of prevention effectively takes root at the design stage” (EU Communication 06/11/08).

According to the Communication, it is important in this context that the competent national authorities make an effort to train designers at schools and at university, making prevention a key part of the curriculum

Roles of Health and Safety Coordinators

The Directive does not define the competencies required to act as coordinator, so there are big differences from one Member State to another. Some states have defined the competences and/or skills of coordinators in great detail, sometimes even requiring that they have specific training or a combination of training and experience (i.e. in Italy). The competencies required of coordinators by the Member States to fulfil their duties differ greatly, and so the standard of coordination varies from one Member State to another.

EU communication states that, because project preparation does not take prevention of occupational risks into account before the design is finalised, the lack of planning for prevention has to be remedied at the execution stage. It is to hope a change of attitude in construction industry; if national legislation made it a requirement for prevention measures linked to the

subject-matter of the contract to be systematically incorporated into the technical specifications for invitations to tender and in the contract performance clauses and quality contract management by the contracting authorities, this could help to change attitudes in this area.

The communication surveys that a lack of coordination in design affects the quality of the coordinator's work at the execution stage. The result is that on-site coordinators often encounter health and safety problems that are difficult to solve because they are generated from the design itself, because of its morphology and construction techniques. This underlines that safety should be considered a design property which affects itself.

3. European comparison

Here it might be helpful to tell briefly the theme of the relationship between design and safety in the European regulatory framework. The considerations, drawn from Bergagnin et al (2012 and 2013), resulted from a project of the Safety Commission of the Federation of Associations of Engineers of Emilia Romagna in 2012, then continued in 2013. Starting from the comparison between the various national laws transposing the Directive yards 92/57/EEC, aspects related to the main figures involved in the member states Germany, UK, Spain, France and Sweden (Aulin and Capone, 2010) have been analysed. Only these few European countries have been selected because in the academic detailed studies Sweden have been added to the work of Bergagnin et al (2012 and 2013).

Italy is our reference country since in the Italian construction system there is actually a weak position of the Health and Safety Coordinators with respect to the designer position in defining principal stages of the design. The study found that the role and requirements of professional technicians who deal with health and safety vary greatly in European countries. In particular, it was noted that while some EU countries have an approach to the issue very similar to the Italian one (i.e. Germany and Spain), other members (such as France and especially Britain) are significantly different, especially as concerns the design and construction management.

The research method was to deepen investigate the Italian legislation with respect to the EU directives, then, basing on literature studies (Bergagnin et al, Bragadin, Capone), other national legislations have been analysed in order to underline the research theme.

Italy

In Italy the first legislation on health and safety in construction sites declared after the EU directive 92/57/EEC was that the Decree 494/96. With subsequent amendments and additions it was in force until 2008, when it was replaced with Decree 81/08. Health and Safety Coordinator at the Design stage is central in the relationship between design and safety, bond never directly explained.

While in the European Directive are cultural recommendation related to the role and to the operative tools of the Health and Safety Coordinators in Design phase, in the national code

specific legal duties and responsibility are assigned to Health and Safety Coordinator at the Design stage. This lead to a strength definition of the Health and Safety Coordinators role in the Decree 81/08 with respect to the EU Directive.

In the following there is a synthesis of the evolution of Italian laws related to the Health and Safety Coordinator at the Design stage:

- Decree 494/96: no substantial differences from the EU Directive about the Health and Safety Coordinator at the Design stage duties. It is important to underline that Health and Safety Coordinator at the Design stage intervention is postponed in the executive design phase.
- Decree 528/99, modify to the Decree 494/96: Health and Safety Coordinator at the Design stage intervene in the generic “design phase”.
- Decree 81/08: not sensible differences from the previous law, except for the coordination of architectural, technical and/or organizational aspects.

At the same time, contents of the Health and Safety Plan evolved; analysing the specific contents of these documents allows us to detect the real competences a Safety Coordinator in Design phase must have with respect to the design. According to Bragadin and Giusti (2015) Health and Safety Coordinator can be seen as a specialized Project Manager and it is important for him to have real designer skills in order to intervene in the whole project.

Article 98 of Decree 81/08 indicates the requirements to be a coordinator: university graduation is not the only requirement, also graduates (surveyor, industrial or agricultural) are in fact admitted to the profession of coordinator. We are so distant from the auspices of the 2008 EU communication in which explicitly refers, as described above, to the design skills of engineers and architects who can assume the role of Health and Safety Coordinator at the Design stage. The debate is as a technician can objectively, without specific design skills, participate in the design phase of the work in relation to the issues of health and safety.

In this context, the stronger link, extremely general and as such address the cultural, is in Article 22 of Decree 81/08, "Obligations of the designers": designers of workplaces should comply with the general principles of prevention in health and safety at the time of design choices. Read extensively, this reminder of the responsibility of the designers – both designers of the building and of the construction site as a workplace - is the strongest bond that the Italian code, only in 2008, re-established with the directive of European origin.

United Kingdom

First aspect of the peculiarity is seen in the great importance that is reserved by the UK Regulations to the concept of design in safety. British standards provide binding obligations of the designer with respect to the safety of the building. In practice, in the UK the designer is required to design the safety of the work for all the people who come in contact with it, by those who realize, the future users and to future maintainers, according to a concept of global security that extends the entire life of the work itself. UK legislation comes to accurately define some technical aspects that the designer has to consider in the design phase, such as the future

maintenance of facilities and structures, or cleaning the windows or translucent walls, or how access to areas where there is the risk of falling.

The coordinator is responsible, on behalf of the client, to monitor the work of the designer, making sure that he complies with the safety provisions in order to receive full cooperation on the preparation of the Health and Safety File. The drafting of Health and Safety File, according to EU directives, is charged to the same coordinator.

Health and Safety Coordinator at the Design stage appointment comes even in the process of definition of the levels of design: once prepared the preliminary draft, is not allowed to proceed in the further steps of the design Health and Safety Coordinator at the Design stage is not appointed. Under these conditions, it is clear that the interaction between designer and coordinator proves effective and not fictitious.

Many clear differences are found between the United Kingdom legislation and other European countries including Italy, about the drafting of Health and Safety Plans. In Britain the customer directly provides information in a pre-construction stage, in order inform the designer, the principal contractor and the contracting companies, about the interesting elements regarding the future building, its construction and the construction site.

In UK Health and Safety Coordinator acts decisively and mainly managerial; he is in charge of ensuring the transfer of information between the various parties and the constant updating of proper documents relating to it. Recognizing the importance of the design in the future realization of the building, the UK code make the Health and Safety Coordinator at the Design stage to take a role of "safety consultant" designer and as such works with designer in a nearly equal ratio.

According Bragadin (2011), it can be said that countries like UK, with greater business culture and social sensitivity, while adopting apparently less strict rules have on their side a positive response statistical accident.

Germany

German legislation is very similar to the contents of Title IV of Italian Decree 81/08. On the design phase they are detected small differences from the provisions of Title IV, although it is clear more attention to the verification of the early interaction between the coordinator and designer, with a strong focus also on the contents of the technical dossier ("Document for Future Work").

France

In France there is an insurance system that is mandatory for public procurement and optional (but very useful) for private procurement; this is the so-called "ten year policy posthumously". Insurance institutions have their own technical specialists of the construction industry to grant

the insurance. The insurance technicians analyse the whole design and can request changes, improvements and any kind of depth, otherwise the denial of insurance coverage. The same procedure is applied to the technicians (from design to construction and safety) that must all be covered by insurance. Once implemented, the insurance thus guaranteed the technical quality of the work.

Furthermore, Health and Safety Coordinator in France cannot carry out any other type of appointment within the same building process.

Spain

In Spain Health and Safety Coordinator at the Design stage is appointed only in the case where there are more designers who do not have corporate links between them, or more professionals, or more member firms, or engineering companies. In practice this implies that Health and Safety Coordinator at the Design stage is not almost appointed in the bigger works because often they are carried out by big engineering companies or professional offices.

This law determines an obvious latency in design and programming of safety, in sharp contrast with the objectives of the European Directive, which provides for a special attention to safety since the embryonic stages of the development of design. Since in many cases the Health and Safety Coordinator at the Design stage is not appointed, it is possible that health and safety of the construction is entirely in the hands of designers work.

Sweden

In Sweden Health and Safety Coordinator at the Design stage participates in the planning and lead the preparation and design of project. Health and Safety Coordinator at the Design stage coordinates the preparation and design of project with regard to health and safety to allow participants involved during this stage to take into consideration each other planning and solutions. The coordination should lead to the execution of different parts of the project together with the construction, installation and others that occurs at different time and stage of the project where the risk of ill-health and accident could arise. Health and Safety Coordinator at the Design stage draws up a Health and Safety Plan if it is required before the construction site is set-up.

In table 1 a synthetic comparison among the countries is reported; in the table can be found the Designer Role in Health and Safety in construction and the Health and safety Coordinator involvement in design stages, with respect to the EU principles.

Table 1: A synthetic comparison among the analysed national legislations.

<i>Criterion Countries</i>	<i>Designer Role in Health and Safety in construction</i>	<i>Health and safety Coordinator involvement in design stages</i>
<i>Italy</i>	<i>weak, not specific duties or responsibility</i>	<i>quite strong but not efficient</i>
<i>United Kingdom</i>	<i>very strong</i>	<i>weak, only duties of control</i>
<i>Germany</i>	<i>weak</i>	<i>quite strong</i>
<i>France</i>	<i>weak, insurance system</i>	<i>weak, insurance system</i>
<i>Spain</i>	<i>weak</i>	<i>weak</i>
<i>Sweden</i>	<i>weak</i>	<i>strong</i>

4. Conclusions

It is clear in this discussion that, despite the common origin (Directive 92/57/EEC), the transposition of the European standard in the different countries was characterized by different hints and in some cases, UK among them, an approach substantially different.

A first objective fact that emerges from the research is the earlier and more intense involvement of the coordinator in the design stage during the project preparation; this takes place in the main European Union countries such as Germany and UK. Especially in UK, the function of Health and Safety Coordinator is purely managerial, having him responsible not only to draw up the Health and Safety Plan but also to control and monitor the activities of the designer. The designer is in fact the main subject invested from the obligation to respect the safety design choices and to provide all necessary information to the coordinator to compile the technical file (Health and Safety File).

An important consequence of the different approach to the safety of European countries, is found in the important role that Health and Safety Coordinator at the Design stage assumes: it has a guiding role to proper design of safety. The Health and Safety Coordinator at the Design stage is given this task with the knowledge that this will translate into lower cost of the work, both during its construction and during its future use.

The comparison shows another obvious fact: the diversity of skills that Health and Safety Coordinator at the Design stage must have. In the main countries is in fact required a high specialization of this figure and some of it expressly forbid to overlap the function of the coordinator with other positions within the same project or construction site. The main EU countries are in fact oriented towards the high specialization of Health and Safety Coordinator.

In conclusion we can say that, from the cross-reading of the rules of the Member States in relation to the European directive, the connection between design and safety has been transposed into national standards in very different ways. This is certainly due to the difference

social reality of the construction industry, made by the technicians who work there and by the fabric of businesses, widely variable from state to state.

Starting from the same EU directives, in some countries relationship between duties of the Designers and the duties of Health and Safety Coordinator is strong, in some other is actually very weak. Sometimes the Designer is not even mentioned in the legislation.

In our view and in accordance with the European community indications, the solution to bring the design to the centre of the construction site safety system is to act on the education of the designers, rather than on that of safety specialists. Only through a cultural awareness of the designers on the issues of health and safety we will tend to the actual achievement of one of the objectives of Directive 92/57/EEC: the reduction of architectural and organizational inadequate choices as a cause of accidents on construction site.

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Safety Constructability Improvement Adding Spatial Dimension and Workers' Safety in the Critical Path Method

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Abstract

In this contribution, at first an approach to analyse safety in the construction process is proposed. This approach includes Building Design for Safety (BDS), a specific method to check both constructability and workers' safety of the critical phases in construction process. Safety management in design and construction phases is one of the essential components that can influence the actual achievement of the constructability goal. Compliance with costs and time, necessarily passes through the risk mitigation of the critical activities, this must be done in order to safeguard the quality of the building. Prefiguring the construction process from the design phase, allows us to manage both safety and constructability. We operate within a framework that has to be used in design phase. In the framework, making use of the construction management instruments, we can identify critical activities for the workers' safety during the future construction process. For critical activities characterized by overlapping of time and physical space of construction, the BDS tool is proposed. BDS makes a check both of constructability and safety of the critical construction activities in order to suggest technical and management solutions to mitigate risks. The tool allows the user to identify measures and procedures for risk prevention and protection, with respect to the constructability. BDS has to be performed during the design phase, in order to prefigure the construction process. This way, risk mitigation can be performed according to the constructability goal, safeguarding the building correspondence to the needs of the design. So far, the results achieved concern the BDS application in many real case studies. Future issue are related to the development of the instrument in BIM technology.

Keywords: Constructability, safety, design

1. Introduction

It is within the last fifty years that quantitative methods for project analysis and scheduling have been developed and documented, and particularly those supported with computerization.

Critical Path Method (CPM) has ever since been the dominant methodology for scheduling construction. (Baldwin, 2014)

In this paper a new approach based on the analysis of construction scheduling supported by a construction simulation is proposed and used in order to increase safety constructability in the phase of activities planning.

Such an approach provides a new tool for extending basic activity-based CPM logic adding workers' dimension and optimizing basic scheduling in function of workers' safety. Traditional CPM uses a single layer of logic which operates only between any two activities. Production occurring inside an activity is described only by duration, and there is no recognition of the worker's position in terms of working areas.

Until now the approach of Location-based management assumes that there is value in breaking a project down into smaller locations and using these to plan, analyze and control work as it flows through these locations.

The location-based planning system takes into account activities and tasks, where a task is made up of a sequence of activities in differing locations. Then it uses CPM external logic to define the logic or connection between different activities within locations wherever they occur. However, unlike CPM, the planning system also considers a task's own internal logic, by calculating durations based on quantities and allowing the planner to plan the location sequence and production rate to achieve continuous production.

Starting to carry out a review of the current practice in the field of Location Based Management Systems (LBMS) a new approach is proposed which generates a logical relationship between working areas and activities and automatically, first, integrates this relationship in the CPM and then manages overlapping activities in terms of risk workers' risk reduction.

This approach comes from the consideration that in construction management, the health and safety is one of the most important element able to influence the entire process-management.

In this perspective it could be useful to remember the close relationship between safety and design (Capone et al., 2015). In safety management, EU Communications refer to architectural, technical and/or organizational choice in order to minimize professional risks. Such choices underline the cooperation needed between designer and safety coordinator at design stage: actually the main issue is related to the effectiveness in reaching the constructability goal.

2. Constructability, design and safety

As referenced by Capone et al. (2015), in the theoretical approach to Constructability the difficulty of designers to lead the construction phases during design phases was straight from the beginning. This opened up to a discussion about the aim to link design phase and construction phase: the results of building's quality are strictly related to the separation/integration between design and construction.

Together with Constructability the development of methods and tools aimed to manage this complex relationship, known as "Constructability", is a strategic resource for the field of Construction management and the progression of this concept shows that the aims could change throughout time depending on many factors such as incidental, environmental, social and economic (Gambatese 2007). According to Russel (1994), the construction time and cost could be depending on the way of running of the relationship between design and workers Healthy and Safety. The aim of directing such factor, according to the Constructability theories, means to find new design tools that aim to manage H&S during the design phase (Gambatese, 2009) (Creaser, 2008) (Taiebat, 2001).

The research line about Constructability has been carried out at two levels of analysis: one is overview level which focuses on the broad picture of Constructability and the other is the practical level, which investigates new tools, created ad hoc, to reach the research objectives. From the relationship between design and safety, the Building Design for Safety (BDS) method has been proposed by Capone (2014). This tool, better explained in Section 4 of the presented paper developed a construction simulation based by starting the activity simulation from the shop drawings. A 2D representation was used to visualize construction operations but the integration of this approach with a construction scheduling tools was not proposed. The presented work first develops a new tool for an automatic re-scheduling of CPM in function of workers' safety and when the tool is not enough proposes BDS as design solution in order to consider safety reasons before construction process starts.

3. Location Based Management System

Location-based management considers there is value in breaking a project down into smaller locations and using these to plan, analyse and control work as it flows through these locations. The location provides a container for project data at a scale which is easy to analyse.

Location-based planning is, in turn, concerned with the process of planning for work to protect production efficiency as work moves through locations. Specifically, the emphasis in location-based planning is to plan for productivity.

Location based methods extend basic activity-based CPM logic to yield an easy-to-use system which possesses the underlying analytic properties of CPM but specifically includes production estimation. This is reached by layered logic which is a simple process of automating the creation of a critical path network by using locations. Traditional CPM uses a single layer of logic while

Location-based planning introduces new layers of logic which add more detail to both the internal task production of the location-based task, and to the external links between tasks.

In this case all the analytic features of CPM are preserved when examining the logic between activities within locations, as activity sequencing is driven by normal CPM algorithms with familiar concepts such as precedence and lags.

In parallel, Location-based control assumes that planning has maximised productivity, found an optimal balance between risk and duration and is feasible to implement.

At least this approach aims to reach a better productivity level without considering how site and workers' conditions change due to overlapping activities and how safety risks increase in construction site.

For this reason the proposed WSiCPM framework, which is explained in section 6, aims to propose a novel approach which consider the integration of CPM with locations but assumes the planning as function of potential hazards which has been calculated using equations depending on different parameters. WSiCPM framework is integrated in a wider framework of design phase as explained in section 5.

4. The method Building Design for Safety (BDS)

The starting point is the idea that the visual simulation is not only a "passive" image of contents, but it is an "active" control in terms of built result. The aim was then to improve the contents of the representation to accentuate its "dynamism", implied in the project. The approach tends to re-elaborate project drawings to clearly express those construction processes implied in the drawings of the constructive details. The approach is to entrust to the design the role of harmonizing different parties. The chosen way is to assess "workers' safety" as the parameter to implement a new tool in order to obtain a safety realizable project. Starting from the representation of construction details, according to Building Design for Safety (BDS), it is possible to simulate the construction of them using the CAD 2D as graphical tool. This can be done through progressive drawings that express the breakdown in construction phases –one phase for each new building product-, chronologically processed and logically related. In these specific drawings are depicted all site facilities (temporary works, machineries and manpower) in order to simulate and verify the real conditions in which it will be the realization. BDS allows both the detailed assessment of safety conditions –by using a traditional risk analysis- for the realization of the item and the Constructability verify of the element itself. It is important that this happen before construction stage, when it is still possible to intervene, where appropriate, with amendments on the project itself. It is possible to find more details on the BDS method in (Capone et al. 2014). The picture below (Figure 2) shows the visual representation of the method.

5. Safety management approach for critical construction phases

In BDS method have been proposed and tested a simulation process of the construction operations, with the specific aim to correct and optimise shopping drawings in order to have a better performance of the building (Capone et al. 2015). After a lot of applications in different case studies, the necessity to consider the “time variable” has appeared, above all in managing interfering activities.

The question should be how to insert BDS method in a wider processual and operative framework, in order to make BDS free from the theoretical, episodic, uneconomical and unrealistic aspect that could have been attributed to it.

To reach this goal the first step was to define an approach that, using the construction management tools, could individuate the critical construction activities in the safety point of view. In professional practice, regarding interfering activities, the Health and Safety (H&S) Coordinator usually gives operative prescriptions to stagger in space and/or in time the interfering activities and gives the instructions to control the efficacy of such prescriptions.

If interfering risks still remain, the H&S Coordinator must determine preventive and protective measures in order to minimise risks.

Nevertheless there are a lot of situations in which is difficult to stagger in space and/or in time the interfering activities preserving together the workers' safety and the Constructability requirements.

Usually the individuation of critical phases is performed by means of the classical construction management tools; with BDS method we have a closer analysis of the critical phases (Figure 2).

Searching for the applications in which the BDS method could be more effective, we investigated different theories linked with construction management and safety (Baldwin and Bordoli 2014).

The link between design and safety suggested us to improve and optimize visual representation of construction site issues, taking distances from the traditional site layouts in order to improve information and make designer tools more effective.

According to the aforesaid traditional theories, planning techniques such as critical path method (CPM) are useful for analyzing the logic of construction activities, identifying critical activities and producing a model form which it is possible to produce schedules for activities and identify milestone/completion events. From the literature review emerged that CPM helps to clearly identify key contractual dates for the start of the activities on site and completion of construction work. CPM confirms production deadlines and contractual obligation. However,

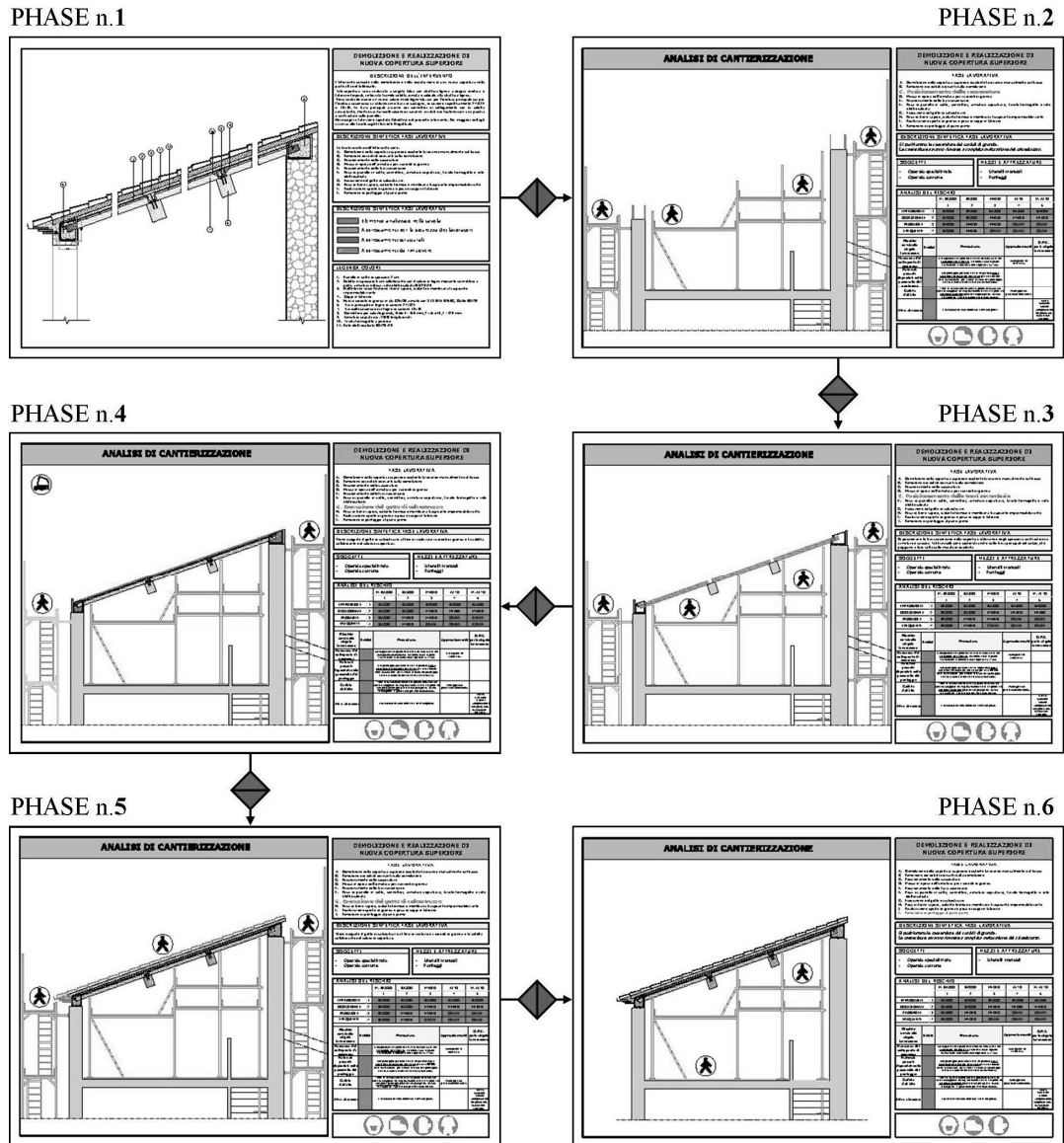


Figure 1: Operative Framework of the BDS procedure for a roof redevelopment (Capone et al. 2014)

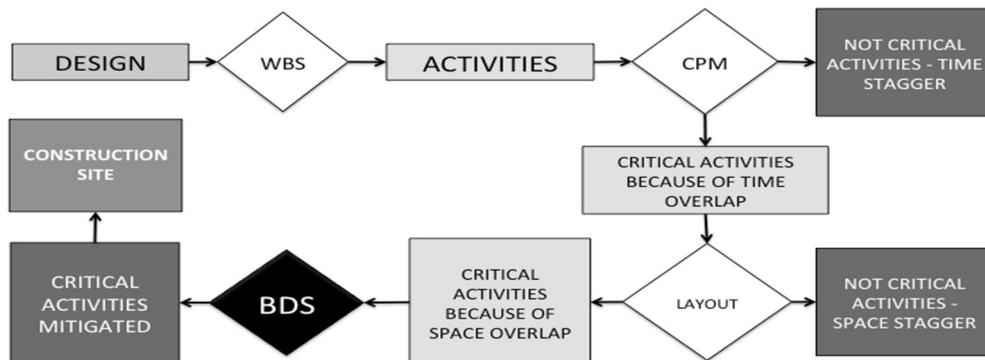


Figure 2: Graphical representation of the approach to safety management of critical construction phases (Capone et al. 2015)

CPM is not the best tools to direct production on site. The great deficiency is the lack of a direct connection between scheduling approach, used for the baseline schedule, and the real site condition. Only introducing the spatial dimension and workers' dimension, considered by BDS method as well, in the traditional construction tools and in CPM planning in this particular case, it could be possible to effectively manage the site conditions.

A step in this direction can be the WSiCPM framework, as in the following it is described.

6. The WSiCPM framework

6.1 The methodology of the WSiCPM framework

An attempt to create a methodology able to incorporate the workers' safety and the spatial dimension into the critical path method (CPM) has been done. Such methodology can be used as a supplemented tool in planning and design phases to identify and remove early the risk of accidents by means of BDS method. The methodology called WSiCPM (Workers Safety into CPM) has been developed to detect time-space-conflicts of activities in order to help health and safety risk assessment in construction management. In WSiCPM framework, a method for qualitative and quantitative risk assessment was programmed and implemented. Probability of potential hazards has been calculated using equations depending on parameters such as: overlapping duration, overlapping working area, number of workers in the observed pair of interfering activities and type of hazard. The severity of the hazard has been estimated analogously, with the compensation of a casualty by insurance companies (through this, the risk can be modified into a monetary value representing the predicted accident cost). Additionally, the framework proposes possible solutions for each pair of interfering activities. BDS has been linked with WSiCPM as a method useful to analyse and resolve health and safety risks in space-time conflicts activities. In figure 3 WSiCPM framework is depicted.

In the following steps the methodology is described using the information from a case study which includes a set of nine different site activities.

6.2 Step 1: Definition of the Overlapping Matrix

This step of the analysis sets out an overlapping matrix which is able to identify and control the *time-overlapping activities* in order to achieve the following aims:

- Organize the analysis of interference activities by way of a pairwise comparison, in order to discuss their interaction;
- To apply the mathematical concept of non-analogue relationship between the two activities of each pair;
- Calculate the overlapping duration of each pair of interfering activities.

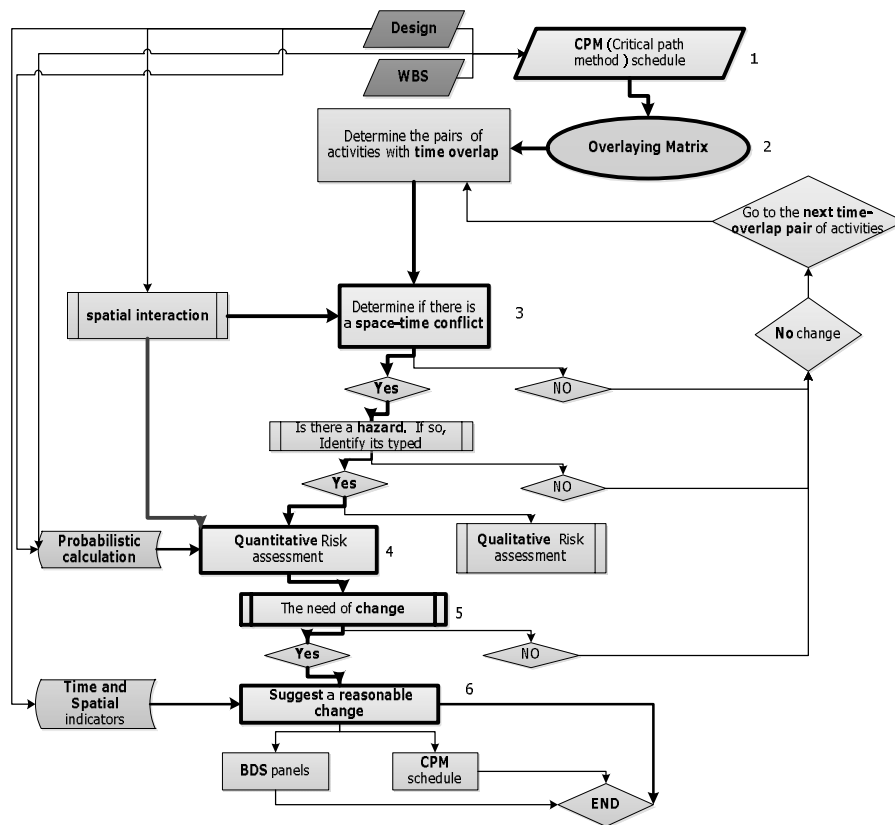


Figure 3: WSiCPM workflow

This is carried out exporting information about the activities' properties (name, duration, finish, dependencies, cost, ...) from the baseline schedule CPM (Fig. 4), practically using MS Project Software, to a pre-set database, practically implemented in MS Access Software.

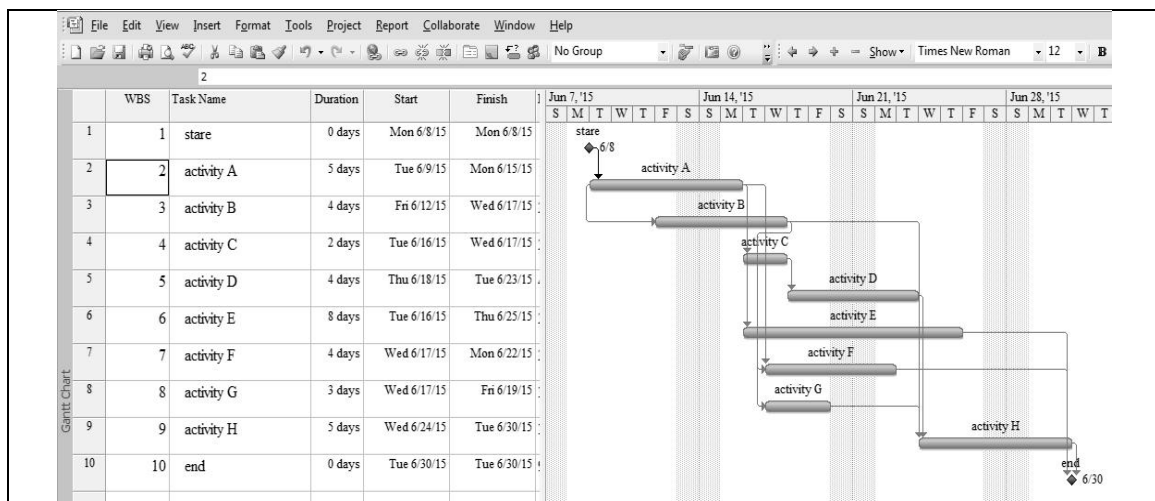


Figure 4: Example of the baseline schedule –CPM- taking into account nine activities by using MS PROJECT

The method automatically fills the matrix in using two type of overlapping scenario: “No conflict”, “Time interference”. The figure 5 shows the matrix for the proposed case study. After this analysis it’s possible to pull the pairs of activities with a time overlap out from the aforesaid matrix.

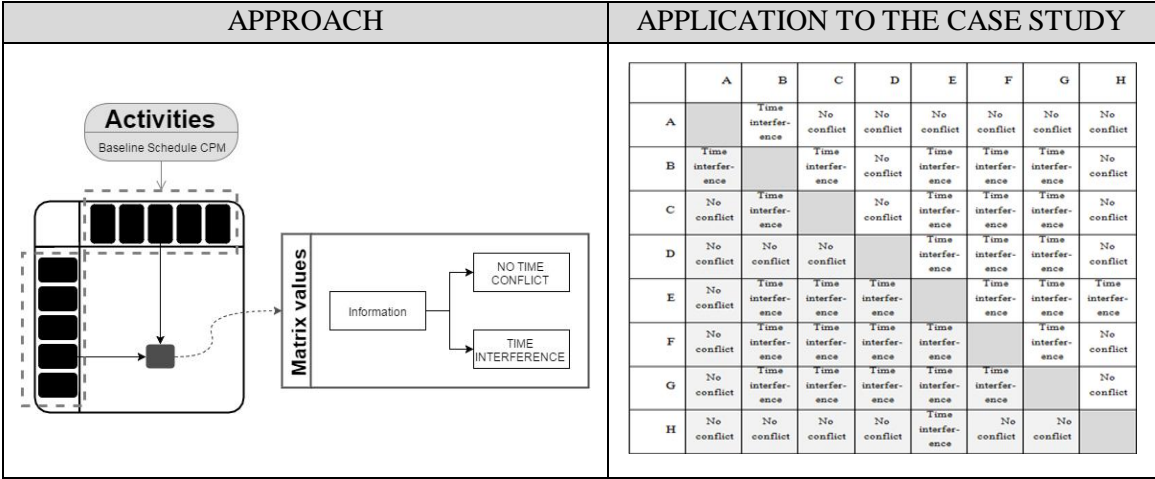


Figure 5: Example of matrix of overlapping

6.3 Step 2: Determination of the space-time-conflicts

According to the framework, after determining the activities with a time overlap, each activity pairs should be processed in order to achieve a double-check: time interaction (as described in the step 1) and spatial interaction as described below, locate the “space-time conflicts”.

This double-check aims to locate the “space-time-conflicts” which mean that there is a spatial interaction between the two activities, even if they are run in separated spaces, since the conflict could be present not only in the activity’s work area but also in in the areas connected to each activities. For this reason, referring back to the designer, the method considers four different kind of areas related to each activity and check their interaction as shown in the Figure 6.

If the two activities run in different places without space interface, then space-time-conflict has not occurred as the Figure 6 shows.

6.4 Step 3: Determine the type of hazard and risk assessment

After determining the space-time-conflicts, it is important to know whether a hazard has been created by each space-time-conflict pair of activities. If so, once hazard has been identified, it is necessary to calculate the associated risk.

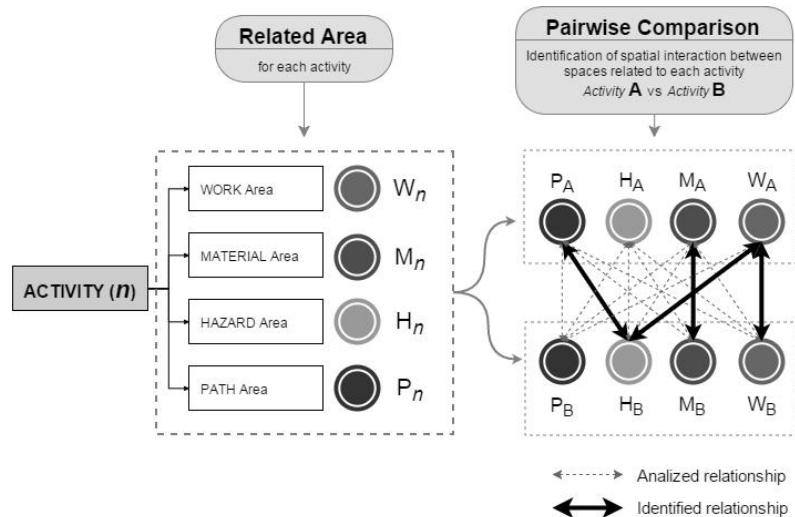


Figure 6: Example of space-time conflicts determination

In WSiCPM a specific quantitative risk assessment has been developed and the risk evaluation is generated by the framework. Inside WSiCPM the probability has been estimated with probabilistic calculation of the time and space probability with respect to the space overlapping areas and the number of workers. The severity of the accidents has been expressed using a method deriving from insurance (monetary quantification of the damage).

6.5 Step 4: Risk response and change request

The WSiCPM framework works like an expert system: the outputs of the quantitative risk assessment, in addition to spatial information and time information from CPM, are the input in this operation. For each space-time hazard conflict pair, the framework suggests a solution.

The framework provides four different kinds of suggestions in order to mitigate risks, helping the decision maker in resolving the conflict.

BDS will be used in WSiCPM to solve the risk situations that cannot be mitigated just with scheduling actions. BDS will be used in case if it would be necessary to have a deep H&S and constructability analysis, coming until the possibility to solve critical situation even by changing the design.

The solutions automatically proposed by WSiCPM are listed as follows.

1- Changing the path

This suggestion is given if there is interference between the hazard area of an activity and the path area of another.

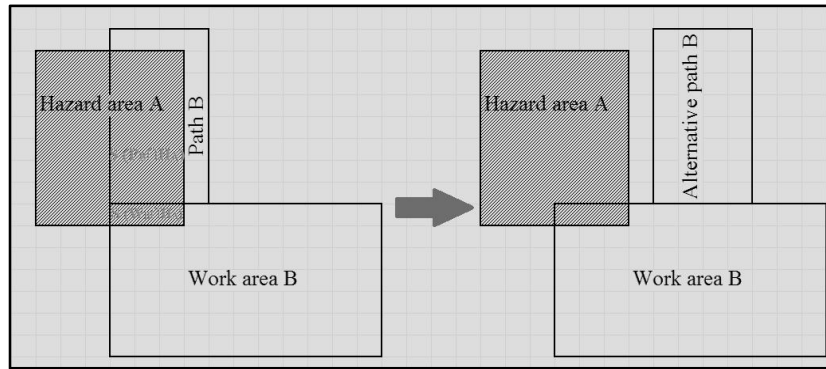


Figure 7: Example of path changing

2- Dividing the areas

This suggestion considers the interference of the hazard area of an activity with the work area of another activity. If this interference is minor with respect to the work area itself and the overlap time is less than the duration of the last activity, taking into account the ability of the last activity to be divided, then the framework will suggest to subdivide it.

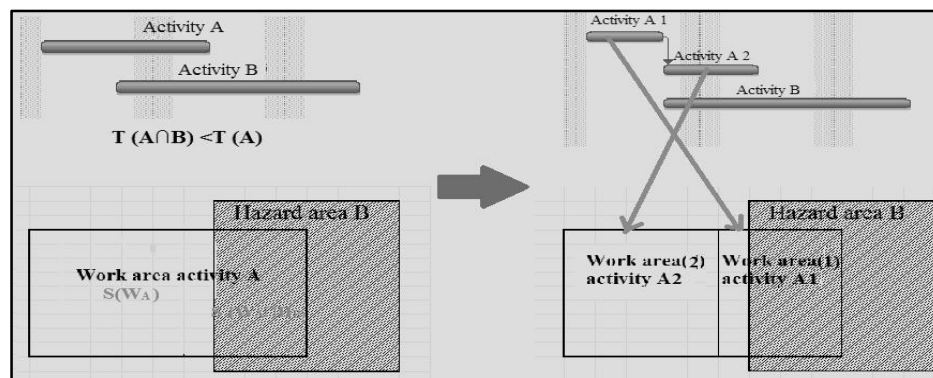


Figure 8: Example of dividing areas

2- Splitting the activity

This suggestion considers that, if the overlap-time is small in comparison with the duration of one of the activities, which can be achieved in two phases and it is not critical, the framework proposes to divide the workload. Thus, the work in the long activity is halted and later continues after the end of the hazard (time dividing).

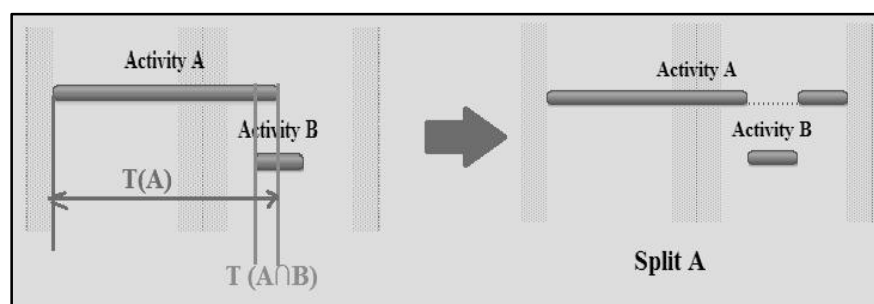


Figure 9: Example of splitting

2- Rescheduling

This suggestion considers that, when the risk is high and the interference of the space is substantial (the two activities take place almost in the same place), and the time overlap is equal to the duration of one of the two activities; re-scheduling the non-critical activities would be the main solution proposed by the framework.

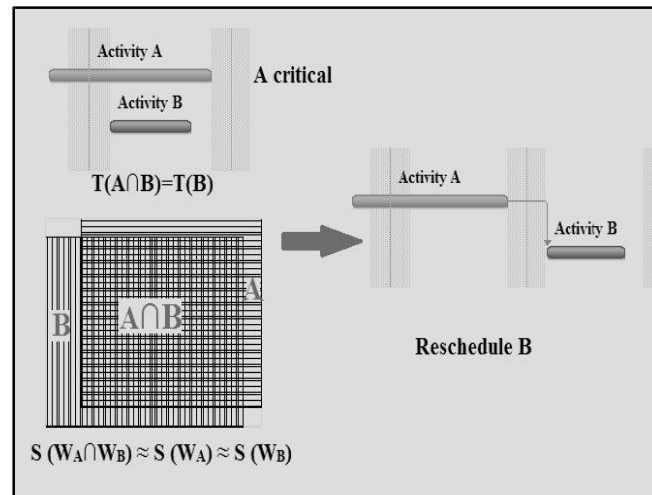


Figure 10: Example of re-scheduling

7. Conclusions

An attempt to propose a framework to analyse, evaluate and solve space-time conflicts with respect to health and safety risk mitigation has been made. If the automate solutions given by the WSiCPM are not suitable for the specific situation, BDS is suggested as the best method to solve the constructability issue mitigating health and safety risk for workers. This way, we tried to individuate acceptance criteria for critical activities overlapping, both in space and in time and then to quantify workers' safety risks.

The analysis, the assessment and the management of health and safety for workers in complex risky activities by using BDS, seems to push future developments in the direction of Building Information Modeling (BIM). In this perspective the research group is working on the implementation of site-analysis in a BIM-environment.

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Resource – Space Charts for Construction Workspace Scheduling

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Abstract

Construction production is typically highly dependent upon space to move, store and fabricate materials and building components, and to perform transformation and assembling activities. Construction planning and scheduling goal is to provide a logical order for activities taking into account safety, space and logic requirements. Construction process scheduling should also incorporate specific features of work-flows of project activities through work spaces. The Location-Based Management System (LBMS) is a recent and innovative method that aims at planning and managing construction projects in a process-oriented way, taking into account activity locations on-site. In an on-going research an improved scheduling method for construction operations has been developed, based on a CPM - Precedence Network plotted on a Resource–Space chart. Space Units of the project work are identified by a Location Breakdown Structure (LBS) like in the LBM System, and project activities are identified by a two dimensions coordinate system based on Resources (i.e. construction crews) and working Spaces (e.g. floors of a multi-storey building). As the Precedence Network is plotted on a resource – space chart, Space Units can be characterized by a maximum resource capacity number for each activity type, thus defining the available space capacity of working crews. In this way project scheduler can verify the quality of the produced schedule during the planning and scheduling process, as dimensions of workspaces and their congestion limits, safety spaces and protection spaces can be easily verified. The method has been tested on a sample project. The proposed scheduling approach can help unexperienced project schedulers to identify specific resource requirements for spaces needed for activities, and to define locations of these spaces and resources on building site. The proposed approach can be useful especially in case of project acceleration and time-cost trade-off, helping the project team to produce an efficient construction schedule.

Keywords: Construction, project scheduling, resource management, precedence network, workspace management

1. Introduction

Construction projects are very specific industrial projects. One of the most important features of construction production is related to the building site. Building construction is an industrial activity in which workers build not only the product but also the working location, i.e. the building site. Therefore, space for construction activities, including materials, machines and fabrication stations, traffic routes, places of construction work and welfare facilities must be designed, organised and planned (Riley, Sanvido, 1997). Construction planning and scheduling has the objective of providing a logical order for activities taking into account safety, space and logic requirements. In particular, it is believed that a construction schedule should focus on space requirements as they can have very important effects on safety and production quality (Akinci, Fischer, Levitt, Carlson, 2002; Ciribini, Galimberti, 2005). Understanding the organization of the various materials, trades, and subcontractors in the project processes is an ability acquired only after years of study and experience. Construction workspace is, at the same time one of the main components and constraints of construction scheduling, due to production context and building product characteristics. So, workspaces are generally difficult to proactively plan and manage, because of the dynamic nature of construction production where site layout and work environment change continuously as processes progresses. Workspaces are key elements of the process model embodied in a schedule, and work-space conflicts prevention is an important feature of a construction schedule. As standard planning and scheduling of a construction project can be achieved through networking techniques, the space – related component of the schedule is difficult to model and to efficiently take into account by an unexperienced project scheduler. Thus, a method to understand schedule workflow and spaces during the scheduling process can be a valuable instrument to achieve project success.

2. Literature review

Many scheduling methods have been proposed in literature in order to improve construction project workspace management with a scheduling model. As crews perform activities from a space unit of the project to another one, it might be advantageous to arrange for such crews to work continuously, without interruptions, thereby preventing idle intervals of equipment and manpower (Selinger, 1980). Riley and Sanvido (1995 and 1997) observed that current space planning in multi-storey building construction is limited to site layout and logistics, and they propose a space planning method that provides a logical order and priority for activities related to their needed spaces. Effectively a construction planner need to: (1) identify the space needed for activities; (2) define locations for these spaces on building floors; (3) develop a sequence of work that defines the order spaces are occupied; (4) identify potential spatial conflicts. Kang et alii (2001) observed that in a multiple repetitive construction project, construction cost and duration are dependent on: number of work areas, proper crew grouping, size of work areas, frequency of repetition of each activity, and provided an heuristic approach to allow optimal construction planning. Yang and Ioannou (2001) proposed a scheduling method with focus on practical concerns in repetitive projects, and implemented in particular the pulling effect in the continuity relationship between activities.

Yi, Lee and Choi (2002) presented a heuristic method for network construction and development for repetitive units project, with the aim of minimizing total project duration by reducing idle time of resources and spaces. Actually the heuristic changes the sequence with which crews complete the scope of work encompassed in each repetitive activity. This approach and general formulation has been applied in earlier and more accurate models (El Rayes and Moselhi, 1998) which guarantee a global optimum solution. Guo (2002) proposed to integrate computer-aided design with scheduling software for the dynamic identification of space conflicts on the jobsite. Work-space types are identified and time-space conflicts are studied. The seminal work of Akinci, Fisher, Levitt and Carlson (2002) investigated the time-space conflicts in construction projects. Six type of spaces required by construction activities were detected and each construction activity requires at least one of these spaces. As activities can have time overlaps, i.e. they can be performed at the same time, time – space conflicts may occur. Ciribini and Galimberti (2005) observed that the H&S Management has widely to deal with working areas and space conflicts. A schedule model should indicate crew workflow directions, space requirements, and spatial buffers between activities. The optimization of the sequences of crews (workflows and production rates) can be done by scheduling work locations. Daewood and Mallasi (2006) and Mallasi (2006) observed that lack of execution pace planning may disrupt the progress of construction activities. Also, spatial congestion can severely reduce the productivity of workers sharing the same workspace, and may cause health and safety hazards to workers. A Critical Space-Time Analysis (CSA) approach is proposed to model and quantify workspace congestion and a computerized tool termed PECASO was developed for workspace management. The basic method suggested by researchers and practitioners for time – space project modeling is the linear scheduling method, flow line or linear planning, integrated with a network model (Kenley and Seppanen, 2010; Russell, Tran & Staub – French, 2014). Kenley and Seppänen (2009, 2010) observed that locations are important in construction because building can be seen as a discrete repetitive construction process, a series of physical locations in which work of variable type and quantity must be completed. They also observed that the location based methodology does not exclude Critical Path Method (CPM), in fact dependencies between activities in the various locations and between tasks (that are made up of activities of the same work item) are realized with CPM logic links. Construction projects are location – based projects (Kelley, Seppanen, 2010), where resources perform the same activity in different locations consecutively. Choy, Lee, Park et alii (2014), observe that current construction planning techniques have proven to be insufficient for work-space planning because they do not account for needed spaces of activities. So a framework for work-space planning is proposed categorizing activity spaces and including 4D Building Information Model (BIM) generation for space identification. Zhang, Teizer, Pradhananga and Eastman (2015) highlight safety and productivity poor performances of construction due to congested site conditions, and propose a method for automated visualization of workspace with BIM. Workspace modelling is based on five workspace sets and a conflict taxonomy.

In summary it is felt that there is a lack of structured planning and scheduling method for workspace management, at the design and schedule level of a construction projects. Workspace is an important concept and viewpoint for understanding characteristics of construction projects. The earlier research has covered already several important methodological characteristics of

construction planning and scheduling with the site space on focus. Although not covered explicitly here some research has covered also computerized assistance for the generation of alternative plans and schedules – for example (Kahkonen, 1994; Märki et al, 2007). The research presented in the following aims at proposing a method to understand work-space characteristics of a construction project for planning and scheduling purposes, thus creating a process-oriented environment for construction schedule production, and enabling high quality scheduling.

3. Proposed Method

3.1 REPNET: Repetitive Networking technique

In an on-going research an improved scheduling method for construction operations has been developed, based on a CPM - Precedence Network plotted on a Resource–Space chart termed Repetitive Networking Technique (REPNET). Locations or Space Units of the project are identified by a Location Breakdown Structure (LBS) like in the LBM System, and project activities are identified by a two dimensions coordinate system based on Resources (i.e. construction crews) and working Spaces (e.g. floors of a multi-storey building) (Bragadin 2010, Bragadin, Kahkonen 2011). As construction projects activities are often performed in many different locations of the building site by the same crew, a basic component of construction process understanding is the modeling of this time – space related process. A project activity performed in different locations, with similar sub-products, is termed repetitive activity. It is important that repetitive activities are planned in such a way as to enable timely movement of crews from one unit to the next, avoiding crew idle time and space - conflicts with other construction activities. The REPNET heuristics provide optimized activity scheduling maintaining the work continuity constraint and also the As-Soon-As-Possible total project duration calculation.

3.2 Resource-flow tracking with a resource – space chart

A Precedence Diagram Network of the repetitive project is plotted on a resource – space chart, with the x-axis representing resources and the y – axis representing space units of the project. The two coordinates identify each network node representing an activity performed in a specific space unit: the first coordinate is the main resource performing the activity (construction crew) and the second coordinate is the work space in which the activity is to be performed. The procedure of plotting the network on a resource – space coordinates has been used by many researchers in the past. In particular Yi, Lee and Choi (2002) presented an heuristic method for network construction and development for repetitive units project, with the aim of minimizing total project duration by reducing idle time of resources and spaces. The heuristic plotted the activity network on a Resource – Space Chart. Resources in the x-axis of the chart were the work crews or the equipment that was intended to perform activities. Resources were grouped by work item i.e. masonry, plastering, floor concrete slab etc. Multiple resources, i.e. multiple crews, were allowed for the same work item in order to perform parallel repetitive activities in different locations of the same task. In this way in every column of the chart activities are

grouped by resources (fig. 1). Space units of the project are plotted on the y-axis. Space units are the locations where only one crew can perform one activity at a time. In the proposed method the Location Breakdown Structure (LBS) can be displayed on the y-axis with a hierarchical decomposition of project locations (fig.3). An activity is defined as the set of construction operation performed by a specialized crew or equipment in a space unit of the construction project. In a repetitive construction project a set of activities, performed by the same crew in more than one space unit, is defined repetitive activity. Resources that perform a repetitive activity are identified by a j code. A task is defined as a set of repetitive activities performed by one or more than one crew for a work item, and is identified by the i code. So a resource path is completely identified as a repetitive activity by the ij code (ie resource path) and a single activity is identified by the ij-k code where k identifies the space unit where the activity is performed (i.e. space path, fig. 1). The k code is a unique alphanumeric character that identifies the operational space of the Location Breakdown Structure.

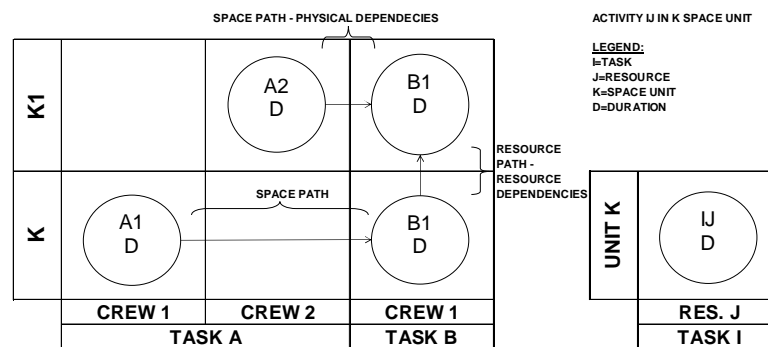


Figure 1: Network Diagram plotted on a Resource-Space Chart (adapted from Yi, Lee and Choi, 2002)

3.3 Space planning with the resource – space chart

The space identification for a construction schedule can be addressed by Location-Based Planning (Kenley and Seppänen, 2010). Location – Based management assumes that there is value in breaking a project down into smaller locations and using these to plan, to analyse and to control work as it flows through these locations. The location provides a container for project data at a scale which is easy to schedule and to control. The emphasis in location – based scheduling is to schedule the construction project achieving high level of productivity, quality and safety. The Location Breakdown Structure (LBS) is the backbone of this design process of on-site operations. Once the project is decomposed into various locations, or space units, understanding the interactions between activities and spaces is needed. In this phase the required spaces for each activity are detected and assigned to space units. Repetitive activities are decomposed into various activities to be performed into specific space units due to their production features, and single activities are allocated to specific spaces of the LBS. The sequence of activities is then generated using Precedence Diagramming Method (PDM). Activities are sequenced with network logic links and consecutive and concurrent work tasks are defined first for each space units and then for the complete building project. The prepared

activity network can now be plotted in the Space – Resource chart. The allocation of activity on the resource – space chart can highlight possible time/space conflicts between activities. Conflict resolution can be performed and the optimized space-allocated schedule can be completed. The flow-chart of the proposed scheduling process can be found in figure 2.

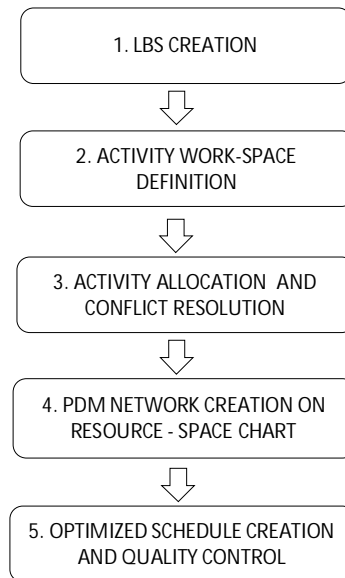


Figure 2: Proposed Scheduling Process

The seminal work of Akinci, Fisher, Levitt and Carlson (2002) investigated the time-space conflicts in construction projects. Six type of spaces required by construction activities were detected: building component space; labor crew space; equipment space; hazard space; protected space; temporary structure space. Each construction activity requires at least one of these spaces. As activities can have time overlaps, i.e. they can be performed at the same time, time – space conflicts may occur (Akinci et alii, 2002; Mallasi, 2006; Zhang et alii, 2015). Time – space conflicts have three characteristics:

- Temporal aspects of time-space conflicts: since activity space requirements change over time, time – space conflicts between activities only occur for certain periods of time.
- Multiple types of time – space conflicts: depending on the types of space conflicting and the quantity of interfering spaces, time – space conflicts can have many types: safety hazard; congestion; design conflict; damage conflict.
- Multiple conflicts can exist between a pair of conflicting activities.

In the proposed method, four types of conflicts are identified for project scheduling purposes:

- Time / space conflicts due to activities' time-space overlapping and consequent contemporary space usage;

- Congestion of space due to labor density. The maximum number of workers per site location should be limited. The increase of labor density can lead to productivity loss and safety hazards.
- Safety hazards due to hazard spaces created by an activity for labor crew spaces of other activities.
- Damage conflicts due to labor crew spaces, equipment space, temporary structure space, hazard space required by an activity conflicts with a protected space of another activity.

The proposed resource – space chart based method can help project planner and production managers to avoid conflicts in many ways. In fact, time-space conflicts can be avoided due to space allocation of activities in the resource-space chart. PDM activities plotted on the resource-space chart give a clear definition of the space used by labor crew for working. At the same time the layout space for each activity execution is identified on the chart, and it is easy to indicate the maximum number of workers per space units. Safety hazard spaces and protected spaces can be represented as unavailable spaces directly on the resource – space chart plotted for a specific time window. Basic limit of the proposed solution is the level of detail of the LBS, and the consequent space requirements for activities and representation of space conflicts between activities. The understanding of space conflicts needs a deep knowledge of the modelled construction process and proper level of detail of work packages.

4. Sample project

A sample project of construction of a small three storey residential building is presented. The created workflow model for the construction phase of the systems and interior finishing works is presented. The residential building of the sample project is composed by two edifices (A and B), joined by a covered corridor. Building A has three storeys while building B has only two storeys. The Location Breakdown Structure (LBS) is depicted in figure 3.

PROJECT	FLOOR	BUILDING	SPACE UNIT DESCRIPTION	SPACE UNIT LBS CODE
SAMPLE PROJECT - 1	2 nd F-SECOND FLOOR: 1.SF	BUILDING A 2 nd F: 1.SF.A	FLAT-U6	1.SF.A.2
			FLAT-U5	1.SF.A.1
		BUILDING B 2 nd F: 1.SF.B	ROOF B	1.SF.B.1
	1 st F-FIRST FLOOR: 1.FF	BUILDING A 1 st F: 1.FF.A	FLAT-U2	1.FF.A.2
			FLAT-U1	1.FF.A.1
		BUILDING B 1 st F: 1.FF.B	FLAT-U4	1.FF.B.2
			FLAT-U3	1.FF.B.1
		ROOF C : 1.FF.C	ROOF C	1.FF.C.1
	GF-GROUND FLOOR: 1.GF	BUILDING A GF: 1.GF.A	CELLARS	1.GF.A.1
		BUILDING B GF: 1.GF.B	GARAGES	1.GF.B.1
		CORRIDOR: 1.GF.C	CORRIDOR	1.GF.C.1

Figure 3: Location Breakdown Structure of the sample project

After the LBS creation work spaces of each activity have been defined, and the maximum number of workers per space unit has been assigned. Labour density limits are set with the aim

of satisfying technology and safety requirements. In figure 4 the maximum number of workers per space unit is shown. In this phase activity allocation on space units is performed with the aim of optimising construction processes in terms of work continuity of crews, safety issues, congestion avoidance due to contemporary space usage and protected spaces usage.

LBS		K	PARTITION W.	PLUMBING	ELECTRIC. SYS.	CEMENT SCREED
A	U6	1.SF.A.2	8	3	3	4
	U5	1.SF.A.1	7	3	3	4
B	U4	1.FF.B.2	6	3	3	4
	U3	1.FF.B.1	5	3	3	4
A	U2	1.FF.A.2	4	3	3	4
	U1	1.FF.A.1	3	3	3	4
A	C	1.GF.A.1	2	3	2	2
B	G	1.GF.B.1	1	3	2	2
		K	J	1	1	1
		I	A	B	C	D

LEGEND:

MAX WORKERS NO.

N

Figure 4: Labour density limits per space unit of the sample project

At the end of this phase activity durations can be computed, as shown in table 1.

Table 1: Sample project activity data

TASK [i]:	A - PARTITION WALLS			B - PLUMBING			C - ELECTRICAL SYSTEM			D - CEMENT SCREED		
SPACE UNIT [k]	SPACE CAPACITY	No. Laborers	DUR. D	SPACE CAPACITY	No. Laborers	DUR. D	SPACE CAPACITY	No. Laborers	DUR. D	SPACE CAPACITY	No. Laborers	DUR. D
1	2	2	10	3	3	3	2	2	5	2	2	2
2				3	3	3	2	2	5	2	2	2
3	4	4	15	3	3	5	3	3	4	4	4	4
4				3	3	5	3	3	4	4	4	4
5	4	4	15	3	3	5	3	3	4	4	4	4
6				3	3	5	3	3	4	4	4	4
7	4	4	15	3	3	5	3	3	4	4	4	4
8				3	3	5	3	3	4	4	4	4

The creation of PDM network on basis of the Resource – Space chart (fig. 5) is easy to perform as a following step, as it is only needed to add logic links on the previous pattern of activity allocation on the LBS (fig. 4). The REPNET heuristics (Bragadin, Kahkonen, 2011) is then performed and a workflow optimised schedule is developed. In figure 6 the flow-line chart of the sample project is depicted. Then the produced schedule needs to be controlled. Firstly it is easy to observe that for the sample project the work continuity requirements has been satisfied almost completely, with the exception of activity D in units no.1 and 2. Also no time – space conflicts are detected and labour density requirement is satisfied (as activity durations were

computed with this constraint in table 1). For each working week the state of the project can be plotted, thus facilitating the controlling process through building site scheduled status representation. Completed and in progress activities are pointed out with successor spaces. Unavailable spaces because of cement screed hardening (after activity D implementation) are highlighted with different colour in the chart, to ease production management of successor construction processes (fig. 7).

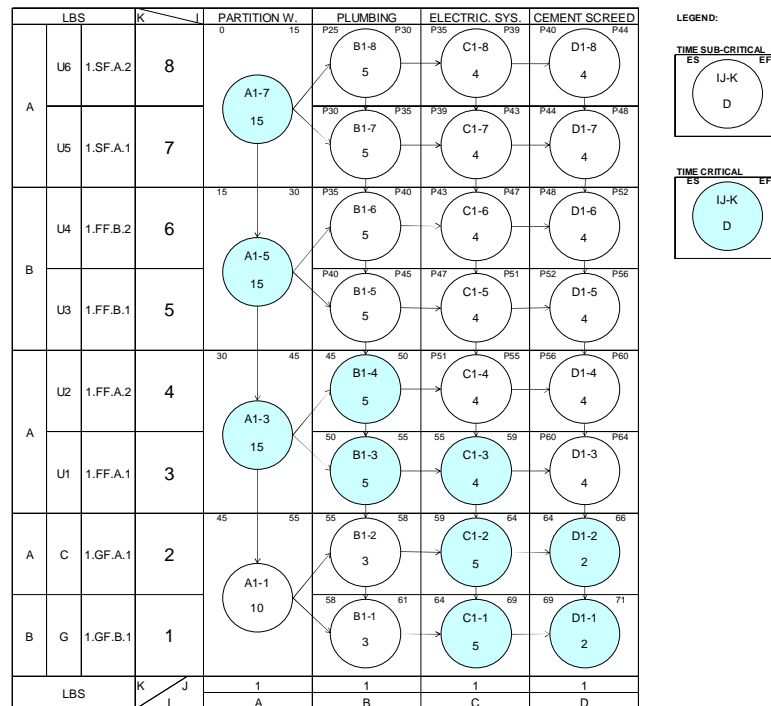


Figure 5: PDM network plotted on a resource – space chart - REPNET

5. Discussion

The proposed method for construction scheduling, is based on workspace management issues. It is considered that the proposed simple method that uses resource – space charts can be useful for preparing schedules of good quality, meaning with this that they are process oriented and easy to update and maintain. On the other hand, the proposed method needs a skilled scheduler especially at the beginning, when LBS is created and activities' work spaces are defined. The need of developing a good LBS is because of the proposed scheduling method structure, i.e. the sharpness of LBS directly affects the sharpness of activities, as project activities are allocated into space units created in the LBS since the beginning. Mistakes and incongruences in this phase can affect schedule development and conflict detection. Also activity allocation and conflict resolution need a good construction expertise for a sharp modelling, but it is believed that the creation of the resource-space chart helps logic thinking and prearranged problem solving. Linking the proposed method with BIM models capturing location details of end product is an interesting way to develop it further. This would mean capturing directly the location data of interest from BIM model to be used for scheduling purpose. With the known spatial needs of different activity types and their operational resources this can provide grounds

for highly advanced and detailed scheduling solutions. As previously mentioned, limitations of the method can be found in the workspace modelling performed by the LBS and the two-dimensions resource-space chart. Detailed BIM models can be very effective for workspace conflict detection (Akinci et alii, 2002; Choi et alii, 2014; Ciribini, Galimberti, 2005; Dawood, Mallasi, 2006; Mallasi 2006; Zhang et alii, 2015), but it is also believed that a simple space modelling approach, as the one based on the LBS development, can be a quick and efficient method for workspace scheduling (Kenley, Seppanen, 2009, 2010; Russell, Tran, Staub-French, 2014).

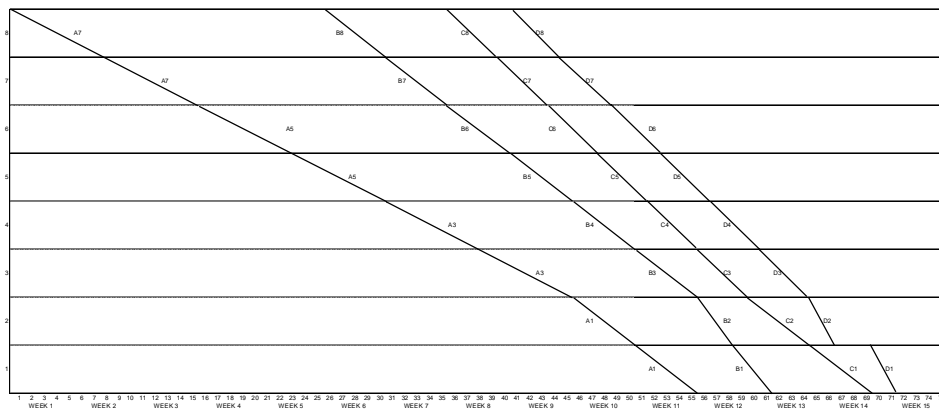


Figure 6: Sample project: flow-line diagram REPNET

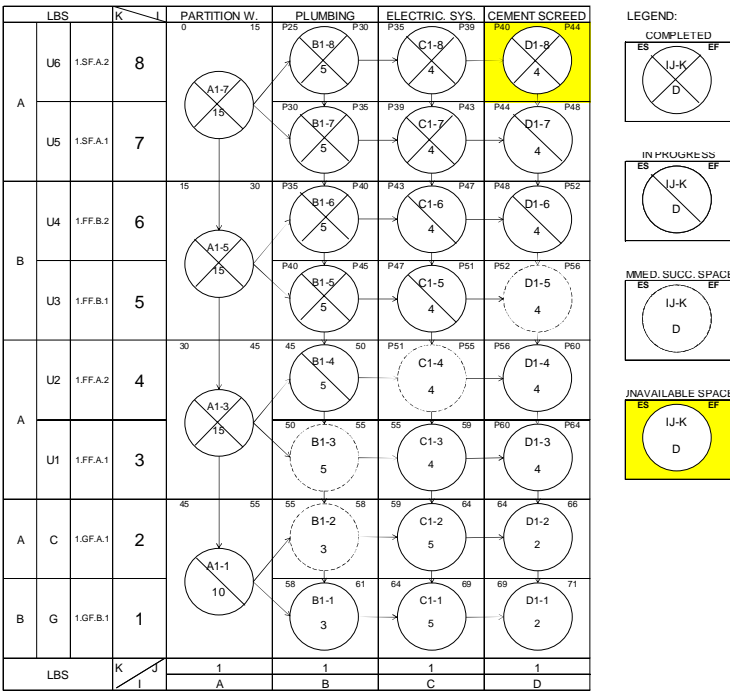


Figure 7. Sample project phase: week 10 plotted on a Resource – Space chart

6. Conclusions

The use of Resource-Space charts for construction workspace scheduling has been presented, since it is considered that explicit inclusion of spatial calculation is essential for preparing construction schedules of good quality. Many researchers and practitioners have highlighted the need of a workspace management system for construction process modelling, planning and scheduling. A Resource-Space chart, based on a Location Breakdown Structure, captures already main part of the logic of construction schedule. Thus, a PDM network can be easily prepared based on this. Accordingly project and production managers are creating process oriented project schedules where time – space conflicts of activities can be prevented, and congestion avoided due to the overall logic of the proposed scheduling method. The proposed method can be linked with BIM models for having direct access to spatial data.

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Analysis of a Time Management Model in Real Estate Projects

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Abstract

Unfortunately, delays are common in the construction industry. They create concerns for project performance and cause losses to project parties. These delays are caused by a number of factors.

The aim of paper is to analyse the main causes of delay in construction projects and to propose a preliminary and structured framework to improve the actual use of time planning tools and control instruments.

The framework is based on assumptions defined to optimise the techniques of tactical-operational planning currently adopted in the academic and professional environment, but reflecting on the Brazilian construction reality. It also assists early risk identification of non-compliance to scheduling and the best ways to compensate for delays.

Initially, a literature review was conducted to identify the main factors influencing the delay of construction projects. One of these surveys was emphasized because it compiled all these factors in a specific list.

Then, an analysis of data from 50 real estate construction projects in Brazilian cities (built in the last eight years) is also described, ordering the results in a frequency rank. This rank showed that the greatest concentration of causes of delay (over 60%) is related to inappropriate use of planning tools, team management and low productivity in the activities.

Using literature review again, this article identifies tools and assumptions to improve the control of project deadlines, thus avoiding the occurrence of various problems raised in the previous rank.

Finally, a time management framework is proposed. It consolidates the tools studied for better managing of time in construction projects. The performance of this preliminary model could be measured by its implementation in new researches, as described in the conclusions of the paper.

Keywords: Delay causes, planning, scheduling tools, construction project, time management

1. Introduction and justification

The execution of real estate projects in Brazil has always been a difficult activity because, historically, the country conditions do not stimulate Brazilian entrepreneurs, such as difficulty in financing, high interest rates, legal risks, defaults, complex regulations and non-qualified labour.

The market scenario started to change in the late 1990s and especially after 2005, with the IPO (Initial Public Offering) of large construction companies, improvement in the country economic conditions and more availability of credit for buyers. This scenario allowed a great market growth, but the sector was not prepared (technically or materially). Thus, despite this positive condition, there was an increase of delays, consumers' complaints and financial losses.

This would be a great opportunity for academic studies in the area. However, Brazilian structured researches about this theme were not found.

In recent years, the situation has been different, due to the global economic crisis and the Brazilian political situation. Even after technical adjustments and market restructuring, delays are still constantly verified. Even with less significant impact, as compared to those of the recent past, the question is what are the reasons why the construction projects are still delaying?

With all these doubts, the importance of academic studies into this subject was identified. This article can provide information and raise the interest of researchers and professionals in the sector.

Outside Brazil, in this period, many studies were observed to identify the most frequent causes of these delays, how they relate to each other and possible mitigation actions. To contribute to future research on the topic in Brazil, De Filippi and Melhado (2015) established a unified list of the most common papers, adapting items based on the Brazilian market scenario.

This article furthered this research, by increasing the number of projects surveyed and established what the main causes would be by studying a sample of companies in Brazil.

Finally, guidelines for a project management model in the construction sector were established, which could minimize the occurrence of the most important causes.

2. Research methodology

The methodology adopted includes some steps, starting from a literature review. The references studied by De Filippi and Melhado (2015) were increased and the new literature review searched not only causes of delay, but also tools to minimize these problems.

Then, using a list of 100 items compiled by De Filippi and Melhado (2015) as a research protocol on a field survey, the authors analysed which of these items influenced the delays of 50 Brazilian construction projects, in the last eight years. The sources of evidence for this analysis were interviews with those responsible for the projects planning and control, besides documents related to the project (plans, schedules, management reports, etc.).

The resulting data were also analysed and classified, resulting in a ranking about the Brazilian scenario.

Based on this ranking, the tools and guidelines by several authors were compared. This study supported guidelines generation to prevent the occurrence of the major causes.

These guidelines were structured as a proposal to improve time management. The application of these guidelines was discussed for developing a time management model (paths supporting the creation of structured methods to overcome the main causes of delay).

3. Literature review on studies into the delay in construction projects

3.1 Delay causes and interference with project time management

Recent researches, such as Fugar and Agyakwah-Baah (2010) in Ghana, Doloi *et al.* (2012) in India, Gunduz *et al.* (2013) in Turkey, Haseeb *et al.* (2011) in Pakistan, Marzouk and El-Rasas (2014) in Egypt and Mydin *et.al.* (2014) in Malaysia, identified the general causes of delay that occur in projects in their respective countries. A number of them allowed verifying different causes of delay and its importance (hierarqy). According to the authors, identifying the most impacting helps professionals and researchers to seek alternative solutions to mitigate delays.

Olawale and Sun (2010) presented an extensive survey on causes of delay with 250 construction companies in the UK, and listed a number of researches on the subject published in a 25-year period, by Ardini *et.al.* (1985 cited by Olawale and Sun, 2010) until the date of its publication.

Other papers discussed the main causes, such as El-Razek *et al.* (2008) in Egypt, which highlighted "financial issues" and "design changes", or Aibinu and Odeyinka (2006), in Nigeria, identifying some main causes, such as "actions and omissions of the project participants" and "external factors".

Assaf and Hejji (2006), in a study in Saudi Arabia, revealed that the most common cause of delay identified in their survey was "change in orders". Yang and Wei (2010) identified similar situations and described that "changes in customer demand" are the main causes of delays and these problems occur in the planning and design stages.

In Brazil, some authors not focused on construction, but who study project management in general, presented very interesting discussions that contributed to this article.

Elder (2006), using TOC (Theory of Constraints) concepts, presented by Goldratt and Fox (2002), established five reasons for projects not to achieve their results, especially the planned deadlines: (i) harmful multi-tasks (constantly changing priorities); (ii) Parkinson's Law (work expands to fill the time available). (iii) Student Syndrome (procrastination of work); (iv) dependency between tasks (probability of dependent events); (v) the termination of an activity does not mean that the other will be started immediately.

Other authors studied how these causes were related to other problems or practices in construction management. In a current survey in the USA, Russell *et al.* (2014) identified not only the causes of time variation in projects, but also the most serious reasons for adding time buffers for the durations of construction tasks.

Several authors, including Rogalska and Hejducki (2007) and La Garza *et al.* (2007) discussed the use of buffers as an improved programming tool and time control over projects.

Nepal *et al.* (2006) stated that accelerating a project can be rewarding but the consequences can be problematic when productivity and quality are sacrificed to keep ahead of schedule. Productivity directly affects the delays, according to Hanna *et al.* (2005), who studied the impacts of overtime with extended duration of the projects.

3.2 Actions to avoid delays and to improve time control

Many of the issues discussed by several authors established guidelines or tools to improve the methods used by managers in their projects.

One of the aspects studied by many authors regards the adequacy of classical planning tools to manage project deadlines. In Malaysia, Abdul-Rahman *et al.* (2006) described the importance of applying appropriate management to deal with the delays in the construction of developing countries.

Although one of the project features is its uniqueness, there is a great repeatability of tasks in construction projects. Different authors identified alternatives to organize the processes when there are repetitive activities or when the projects can be repeated with few changes.

Vanhoucke (2006) affirmed that in repetitive projects, a major goal of the planning is to maintain the continuity of the work and to minimize the downtime of resources.

Under these conditions, traditional tools such as CPM - Critical Path Method would be too complex or they would not add the value expected. In projects with this feature, several authors such as Mattila and Park (2003), Fan and Tserng (2006), Kallantzis *et al.* (2007), Lucko (2008), and Hegazy and Menesi (2010) studied the use of linear programming tools or a repetitive scheduling method, along with their limitations and risks.

Some authors analysed other CPM limitations. Kim and La Garza (2003) stated that a traditional schedule based on CPM is not realistic, because it assumes unlimited resources. Ibbs and Nguyen

(2007) described that the delay analysis without the resource allocation practice substantially affects the results. Some delay may cause the unrealistic allocation of resources in the subsequent service, which could further delay the project.

Yi *et al.* (2002) and Barraza (2011) declared that tools such as CPM constitute a logic established by intuition and human experience; therefore, it could mean that there is a variety of alternative networks and this can bring inconsistencies in planning.

Arditi *et al.* (2002) attempted to establish improvements in the use and representation of the line of balance tool, including the development of an algorithm that improves the project acceleration with efficiency, dealing with resource constraints and deadline milestones, and a new concept of criticality, including the learning curve effect.

Kim and La Garza (2005) advocated the use of the Critical Path Method with multiple calendars to effectively represent the various project conditions, such as site properties, the availability of resources, weather conditions, etc.

In Brazil, a survey conducted by Quelhas and Barcaui (2004), not for the construction market analogously to Elder (2006), described the concept of CCPM (Critical Chain Project Management) as the application of TOC (Theory of Constraints) to the project environment. The authors suggested how best actions: (i) reduction of safety margins per task; (ii) reduction of multitasking; (iii) use of dependencies also based on resources and not only on predecessors; (iv) use "later start dates" to the tasks; and (v) use of buffers at the end of the critical current (project buffer).

4. Classifications of causes of delay

The paper by De Filippi and Melhado (2015) brought a correlation of the main researches classifying the causes of delay. The authors sorted them into groups common to most authors¹, as can be seen in Table 1.

While there are several other studies related to project delays, we chose surveys that effectively brought qualitative descriptions and frequency as they appear in the construction projects in each of the countries where the surveys were conducted.

¹ the authors are references in the paper De Filippi and Melhado (2015)

Table 1: Classifications of causes of delay (De Filippi and Melhado, 2015)

Group	<div style="text-align: center;"> <div style="display: inline-block; transform: rotate(-45deg);"> Authors¹ </div> <div style="display: inline-block; transform: rotate(45deg);"> Delay Causes </div> </div>	Abd El-Azek et al. (2008)	Albinu & Odeyinka (2006)	Alwi & Hampson (2003)	Assaf & Al-Hejji (2006)	Chan & Kumaraswamy (1997)	Couto (2007)	Faridi & El-Sayegh (2006)	Fugar & Agyakwah (2010)	Gunduz et al. (2013)	Lo et al. (2006)	Marzouk & El-Rasas (2014)	Mydin et al. (2014)	Odeh & Battaineh (2002)	Sambasivan & Soon (2007)	Sweis et al. (2008)
Scope / Feasibility	Conflicts between owners	-	-	-	x	-	-	-	-	x	-	-	-	-	-	-
	Inadequate definition of project scope/construction product	-	-	-	x	-	-	-	-	x	-	-	-	-	x	-
	Legal disputes between project participants	-	x	-	x	-	-	-	x	x	x	-	-	-	x	-
	Type of project bidding and award (negotiation, bidder...)	-	-	-	x	-	x	-	-	-	x	x	-	x	-	-
	Type of construction contract (turnkey, construction only...)	-	-	-	x	-	-	-	-	x	-	-	-	-	-	-
	Unreal duration of original contract (too short)	-	-	-	x	x	-	x	-	x	x	x	-	x	x	-
	Lack of incentives for contractor to finish ahead of schedule	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
	Ineffective delay penalties	-	-	-	x	-	-	-	-	x	-	x	-	-	-	-
	Errors in the specifications or contract documents	-	x	-	-	-	-	-	-	-	x	-	-	x	x	-
	Improper project feasibility study	-	-	-	-	-	-	-	-	-	x	-	-	-	-	x
Owner	Lack of experience of owner in construction projects	-	-	x	-	-	-	-	-	x	-	-	x	-	-	-
	Slow decision making	x	x	x	x	x	-	x	-	x	-	x	x	x	x	x
	Owner's interference in the operations / project	-	-	-	-	x	-	-	-	-	-	x	-	x	x	x
	Owner's failure in project information communication	-	-	-	x	-	x	-	-	-	-	-	-	-	-	-
	Delay in revising/approving design documents by owner	-	x	-	x	-	-	x	-	x	x	x	-	-	-	x
	Delay in delivering site to contractor by the owner	-	-	-	-	-	x	-	-	x	x	x	-	-	-	x
	Delay in progress payments	x	x	-	x	x	-	x	x	-	x	x	x	x	x	x
	Design changes by owner or his agent during construction	x	x	-	x	-	x	x	x	x	x	x	x	x	x	x
	Delay in delivery of the material by owner	-	-	-	-	-	x	-	-	-	x	-	-	-	-	-
	Suspension of work by owner	-	-	-	x	-	x	-	-	-	-	x	-	-	-	x
Consultant	Lack of experience of consultant in construction projects	x	-	-	x	x	-	-	-	x	-	x	x	-	-	x
	Inadequate project management assistance	x	-	-	-	-	-	-	x	-	-	-	-	-	-	x
	Delay in budget definitions or work package price	-	x	-	-	-	-	-	x	-	x	-	-	-	-	-
	Late in reviewing andin approving design by consultant	x	x	x	x	x	-	x	-	x	-	x	-	x	x	x
	Delay in approving changes in scope of work by consultant	-	-	-	x	-	-	-	-	x	-	-	x	-	-	x
	Inflexibility (rigidity) of consultant	x	-	-	x	-	-	-	-	-	-	-	-	-	-	-
	Conflicts between consultant and design engineer	x	x	x	x	-	-	x	-	x	x	-	x	-	-	x
	Quality control problems	x	x	-	-	-	-	-	-	-	x	x	-	x	x	x
	Delay in performing inspection and testing	x	-	x	x	-	-	x	-	x	-	-	-	-	x	x
	Project management process	-	x	-	-	-	-	-	x	-	-	-	-	x	x	-
Design	Misunderstanding of owner's requirements by designer	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
	Insufficient data collection and survey before design	-	x	-	x	-	-	-	-	x	-	-	-	-	-	-
	Complexity of project design	-	x	-	x	x	-	-	x	x	-	-	-	-	-	-
	Delays in producing design documents	-	-	-	x	x	x	-	-	x	-	-	-	-	-	-
	Unclear and inadequate details in drawings	-	x	x	x	-	x	x	-	-	-	x	x	-	-	-
	Mistakes and discrepancies in design documents	-	x	x	x	x	x	x	x	x	-	x	-	-	-	x
	Insufficient specifications or designs	-	x	x	-	-	-	-	x	-	-	-	-	-	-	-
	Excessive design changes	-	-	x	-	-	-	x	-	-	-	-	-	-	-	-
	Poor use of advanced engineering design software	-	-	-	x	-	-	-	-	x	-	-	-	-	-	-
	Lack of experience of design team in construction projects	-	-	-	x	-	-	-	-	x	-	-	x	-	-	x
Contractor	Inadequate contractor's experience	x	-	x	x	x	-	x	-	x	x	x	-	x	x	x
	Difficulties in financing project by contractor	x	x	-	x	x	x	x	-	x	x	x	x	-	-	x
	Ineffective financial / cash flow planning	-	x	-	-	x	x	x	-	-	x	-	-	-	-	-
	Conflicts between contractor and other parties	-	x	-	x	-	-	-	-	-	x	-	x	-	-	-
	Poor site management and supervision	x	-	x	x	x	x	x	x	x	x	x	x	x	x	x
	Poor / inefficient sub-contractors' supervision	-	x	x	-	x	x	x	x	x	-	x	-	-	-	-
	Delays in internal production decisions	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-
	Ineffective project planning and scheduling	-	x	x	x	x	x	x	x	x	-	x	-	x	x	x
	Inappropriate physical reprogramming	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-
	Delay in preparing specifications or material samples	-	x	-	-	-	-	-	-	-	-	x	-	-	-	-

Table 1: Classifications of delay causes (De Filippi and Melhado, 2015) – continuation

Group	<div style="text-align: center;"> <div style="display: inline-block; transform: rotate(-45deg);">Authors</div> <div style="display: inline-block; transform: rotate(45deg);">Delay Causes</div> </div>	Abd El-Azek et al. (2008)	Albinu & Odeyinka (2006)	Alwi & Hampson (2003)	Assaf & Al-Hejji (2006)	Chan & Kumaraswamy (1997)	Couto (2007)	Faridi & El-Sayegh (2006)	Fugar & Agyiakwah (2010)	Gunduz et al. (2013)	Lo et al. (2006)	Marzouk & El-Rasas (2014)	Mydin et al. (2014)	Odeh & Battaineh (2002)	Sambasivan & Soon (2007)	Sweis et al. (2008)
Contractor (cont.)	Slow mobilization of labour	-	x	-	x	-	x	-	-	x	x	x	-	-	-	x
	Poor layout of site or logistic planning	-	-	x	-	-	-	-	-	-	x	-	-	-	-	-
	Rework due to errors	-	-	-	x	-	-	x	-	x	x	x	x	x	x	-
	Inappropriate construction methods	-	-	x	x	-	x	x	x	x	x	x	-	x	x	x
	Conflicts on sub-contractors scheduling during execution	x	-	-	x	-	-	-	x	-	-	-	-	-	-	-
	Delay in progress payments	-	x	-	-	-	-	x	-	-	-	-	-	-	-	-
	Delay in sub-contractors' activities / tasks	-	-	-	x	x	x	x	x	x	x	x	-	x	x	-
	Sub-contractor's interference in the site operations	x	x	-	-	-	x	-	-	-	-	-	-	-	-	-
	Frequent change of subcontractors	-	-	-	x	-	-	-	-	x	-	-	-	-	-	-
	Work overload	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-
Materials	Shortage of construction materials	x	x	x	x	x	x	x	x	x	-	x	x	x	x	x
	Late delivery of materials	x	x	x	x	-	x	-	x	x	-	x	x	-	-	x
	Poor procurement process/ material delivery programming	x	-	x	x	x	-	x	-	x	-	-	-	-	-	-
	Delay in defining the finishing materials(options)	x	x	-	x	x	-	x	-	-	-	-	-	-	-	-
	Delay in manufacturing materials	-	-	-	x	-	-	x	-	-	-	-	x	-	-	-
	Changes in material and specifications during construction	x	-	x	x	x	-	x	-	x	-	-	-	-	-	x
	Poor quality of construction materials	-	-	x	-	-	x	-	-	x	-	-	-	x	x	-
Labour	Damage of sorted materials	-	x	x	x	-	x	-	-	x	-	x	-	-	-	-
	Labour work shortage	x	x	-	x	x	x	x	x	x	-	x	x	x	x	x
	Unqualified/inexperienced workers	-	-	-	x	x	x	x	x	x	-	x	x	-	-	x
	Skilled workers' shortage	-	-	-	x	-	x	x	-	-	x	x	-	-	-	x
	Low worker productivity	x	-	-	x	x	x	x	-	x	-	x	x	x	x	-
	Low worker motivation and morale	-	-	-	-	x	-	-	-	x	-	-	-	-	-	-
	Nationality of labours / effect of social and cultural factors	-	-	-	x	-	-	-	-	-	x	-	-	-	-	-
Equipment	Personal conflicts among workers	-	-	-	x	-	-	-	-	x	-	-	-	-	-	-
	Equipment allocation problem	x	x	x	x	x	x	x	-	x	-	x	x	-	-	x
	Frequent equipment breakdowns	-	x	x	x	x	x	x	x	x	-	-	-	x	x	x
	Slow mobilization of equipment	-	x	-	-	-	x	-	-	x	-	-	-	-	-	-
	Low level of equipment-operator's skill	x	-	-	x	-	-	-	x	-	-	-	-	-	-	-
Project / Construction	Improper equipment	x	x	x	x	x	x	-	-	x	-	-	-	-	-	x
	Unexpected surface conditions (soil, water table)	x	-	-	x	x	x	x	x	x	x	x	-	x	-	-
	Loss of time by traffic control and restriction on job site	-	-	-	x	-	-	x	-	x	-	x	x	-	-	-
	Unavailability of utilities on site (water, electricity...)	-	-	-	x	-	x	-	-	-	-	x	-	-	-	-
	Delay in providing utility services (water, electricity...)	-	-	-	x	-	-	-	-	x	-	x	-	-	-	-
	Accidents during construction	x	-	x	x	-	x	-	x	x	x	x	-	-	-	-
	Poor document controls on the site	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-
	Poor working conditions on the construction site	-	-	x	x	-	-	-	x	-	-	-	x	-	x	-
	Differing site (ground) conditions	-	-	-	x	-	x	-	-	x	-	-	-	-	-	-
	Usual design changes during construction	-	-	-	-	x	-	x	x	-	x	-	-	-	-	-
External factors	Problem with neighbours	-	-	x	-	-	-	-	-	x	-	x	-	x	x	-
	Incompatibility between activities and site infrastructure	-	-	-	-	-	-	-	-	x	x	-	-	-	-	-
	Unfavourable weather conditions	x	x	x	x	-	x	x	x	x	x	x	x	x	x	x
	Environmental restrictions	-	-	-	-	x	-	-	-	-	x	x	-	-	-	-
	Changes in government regulations and laws	-	x	-	x	-	x	-	-	x	-	x	x	x	x	x
	Delay in obtaining permits from municipality	x	x	-	x	-	x	x	x	x	x	x	-	-	-	x
	Delay in inspection and in certification by a third party	-	-	-	x	-	-	-	-	x	-	x	x	x	-	-
	Poor communication and coordination with other parties	-	-	x	x	x	x	x	x	x	x	x	x	x	x	-
	Inadequate organizational structure (project parties)	x	-	-	-	x	-	-	-	-	-	-	-	x	x	-
	Price fluctuations / material or equipment prices	-	x	-	-	-	-	-	x	x	-	x	-	-	-	x
	Natural disasters (flood, hurricane, etc.) or Conflicts (war)	-	x	-	-	-	x	x	-	x	-	x	-	-	-	-

5. Field survey

For the field survey, an extended protocol was used, based on Table 1 items. The protocol aimed to ensure that all possible causes of the delays would be verified in all the projects, acting as a research guide.

Based on the monthly reports of each project, which described physical performance and the facts interfering with the schedule, it was possible to analyse when and why problems occurred along these projects and their impact on the deadline.

Complementing the analysis of the facts, interviews with the project professionals were made, mainly with the planning team. Interviews were able to recover some hidden problems in reports.

The sample sought elements from different economic realities. However, so that the results could be compared, it sought projects with some similar features such as:

- Residential or commercial real estate projects, in several different construction companies;
- Vertical buildings (towers) with more than 10 floors (where there is repeatability);
- Projects with at least 5% delay (which had clear problems in the schedule).

Based on these specifications, 50 projects were selected. They presented these characteristics:

- 15 different locations: projects in São Paulo City (33), projects in other cities in the State of São Paulo (12), projects in cities in other States (5);
- 24 constructors: small/local firms (12), medium/regional companies (7); large companies (5);
- Built-up areas: 8,140 to 80,750 sq. meters;
- Number of towers: one tower (25), two (11), three (7), four (5) and six (2);
- Project time foreseen: 13 to 35 months;

Using the history of each project throughout its execution phase, we performed a qualitative assessment of the facts that caused partial delays in scheduled activities and their sum resulted in significant final delays (more than three months, at least).

This survey did not identify which facts more significantly affected the final delay (those most affecting the critical path), but how often they occurred in the projects. Later, in a more comprehensive research, the classification of these impacts was also studied.

We identified in how many projects (of all the 50) each cause was found (in reports or interviews) and this result was characterized as the "frequency" of occurrence. In addition, to facilitate the analysis of the results, the frequency was ordered, creating a ranking as shown in Table 2.

Only the results above 40% of frequency in the rank were analysed, considering that the other items not were impactful or they were outside of the critical zone for future analysis.

Table 2: Rank of delay causes in construction projects

<i>Cod.</i>	<i>Description</i>	<i>Group</i>	<i>Frequency</i>
<i>a</i>	<i>Poor site management and supervision</i>	5	68,0%
<i>b</i>	<i>Sub-contractor's interference with the site operations</i>	5	66,0%
<i>c</i>	<i>Ineffective project planning and scheduling</i>	5	60,0%
<i>d</i>	<i>Low worker productivity</i>	7	60,0%
<i>e</i>	<i>Slow mobilization of labour</i>	5	54,0%
<i>f</i>	<i>Rework due to errors</i>	5	54,0%
<i>g</i>	<i>Late delivery of materials</i>	6	48,0%
<i>h</i>	<i>Labour work shortage</i>	7	46,0%
<i>i</i>	<i>Delays in internal production decisions</i>	5	44,0%
<i>j</i>	<i>Inappropriate physical reprogramming</i>	5	42,0%
<i>k</i>	<i>Conflicts over sub-contractors scheduling during project execution</i>	5	42,0%
<i>l</i>	<i>Poor procurement process or material delivery programming</i>	6	42,0%
<i>m</i>	<i>Unreal duration of original contract (too short)</i>	1	42,0%
...	<i>Delay in sub-contractors' activities / tasks</i>	5	38,0%
	<i>Slowness in decision making by owner</i>	2	36,0%
	<i>Slow mobilization of equipment</i>	8	36,0%
	<i>Inadequate definition of project scope or construction product</i>	1	30,0%
	<i>Poor / inefficient sub-contractor supervision</i>	5	30,0%
	<i>Frequent change in subcontractors</i>	5	30,0%
	<i>Unfavourable weather conditions</i>	10	30,0%

In Table 2, group 05 (contractor) held the greatest concentration of delay causes. In almost 2/3 of the projects studied, there were problems related to inappropriate use of planning tools and to managing the work teams.

Low productivity problems also appeared with great frequency, the only featured item that was not in group 05.

Then, less highlight, but also important, procurement items were also listed in the survey, which included not only the buying process, but also "delivery delays" and "shortage of labour".

6. Discussion

Based on the literature and experiences of this paper's authors, we sought to identify, several guidelines related to the focus of this study. It focused on minimizing problems, especially those related to Group 05 (team management in construction, correct planning, rework and reprogramming).

The actions can be grouped into just four groups, which are the most frequent causes in research results and coded as the first column of Table 3, as shown below:

Table 3: Guideline to treat the main causes of delay

Guideline Group	Cause Code
<i>I. Planning of bold goals without the inclusion of random floats, but with realistic assumption of estimate;</i>	<i>c,d,j,m</i>
<i>II. Establishing the continuity of services, ensuring the end of the activity before starting the next task;</i>	<i>b,d,f,g,h,k,l</i>
<i>III. Constantly identifying operational constraints and their elimination with the deployment of simple systematic risk management</i>	<i>a,d,e,f,j</i>
<i>IV. Clear definition of hierarchy in decision and elimination of slowness or lateness in decisions affecting the critical path.</i>	<i>a,e,i,k</i>

For each guideline, the authors suggest some activities that could be implemented in a structured way in each project. These will be later used as the basis of a management method. See Table 4.

These actions were based on recommendations of several authors, as presented in Section 3.2 or in the analysis of good current practices effectively observed in some of projects belonging to the sampling of the field survey described in Section 5 (but not were in this article).

7. Conclusions

As evidenced, the most significant causes of delay identified were relatively different from those presented by the authors surveyed. The main problems were more concerned with internal issues, organization of construction site or the management of the construction companies hired, than with external issues.

Thus, the authors of this paper identified the importance of investing in qualifying, systems or planning and control methodologies, even if they are simplified. A number of delays are verified to derive from external factors (rain, soil, market, customer, etc.) and the apologies to justify the delays are usually based on these aspects. Yet these factors were identified as less relevant.

Similarly, the results of this research can be useful to promote studies to identify causes of delay in different kinds of projects (such as horizontal constructions or in other regions of Brazil with different characteristics) or to establish more detailed actions or methods that help reduce the problems of delays.

This fact further motivates the studies into the theme showing that it is necessary to apply efforts to understand processes, tools, resources, and their relation to the project success.

Table 4: Actions for improving operational planning

Guide	Suggested practice	Actions suggested for improving operational planning
I. Realistic schedule and bold goals	Establishing “most likely” durations to define the project baseline	<ul style="list-style-type: none"> - Not accepting the most favorable scenario as a reference; - Establishing details of the initial schedule (at least in the critical paths); - Validating schedule references identifying risks in task completion; - Separating the contractual dates and the target operational dates (realistic references vs. best scenario to target planning).
	No float in each task / controlling with safety buffers	<ul style="list-style-type: none"> - Avoiding Parkinson's Law (resource demand tends to expand to the total resource offered) and the Student Syndrome (planned procrastination); - Include controlled buffers only in the critical path.
	Calendars differentiated by activity type	<ul style="list-style-type: none"> - Forecasting of rain days not worked (services affected); - Including regional characteristics, local restrictions; - Analysing seasonality, market realities or partners' restrictions.
II. Establishing continuity of services	Avoiding high productivity periods	<ul style="list-style-type: none"> - Stabilizing production (cadence of tasks); - Applying line of balance; - Prioritising the work teams maintenance.
	Guarantee of task completion	<ul style="list-style-type: none"> - Not accepting rework of tasks; - Not anticipating activities that do not add value to project; - Incorporating learning curves in production estimative.
	Anticipating procurement activities	<ul style="list-style-type: none"> - Validating previously the task quantitatives; - Placing material orders in advance (critical path items); - Defining compatible delivery schedules; - Transparency in negotiating and in managing suppliers (fidelity); - Join into service orders both "easy activities" such as "hard works".
III. Management focusing on restriction identification and its elimination	Identifying and removing tasks restrictions	<ul style="list-style-type: none"> - Eliminating the programming restrictions previously; - Action plan for recovering unfulfilled items or avoiding reoccurrence; - Developing database with more common items (restrictions check-list).
	Identifying and monitoring the planning assumptions	<ul style="list-style-type: none"> - Establishing main services variables towards productivity control; - Formalising plan of attack with leaders and team workers - Defining detailed schedules for critical path services; - Developing contingency plans / anticipating alternatives to recovery.
	Managing risks of task completion	<ul style="list-style-type: none"> - Quantifying the risks to identify the critical ones; - Highlighting the critical path activities that will be carefully controlled; - Checking the best moment of intervention (triggers); - Defining schedule milestones to control.
IV. No slowness of decisions	Identifying schedule priorities	<ul style="list-style-type: none"> - Identifying responsibility and decision deadlines with formal methods; - Establishing a priority list based on the impact on the critical path;
	Proactive and immediate actions	<ul style="list-style-type: none"> - Knowing who is responsible for the activities and treating the problems directly with them and as soon as possible (war room concepts). - Applying the GEMBA concept, solving problems in the “real place” (production site, where value is created).

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How Prepared are Small Businesses for Another Earthquake Disaster in New Zealand?

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Abstract

Earthquakes are low probability, high consequence events which are known to cause significant damage. Small to medium-sized enterprises (SBEs) are particularly vulnerable to impacts arising from such disasters, including: business disruption, employee health and safety, financial strain, or even total loss of business. Owners of these SBEs can make a few key decisions to prepare their businesses for an earthquake, in order to ensure business continuity and the wellbeing of their employees. This study sought to examine the level of earthquake preparedness of SBEs located in high seismic risk regions by examining the extent of mitigation measures adopted five years post the Canterbury earthquake disaster. Using a mixed-methods research approach, combining both qualitative and quantitative data, the research findings revealed that a majority of SBEs operating in regions of high vulnerability to disaster are underprepared for a potential earthquake disaster, despite the general increased awareness of earthquake risks in New Zealand. Cost, time, insurance processes, and access to disaster mitigation information, were identified to be the most important and constraining factors in the overall decision-making process. The research findings will provide strategies to local authorities on how to assist SBEs in making better informed preparedness decisions, ultimately improving their resilience to earthquakes, and thus improving the resilience of the New Zealand community as a whole. How Prepared are Small Businesses for Another Earthquake Disaster in New Zealand?

Keywords: Small business enterprises (SBEs), earthquake, preparedness initiatives, New Zealand

1. Introduction

The severity of the recent 2010/2011 Canterbury earthquakes demonstrated the vulnerability of communities which are inadequately prepared for such disasters. These earthquakes created significant economic and social strains on the Christchurch region, as a result of a large drop in economic activities within the central business district (CBD) of the city, and generally on the New Zealand economy. Consequently, this resulted in a staggering 34.6% drop in the number of businesses operating (Statistics New Zealand 2012). Buildings which have insufficient seismic capacity – termed “earthquake-prone buildings” (EPBs) – have been found to contribute to major losses during an earthquake (Egbelakin, 2013). An EPB is considered to be a building that will have its ultimate structural performance capacity exceeded in a moderate earthquake, and would likely collapse causing injury or death to persons in the building or to persons in another property or damage to adjoining structures (Department of Building and Housing 2004). The definition of an EPB contained in the Act is the legislative expression of the New Zealand Government’s policy objective to reduce the level of earthquake risks posed by EPBs to the public. These buildings are particularly vulnerable to impacts from an earthquake disaster, due to being built from inadequately strong construction materials, and prior to advancements in seismic design codes, specifically since 1976 (Egbelakin 2013).

The Ministry of Business, Innovation, and Employment define an SBE as one which consists of between 0 to 20 full-time employees (Ministry of Business & Innovation and Employment (MBIE) 2014). These enterprises are a prominent part of New Zealand’s economy, collectively make up 99.0% of the nation’s business population, and contribute to approximately 30% of the national GDP (Ministry of Business & Innovation and Employment (MBIE) 2014). The majority of SBEs reside in the CBD (Burgess 2008). It is common to find a large proportion of the city’s old building stock in the CBD, which are likely to be earthquake-prone due to their age and construction materials. SBEs are the majority leaseholders of these EPBs due to attractive rent prices and greater accessibility to customer foot traffic whilst residing in the CBD (Murphy 2007). Due to inherent risks posed by residing in an EPB, these SBEs are highly vulnerable to damage and losses from a potential earthquake disaster, as evident in the Canterbury earthquakes.

The decision-making process a business owner follows in order to prepare for an earthquake is crucial for maintaining business operations, and post-earthquake continuity, as well as for ensuring employee health and safety. The business owners who are tenanted in these buildings are likely to make a few key decisions regarding earthquake risk mitigation: adopt appropriate risk mitigation measures; accept the risk and do nothing about it; or ignore the risk completely (Egbelakin, 2013). Despite the rising intensity of low probability and high magnitude earthquake disasters, there is a consistently low rate of earthquake preparedness generally in New Zealand. Moreover, earthquake preparedness of local businesses is vital for local communities, whose economic prosperity depends on the types of mitigation decisions made by the owners of SBEs. Mostly, collective losses of these businesses generally devastate the local economy (Yoshida and Deyle 2005). Thus, this has created a need for a study to evaluate the types of decisions and earthquake mitigation initiatives implemented by SBEs, in order to

alleviate the damage caused by these disasters. Hence, this study sought to examine the level of earthquake preparedness of SBEs located in high seismic risk regions by examining the extent of mitigation measures adopted five years post the Canterbury earthquake disaster. The research findings will provide strategies to local authorities on how to assist SBEs in making better informed preparedness decisions, ultimately improving their resilience to earthquakes, and thus improving the resilience of the New Zealand community as a whole.

2. SBEs Disaster Preparedness

A plethora of research exists regarding businesses and their preparation for earthquakes. Studies into earthquake preparedness have been conducted predominantly internationally, and also in New Zealand, as a result of several earthquakes since 2007. Disaster preparedness can be regarded as any activity which is implemented in order to reduce damage caused by a natural disaster such as earthquake (Alesch, Holly et al. 2001). There are several of ways an SBE can mitigate risks posed by an earthquake disaster; these are termed earthquake risk mitigation measures or initiatives. Implementing these measures is vital for the resilience of an SBE, as they reduce the seismic risks that they can be exposed to, allowing them to thrive and find opportunities in times of distress (Stevenson, Seville et al. 2011). Several mitigation measures exist which are available for SBEs to implement. These comprise reasonably technical measures such as the purchase of earthquake insurance, and also less complicated low-effort measures such as employee disaster preparation. Despite the abundance of ways which an SBE can prepare for an earthquake, consistently low earthquake preparedness is reported by SBEs in New Zealand (Brown, Seville et al. 2013). Several factors have been identified in the literature to affect SBE owners' decisions to prepare for an earthquake and these are discussed in a subsequent section. The most significant ones will be outlined below.

2.1 Business Characteristics

The ability of an SBE to implement earthquake risk mitigation measures was found to be dependent on certain factors, which are inherent in the nature of the business and its physical operating environment. The size of the business, measured by the number of full-time employees, was consistently found to affect business' earthquake preparedness (Chang and Falit-Baiamonte 2002). According to Brown et al. (2013), small businesses are particularly vulnerable to the damage resulting from an earthquake due to a lack of resources; both in terms of finance and staffing that could be devoted to potential earthquake risk mitigation measures. Large businesses, on the other hand, are more readily able to raise finance due to their ease in accessing business reserves (Chang and Falit-Baiamonte 2002). They are more able to devote greater resources towards possible mitigation measures, and therefore exhibit a greater sense of preparedness compared with SBEs. Drabek (1991) found that businesses in operation longer than six years were involved with greater disaster planning. These older firms are more prominent, have greater financial resources, and more opportunities to consider earthquake planning in their daily business operations. Owning the building in which the business operates, as opposed to leasing, was found to be significant. Dahlhamer and D'Souza (1995) found that owners of the business property were more likely to adopt disaster preparedness measures than

lease-holders. Webb, Tierney et al. (2000) explained that the owners of the building have more to lose than lease-holders in the event of an earthquake, which indicated they are more likely to be place greater importance on earthquake planning.

Many older buildings with the potential of being earthquake-prone located in the CBDs of many cities and towns in New Zealand are more likely to be impacted by a potential significant earthquake (Egbelakin 2013). Many SBEs are likely to be tenanted in these EPBs. These businesses are highly vulnerable to the damage dealt from earthquakes and business operations within the community in general, as was evident from the Canterbury earthquake (Brown, Seville et al. 2013). Also, whether a business is independently owned at a sole location, or if it is part of a franchise operating in multiple locations, plays a huge part in the overall decisions they make. Franchise firms have an ability to spread their risk across multiple locations (Dahlhamer and Tierney 1998). These firms have the added benefit of being at ease with regard to financing their capital and starting up costs, as they can be funded by the franchiser. Businesses operating in the insurance, finance and real estate sectors were generally better prepared for disasters (Yoshida and Deyle 2005). This is mainly due to the fact that these businesses have high regulations, and have greater awareness of risk due to the inherent nature of their work.

2.2 Behavioural Factors

Several behavioural factors could affect how owners or managers of SBEs make disaster preparedness decisions. Past experience in a disaster could intuitively enhance readiness for a disaster in the future (Egbelakin, Wilkinson et al. 2011). The decision-making process may require an individual to identify a risk, perceive and assess the risk, and through trade-offs between risks and rewards, come to a final decision on whether or not to mitigate the risk (Egbelakin, 2013). An individual's awareness of the risks they are subjected to, and how they perceive and respond to them, is critical in influencing the final decision carried out (Slovic 2001). Given that perception of risk is regarded to be the one of the most notable barriers to adopting earthquake preparedness measures (Egbelakin & Wilkinson, 2010), this facet is important to consider when studying the decision-making patterns of SBE owners. A study carried out by Egbelakin, Wilkinson et al. (2011) aimed to understand potential behavioural factors which hindered the decision-making process of seismic retrofitting in New Zealand found that many respondents have fatalistic mind-sets and were not concerned about the risks associated with an earthquake disaster, and were unlikely to implement mitigation measures in the future. Fatalistic mind-sets may be attributed to hazard anxiety, and consequently a denial of risk (Paton 2003). Moreover, Webb *et al.* (2000) emphasised that businesses which showed drastic improvements in their preparations were ones which had already prioritised planning, and had the resources to do so. This is further supported by the findings arising from the study conducted by Powell and Harding (2009), which explained that "the careful become more careful" and those who didn't have any mitigation measures in place before the disaster were less likely to employ more measures after.

Legislation plays a key role in earthquake risk mitigation in New Zealand. The Building Act 2004 contains provisions which address EPBs. TAs are required to implement an earthquake-

prone building policy, to lessen the seismic risk from EPBs, such that a perceived level of safety is developed (Egbelakin, 2013). In addition, depending on the approach taken, the TAs requires building owners to have an engineer assess their buildings, if necessary, for potential seismic risk. This is vital for business owners, especially ones who are tenanted in an earthquake-prone building. Decisions revolving around seismic strengthening are beyond their grasp, and they must rely on their landlord (the building owner) to act. Knowledge and awareness of these practices is essential in the decision-making process.

2.3 Business Operations and Emergency Planning

The ability for a business to survive a major disaster depends on the organisational structure and operations systems in place (Seville et al., 2008). In New Zealand, prevention of harm to all persons at work and other persons in the vicinity is promoted by the Building Act (2004) and Health and Safety Act (2013). The Health and Safety Management Act was enacted to ensure that employers, and their representatives, adopt practicable steps are taken to ensure the safety of their staff while at work. It is expected that a procedure for dealing with emergencies that may arise during business hours is in place and that this information is readily accessible. Also, safety and emergency policy and practices adopted by the organisation should be known to all employees.

3. Research Methods

A mixed-methods research approach was adopted in this study, combining both qualitative and quantitative data, because of the nature of the research objective, and to overcome deficiencies intrinsic to a single research approach. The basis for this choice was due to the exploratory nature of this study, which was very similar to the study which Egbelakin (2013) conducted on building owners. An online survey was conducted using a questionnaire as the data collection instruments for the quantitative study, which mainly assesses the profile of the SBEs, decision-making processes and the factors that were significant to affect an SBE to implement mitigation measures. Semi-structured face-to-face interviews were undertaken for the qualitative study, in order to gauge a more in-depth understanding of respondents' behaviour. This type of interview allows the researcher to "probe" for in-depth information. In order to ascertain a sample for data collection, a database was formed using data provided by the Napier City Council. The information contained a list of the addresses of approximately 167 SBEs located in the Napier CBD, and mainly in EPBs. Napier was selected as a case study to represent a high seismic hazard region in New Zealand. The selection criteria were predominantly based on: a high seismic hazard factor, Z , of 0.38 (Standards New Zealand, 2004); and the occurrence of a previous significant earthquake disaster in the region in 1931 (Hawke's Bay Earthquake). This earthquake resulted in the emergence of a unique Art Deco architectural style for older buildings within Napier, which has attracted great interest from the local community and the tourism industry. There is a large heritage importance placed on these buildings by the community, and it is therefore necessary to enhance decisions made by SBEs operating in such buildings. Both questionnaire and interviews were administered in one of New Zealand regions susceptible to high earthquake risks; Napier. Care was taken to exclude the interview participants from the

survey. Industry experts reviewed the findings for comments and confirmation in order to establish data validity. A total of 42 questionnaires were returned out of 167 sent out. Only 38 were usable surveys due to a large amount of missing responses, generating a response rate of 23%, which is expected for a study of this nature and is similar to that found in previous studies. The extent to which an SBE was prepared for an earthquake was measured by counting the amount of mitigation measures they had implemented as at the present time, out of a possible 21 measures. Potential disaster preparedness measures an SBE could have implemented are summarised in Table 2. A variety of mitigation measures are covered and grouped under four categories, namely knowledge enrichment, insurance and business continuity, business survival, and structural and non-structural mitigation (see Table 2 for details).

4. Results

4.1 Respondents Profile and Business Characteristics

The respondents' profiles and business characteristics are summarised in Table 1. The respondent comprises mainly micro and small businesses (90%). Therefore, the research results and findings results are limited to the research participants. Half of the respondents are business owners, and the rest were personnel acting on behalf of the owner. Sixty-three percent of respondents are above 40 years of age, and 42% of the predominant ownership comprised of female business owners (42%) and combined (male and female) ownership (42%). Seventy-four percent of these SBEs were micro-sized and 58% have been in business for at least 10 years. All SBEs were reported to be operating in the CBD, with 79% operating in the retail sector. Eighty-seven percent of SBEs are located on the building's ground floor level. More than half of the SBEs were operating in a sole location of a locally-owned business, and all were in a separate location for their business (i.e. not operating from home). A majority of the SBEs surveyed in this study leased the building in which they operate. Almost all respondents (95%) had experienced an earthquake in the past. It is interesting to note that only 29% of respondents had been in an earthquake causing physical building damage. Nearly all respondents reported no damage to their personal well-being or their business from the last earthquake they had experienced (86% and 92% respectively).

Table 1: Respondents' profiles and business characteristics

<i>Respondents' Profiles</i>		<i>Frequency</i>	<i>%</i>	<i>Business Characteristics</i>		<i>Frequency</i>	<i>%</i>
<i>Type of Respondent</i>	<i>Business Owner</i>	19	50	<i>Size of business / Number of full-time employees</i>	<i>1 - 5 (micro)</i>	28	74
	<i>Director</i>	1	3		<i>6 - 19 (small)</i>	6	16
	<i>Manager</i>	15	40		<i>50-99 (medium)</i>	4	10
	<i>Employee</i>	1	3	<i>Age of business</i>	<i>< 1 year</i>	3	8
	<i>Other</i>	2	5		<i>1-5 years</i>	9	24
<i>Age</i>	<i>21 - 30 years</i>	7	18		<i>6-10 years</i>	4	11
	<i>31 - 40 years</i>	7	18		<i>11-20 years</i>	6	16
	<i>41 - 50</i>	8	21		<i>21 - 30 years</i>	7	18

Respondents' Profiles		Frequency	%	Business Characteristics		Frequency	%
	years						
	51 - 60 years	10	26		31 - 40 years	3	8
	61 - 70 years	6	16		41 - 50 years	1	3
	Female	30	79		> 50 years	5	13
Gender	Male	8	21	Industry of business	Retail, trade, and hospitality	30	79
	< 5 years	16	42		Finance, insurance, and real estate	2	5
Number of years in business	5-10 years	13	34		Business and personal services	1	3
	11-15 years	3	8		Health services	1	3
	16 - 20 years	1	3		Legal services	1	3
	21 - 25 years	1	3		Art and membership organisations	3	8
	> 25 years	4	11		Location pattern	Separate business location	38
	Years of industry experience	≤ 5 years	7	18		Home-based business	0
5-10 years		13	34	Operational pattern	Sole location of locally owned business	22	58
11- 15 years		3	8		One of several locations of locally owned business	5	13
16 – 20 years		4	11		One of several locations New Zealand wide	8	21
21 – 25 years		4	11		Part of a Franchise	3	8
> 25 years		7	18		Predominant ownership by gender	Male	6
			Female	16		42	
			Combined - Male and Female	16		42	
			Age of predominant owner(s)	21 - 30		4	11
				31 - 40	5	13	

4.2 Earthquake Mitigation Initiatives of SBEs located in High-Risk Regions

The extent to which an SBE was prepared for an earthquake was measured by counting the amount of mitigation measures they had implemented at the present time, out of a possible 21 measures. Table 2 provides a summary of disaster preparedness measures an SBE have

implemented. A variety of mitigation measures are covered and include: knowledge enrichment, insurance and business continuity, business survival, and structural and non-structural mitigation. The respondent's sense of earthquake preparedness was categorised based on the number of mitigation measures they had implemented, being: 0-5 (underprepared); 6-10 (somewhat prepared); 11-16 (prepared); and 17-21 (highly prepared). The research findings showed that SBEs were found to have mainly implemented low-effort, less technical mitigation measures, such as insurance, first aid kits, employee preparation, and data backup. These measures are generally easy to acquire and take less time compared to more complex measures such as the seismic retrofitting of buildings and implementation of business disaster continuity plans. Regarding insurance and business continuity plans, a majority of the SBEs had purchased business contents insurance (61%), and 55% had purchased business interruption insurance. In contrast, only three SBEs had developed a business continuity plan, while only one had a business relocation plan. Concerning the knowledge enrichment disaster preparedness activities, a majority of the respondents have discussed with their employees about what to do in the event of an earthquake (42%), while 32% have provided written information on earthquake preparedness to their employees, and 13% of the participants regularly conduct earthquake drills with their organisation. Sixty-three percent did not know whether their building was earthquake-prone or not, and about 50% of the respondents were not aware of the seismic assessment practice. Overall, the respondent's sense of earthquake preparedness was categorised based on the number of mitigation measures they had implemented. The research findings showed that 66% of the SBEs are very underprepared for survival in the occurrence of another major earthquake in the region (see Figure 1).

Table 2: Earthquake risk mitigation measures initiatives adopted by SBEs

<i>Earthquake risk mitigation measures initiated adopted by SBEs</i>	<i>Frequency</i>	<i>%</i>
<i>1. Knowledge Enrichment Disaster Preparedness Activities</i>		
<i>Talked with employees about what to do in the event of an earthquake</i>	<i>16</i>	<i>42</i>
<i>Have written information on earthquake preparedness</i>	<i>12</i>	<i>32</i>
<i>Attended a first aid course</i>	<i>9</i>	<i>24</i>
<i>Earthquake drills or exercises for your employees</i>	<i>5</i>	<i>13</i>
<i>Earthquake preparedness or training programs for your employees</i>	<i>1</i>	<i>3</i>
<i>2. Insurance and Business Continuity Plans</i>		
<i>Purchased business contents insurance</i>	<i>23</i>	<i>61</i>
<i>Purchased business interruption insurance</i>	<i>21</i>	<i>55</i>
<i>Purchased earthquake insurance to cover damage to building</i>	<i>10</i>	<i>26</i>
<i>Developed a business disaster recovery plan</i>	<i>3</i>	<i>8</i>
<i>Developed a business emergency plan for event of earthquake</i>	<i>3</i>	<i>8</i>
<i>3. Business Disaster Survival Actions</i>		
<i>Obtained first aid kit, extra medical supplies</i>	<i>18</i>	<i>47</i>
<i>Stored water and canned food</i>	<i>6</i>	<i>16</i>
<i>Stored extra fuel or batteries</i>	<i>5</i>	<i>13</i>
<i>Business relocation plan</i>	<i>1</i>	<i>3</i>
<i>Obtained an emergency generator for power failure</i>	<i>0</i>	<i>0</i>

<i>Earthquake risk mitigation measures initiated adopted by SBEs</i>	<i>Frequency</i>	<i>%</i>
<i>4. Structural and Non-Structural Measures Implemented</i>		
<i>Ensured computer and electronic data backup</i>	<i>20</i>	<i>53</i>
<i>Engineer conducted a seismic assesSBEnt</i>	<i>12</i>	<i>32</i>
<i>Secured shelves, cabinets or objects</i>	<i>11</i>	<i>29</i>
<i>Ensured heavy objects are stored on the floor</i>	<i>10</i>	<i>26</i>
<i>Secured business records and supplies</i>	<i>6</i>	<i>16</i>
<i>Retrofitted the building to higher seismic performance</i>	<i>4</i>	<i>11</i>

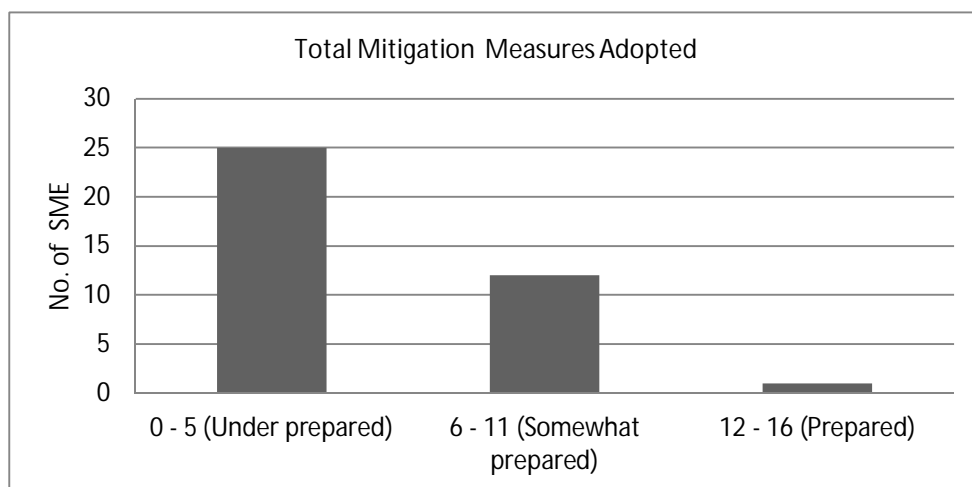


Figure 1: Summary of mitigation measures adopted by SBEs

5. Discussion of Findings

The capability of a business to implement earthquake risk mitigation measures was found to be dependent on certain factors, which are inherent in the nature and characteristics of the business, and its physical operating environment. SBEs in Napier were found to be underprepared for a potential earthquake disaster. Only five earthquake risk mitigation initiatives or measures were implemented, on average, out of a possible 21 options. This finding is similar to previous research conducted in the USA by Han and Nigg (2011). The low rate of preparedness is surprising given the region's high vulnerability to earthquake occurrence. Intuitively, a greater concern towards earthquakes would be expected due to Napier's location in a high seismic hazard zone, and its historical and cultural underpinning due to a past earthquake in 1931. Interestingly, 74% of respondents believed it was important to give consideration to earthquakes in relation to their business operations, yet a vast amount of the participating SBEs were inadequately prepared for a potential earthquake disaster. One of the respondents wrote that "Napier is making its tourist trade a little bit on the fact that it's been through an earthquake,

and so I think the knowledge of earthquakes in Napier is pretty good". Due to the region's increased awareness of earthquakes, individuals may have become complacent when giving thought to earthquake preparation. Some business owners were reported to express a sense of optimistic bias and complacency in their approach to disaster preparedness initiatives.

In addition, the majority of respondents who took part in the questionnaire were greater than 40 years of age. The research findings revealed that concern for earthquakes decreased greatly as the age of an individual increased. This may be explained by a complacent or fatalistic attitude which manifests with greater age. When asked if there were specific factors which influenced their preparation for an earthquake, one interviewee mentioned that: "It's quite nice to think that you're a bit secure because you do have the earthquake proofing done up to a standard, but I'm a bit fatalistic to be honest". Many of the respondents demonstrated similar behaviour during the face-face data collection, strongly expressing that earthquakes were an inevitable event, and no amount of preparation would be useful. Due to the large number of older respondents, there may be a prevalence of a fatalistic attitude, resulting in a lesser perception of risks and mitigation measures. This is similar to the findings of Egbelakin, Wilkinson et al. (2011), and this therefore negatively impacts overall earthquake preparedness. This finding is intriguing as one would expect individuals residing in high seismic hazard regions to exhibit more concern about earthquakes.

The size of an SBE measured in terms of the number of full-time employees could be attributed to the number of mitigation initiatives or measures adopted. A majority of SBEs had less than five full-time employees, and hence could be less prepared for an earthquake due to lack of resources to devote to disaster preparedness, and therefore lack the ability to have access to staff, and experts, specialising in disaster mitigation. This may provide a possible explanation as to why such a low sense of earthquake preparedness was observed. In addition, SBEs normally have greater financial constraints than their larger counterparts. A firm's financial capabilities have been proven to be a potential impediment in the preparedness process from past literature. As expected, cost and time were identified in the survey to be the important and constraining factors in an SBE's earthquake preparedness decision. Furthermore, respondents were found to have a low awareness and knowledge of building seismic assessment procedures. This is interesting given Napier's history with a previous devastating earthquake; one would expect that the respondents would be more proactive in their understanding and knowledge of seismic risks regarding the building in which they operate their businesses. The low level of awareness and knowledge of the building seismic risks may explain the low preparedness in Napier. For those respondents who were aware of seismic assessment procedures, it was reported that there were issues in consistency. One interviewee stated that: *"What I've noticed is there doesn't appear to be a consistent application of the rules, or understanding of the policies and I think there's been a frustration in that, businesses have found that engineers say one thing, and then another engineer comes around and says 'what were they talking about?'"* These disparities create confusion for SBEs, and complicate the decision to adopt risk mitigation measures (Egbelakin, Wilkinson et al. 2011). A low perception of risk was observed by SBEs in Napier. As discussed above, given the region's history with a prior earthquake, one would expect a greater perception of risk. The low perception may be due to the fact that 71.1% of respondents had not been in an

earthquake causing physical building damage. Past experience with an earthquake may affect an individual's perception of hazard exposure.

6. Conclusion

The objective of the study reported in this article is to examine whether SBEs located in regions of high vulnerability to seismic hazard are well prepared by adopting a range of earthquake preparedness initiatives. The research findings revealed that SBEs having less than 20 employees located in Napier were generally underprepared in the event of a potential earthquake disaster, and an average number of five mitigation initiatives or measures were observed out of a total of 21 initiatives. There is a general lack of knowledge and awareness of seismic assessments and risks posed by the building from which they operate, which could be due to the fatalistic attitudes, or a sense of complacency exhibited among the respondents. Cost, time, insurance processes, and access to mitigation information, were the most important and constraining factors for SBEs in preparing for an earthquake. SBEs need to be better informed about seismic assessment procedures. In particular, communication between TAs, building owners, and business owners must be enhanced. In addition, the local authority approach requires some form of increased consistency in building seismic risk assessment results, to allow a greater understanding of the potential risks for SBEs. SBEs need to have greater access and exposure to reliable and effective mitigation measures which have been proven to work. These must be provided by credible individuals or organisations, in order to motivate SBEs to become more active in earthquake planning procedures.

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Achieving Incremental Cost Reduction via Kaizen Costing in the Nigerian Construction Industry

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Abstract

Nigerian small and medium scale construction firms are facing challenges of cost and time overruns which have led to project abandonment and liquidation of some of these firms. This is also as a result of large scale dissatisfaction of clients. This study focuses on how to improve the post-contract cost management in Nigerian construction firms by using Kaizen costing. Kaizen presents a better solution to cost and time overruns, and client satisfactions. This method of managing post-contract cost had been proven to create more profit, quality, value and improved relations with the stakeholders involved in construction activities. Incremental cost reduction is the key element of Kaizen. The most critical activities which can influence kaizen costing implementation in the Nigerian construction industry are addressed in the paper.

This investigation identified eight crucial activities for continuous cost reduction from literature. Based on the existing literature, a Likert scale questionnaire was produced. Data was gathered from one hundred and thirty-five (135) cost and project managers in Lagos, Nigeria. The Kendall's coefficient of concordance was used to test the identified activities based on the agreement of the respondents. Important activities were ranked by respondents. The findings identified "overhead cost related to paying suppliers, sub-contractors and labourers can be reduced continually throughout the construction phase to keep the project cost within budget" as the most critical activity for continuous cost reduction during Kaizen costing. Assessing the essential procedures carried out during construction creates an avenue to implement Kaizen philosophy and Kaizen costing in a developing economy such as Nigeria. Therefore, the benefits of Kaizen are easily transferred for alleviating the challenges of cost and time overrun, effective post-contract cost controlling, profitability of small and medium scale construction firms and client satisfaction.

Keywords: Activities, cost reduction, incremental, Kaizen costing, Nigeria

1. Introduction

Construction cost management in many countries have been using the same conventional cost management systems since the 1920s from inception (Kern & Formoso, 2006; Owens, Burke, Krynovich, & Mance, 2007; Rad, 2002). Johnson and Kaplan, (1993) as cited by Kern and Formoso (2006) stated that the same cost management system which has been used in the 1920s is still in use in many construction firms. Ostrenga et al., (1998) as cited by Kern and Formoso (2006) noted that traditional cost management cannot provide the precise product cost and the system cost estimation does not include managerial decision making approach which eventually brings a positive impact on the project. Traditional cost management system is the conventional cost management system used since the 1920s. This term is used because of modern systems such as value management system and earned value management system which are operation in many construction firms around the world. However, systems such as the value management system, earned value management system, expert systems, benchmarking and building information modelling have emerged over the last sixty years to redefine the art and science of construction cost management. The enormity of negative factors influencing cost estimates at the pre-tender phase as stated by Ashworth (2010); Oyedele (2015) and Samphaongoen (2010), cost estimates always have latent errors which arises during the construction phase. Therefore, the need to focus more on post-contract cost control by project managers and cost managers during a construction project is imperative.

Cost estimation in construction has set rules by the Royal Institute of Chartered Surveyors and other Quantity Surveyor bodies in the various countries when construction cost estimates are prepared. Nonetheless, the same problems of cost and time overruns, variations during construction, construction disputes have always plagued construction activities. Ashworth (2010) noted the factors which influence the accuracy of cost estimates as being difference in design information, market conditions, experience of the project manager, project complexity and historical data. In a developing economy such as Nigeria, the challenges facing cost estimation is peculiar.

2. Literature review

This section addresses the challenges facing the conventional cost estimating system in Nigeria, the importance of kaizen costing as an effective panacea to the prevailing cost management challenges and the justifications for this investigation.

2.1 Factors affecting traditional cost estimation in the Nigerian construction industry

The unique challenges facing most cost and project managers during estimate preparation are related to a number of factors. Oyedele (2015) highlighted the various influencing factors as:

- a) Political situation: Most cost estimates are accurate during stable political times
- b) Government policy: Influence of local content investment policies, importation policies, taxes, method of procurement, number of foreign contractors or expatriates are some of the policies which may affect accuracy of cost estimates at a point in time.
- c) Economic condition such as inflation, monetary rate, interest rate on lending.

- d) The construction season such as rainy season and dry season may affect on-going construction work
- e) Geographical location of the project may also affect accuracy of estimates. In places such as the Niger Delta and Northern parts of Nigeria, the accuracy of estimates may be influenced by the topography, swamp or soil conditions
- f) Risk emanating from security may also have a drastic effect on the accuracy of construction cost estimates, especially in the Northern parts of Nigeria where there is high level of Islamic insurgency.
- g) Years which are close to the general elections in Nigeria have a lot of influence on the cost estimates because prices of building materials are lower and there are a lot of procurement activities and award of contracts.
- h) Corruption is a factor which affects cost estimates in Nigeria. Most cases of kickback during procurement have led to inflated cost estimates.

These factors can mar a construction project during the execution phase if they are not addressed. Although, other construction cost management systems, methods and techniques such as earned value analysis, value management, building information modelling may have been applied to curb the excessive cost and time overruns.

2.2 What is Kaizen costing?

Kaizen costing is a continuous improvement technique which emanates from Kaizen, a product of the lean philosophy (Suárez-Barraza & Lingham, 2008; Suárez-Barraza & Miguel-Dávila, 2014; Suárez-Barraza, Ramis-Pujol, & Dahlgaard-Park, 2013). Kaizen costing mean continuous improvement of the cost of production, it was first introduced in the 1960s in Toyota (Arya & Jain, 2014; Brunet & New, 2003; Prošić, 2011; Puvanasvaran, Kerk, & Ismail, 2010). *Therefore, Kaizen costing is the cost management aspect of Kaizen which is usually utilized during the production phase.* The benefits of Kaizen has been transferred to other sectors such as manufacturing , business management, development of small and medium scale industries and construction (Arya & Jain, 2014; Berger, 1997; Puvanasvaran et al., 2010). Several case studies by (Puvanasvaran et al., 2010; Suárez-Barraza & Lingham, 2008; Suárez-Barraza, Ramis-Pujol, & Kerbach, 2011) concluded that Kaizen is very useful for improving manufacturers' profit in this instance contractors, enhancing the quality of products, providing more client satisfaction and encouraging better employee-employer relationship. This aspect of Kaizen is the continuous improvement in the work place. However, the costing aspect involved the process which stems from a Plan-Do-Check-Action (PCDA) process. This process is based on an incremental approach of maintaining and reducing production cost.

This process stands on standardized production. Imai (1997) noted that the three M's in Kaizen are muda (waste), Mura (irregularity) and muri (strain). These three words are the major check points of the Kaizen process. Wastes are identified during the course of construction and eliminated. This lean related concept ensures adequate stakeholders involvement in the overhead cost reduction process. A Kaizen costing team comprising the project manager, architect, cost manager and other relevant stakeholders take on the responsibility of identifying waste and elimination processes. Follow up activities are also carried out during this process for incremental cost reduction.

2.3 Activities for incremental cost reduction during construction

Post-contract cost control activities are based on techniques such as interim valuations, preparation of monthly statement of accounts, cash flow, variation management and monitoring of all activities related to the construction work. There is no technique for continuous cost maintenance and reduction. The traditional cost management technique available in most construction companies do not consider cost maintenance and reduction during construction. Kaizen costing during construction involves specific activities related to transportation, handling of materials on site, overhead cost monitoring and reduction, variations, equipment and plant cost, purchase orders, suppliers' and sub-contractors' cost, planning and preliminary items of work (IFS, 2010; Lin et al., 2001; Ashworth, 2010; Sanni and Hashim, 2013). These activities are very delicate and may lead to cost and time overrun if they are not monitored. In kaizen costing, these activities are monitored for waste, irregularities and strain. The continuous cost reduction process are based on these activities. They are summarized in table 1 below.

Table 1: Cost reduction activities required for incremental cost reduction

<i>S/N</i>	<i>COST REDUCTION ACTIVITY</i>	<i>REFERENCES</i>
<i>1</i>	<i>Continual reduction of plant and equipment depreciation overhead cost throughout the construction phase will keep the project cost within budget</i>	<i>Shang and Pheng, 2013; Granja et al., 2005; Suárez-Barrazaa and Lingham, 2008</i>
<i>2</i>	<i>Continual cost reduction of overhead cost of activities related to mobilization and equipment setup will keep the project cost within budget</i>	<i>Granja et al., 2005; Prošić, 2011</i>
<i>3</i>	<i>Continual reduction of activities related to drawing reviews and other variations or alterations will eliminate unnecessary cost thereby keeping the project cost within budget</i>	<i>Suárez-Barrazaa and Lingham, 2008; Granja et al., 2005; Martin, 1993; Kaur and Kaur, 2013</i>
<i>4</i>	<i>Ensuring activities related to construction variations are continually minimized will create more profit for the contractor</i>	<i>Ashworth, 2010; Dada and Jagboro 2007</i>
<i>5</i>	<i>Cost of activities related to purchase orders and material deliveries can be reduced continually throughout the construction phase to control the project cost for optimum profit</i>	<i>Lin et al., 2001; Mansuy, 2002</i>
<i>6</i>	<i>Overhead cost related to paying suppliers, sub-contractors and labourers can be reduced continually throughout the construction phase to keep the project cost within budget</i>	<i>Lin et al., 2001; Mansuy, 2002;</i>
<i>7</i>	<i>Continual reduction of overhead costs related to construction cost planning, general planning, resource planning and project reports will create more profit for the contractor</i>	<i>Sanni and Durodola, 2012, Sanni and Hashim, 2013; Lin et al., 2001; Granja et al, 2005</i>
<i>8</i>	<i>Continual reduction of overhead costs associated with preliminary items of work such as site office, storage, security, electricity, water supply, first aid and so on will</i>	<i>Sanni and Hashim, 2013; Sanni and Durodola, 2012; Lin et</i>

	<i>eventually help the creation of more profit and improve project delivery</i>	<i>al., 2001; Granja et al, 2005</i>
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The cost activities identified above were gathered from various articles related to important activities which are carried out during construction. They are also a product of the questionnaire designed for the data collection.

2.4 Research objective

The objective of this study is to assess the most critically important construction activities required for incremental cost reduction in the Nigerian construction industry. Having identified the objective of this paper, the following section discusses the research methodology adopted for this study.

3. Research Methodology

Data was obtained from one hundred and thirty-five cost and project managers in Lagos, Nigeria. The questionnaire was designed in a Likert scale format. The range was from 1 to 5, spanning from strongly agree to strongly disagree respectively. The questionnaire is based table 1. This survey questionnaire was aimed at assessing the attitude and beliefs of the respondents towards the costs that might be required to reduce during the construction stage. Therefore, the questionnaire is logically designed to fit the continual cost reduction objective through Kaizen costing.

Two hundred and fifty (250) questionnaires were distributed but only one hundred and thirty-five (135) could be retrieved. The respondents had work experience range of two (2) to forty years (40), this is illustrated in figure 1 below. Seventy-seven (77) cost managers and fifty-eight (58) project managers responded to the questionnaire. Some of these respondents are from the same construction company. However, a total of eighty-seven (87) companies responded to the questionnaire.

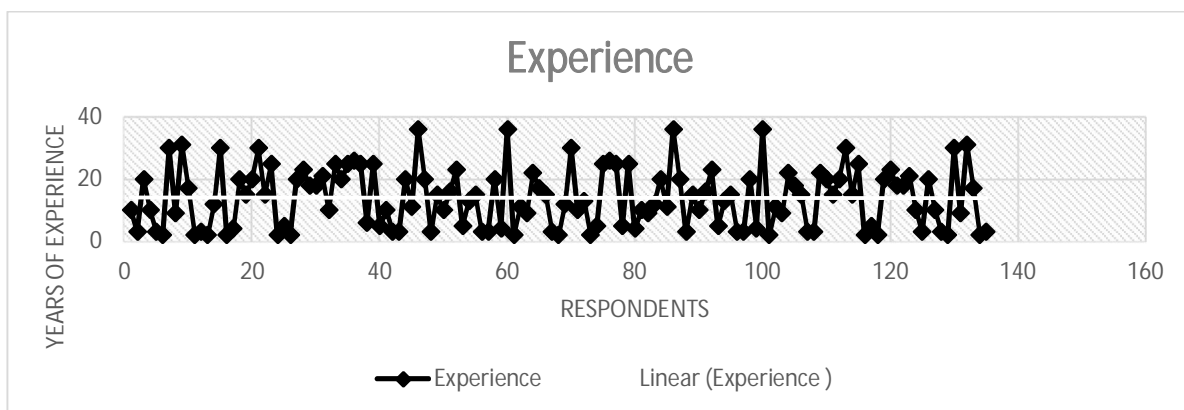


Figure 1: Years of experience of the respondents

In the graph above the linear years of experience for the respondents is fifteen (15). Very few respondents have experience above thirty years.

3.1 Investigating the presence of Kaizen costing

The presence of Kaizen costing in Nigeria was investigated. The questionnaire distributed was aimed at identifying the type of post-contract cost control method in use in Nigeria. It included the conventional cost management system in construction, earned value analysis, value engineering, activity based costing and Kaizen costing. The findings in figure 2 below show that ninety-eight (98) percent of the respondents are still using the traditional post-contract cost control method, while 1.2 percent are using earned value analysis.

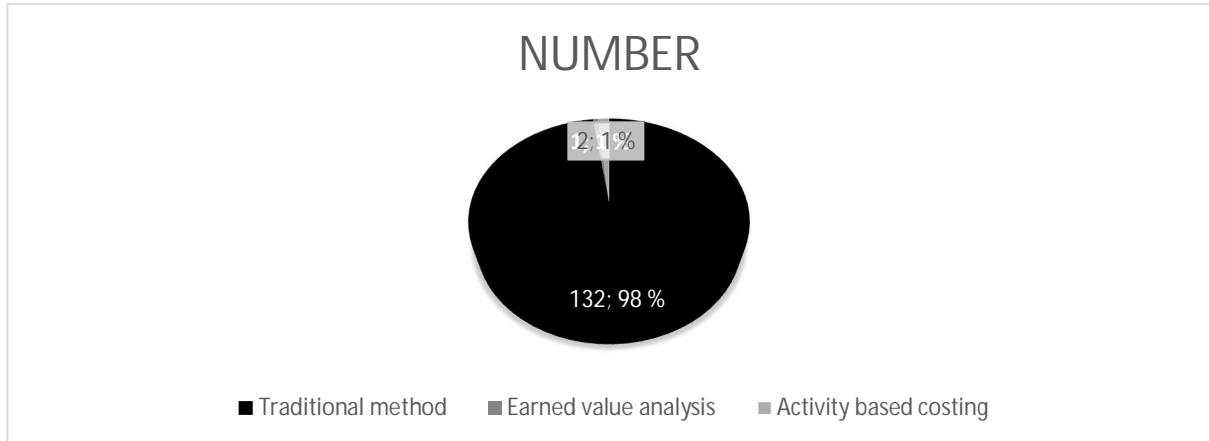


Figure 2: Pie chart showing the type of post contract cost control methods used

1.1 percent of the sample population made use of activity based costing. Kaizen costing is still very new to the construction industry in Nigeria.

3.2 Assessing the most critical post-contract cost control activities

This section addressed the key critical post-contract cost control activities which enables the researcher to evaluate the critical activities which will be required for continual cost reduction on site. This will be meant for small and medium scale construction firms in Lagos, Nigeria. The critical success factors are itemised below.

Table 2: Abbreviations for the activities

<i>Abbreviation</i>	<i>Meaning</i>
MESETUP	<i>Continual cost reduction of overhead cost of activities related to mobilization and equipment setup will keep the project cost within budget</i>
DRR	<i>Continual reduction of activities related to drawing reviews will eliminate unnecessary cost thereby keeping the project cost within budget</i>
PI	<i>Continual reduction of overhead costs associated with preliminary items of work such as site office, storage, security, electricity, water supply, first aid and so on will eventually help the creation of more profit and improve project delivery</i>

CGPG	<i>Continual reduction of overhead costs related to construction cost planning, general planning, resource planning and project reports will create more profit for the contractor</i>
CVMINI	<i>Ensuring activities related to construction variations are continually minimized will create more profit for the contractor</i>
PEOVER	<i>Continual reduction of plant and equipment depreciation overhead cost throughout the construction phase will keep the project cost within budget</i>
POM	<i>Cost of activities related to purchase orders and material deliveries can be reduced continually throughout the construction phase to control the project cost for optimum profit</i>
PSL	<i>Overhead cost related to paying suppliers, sub-contractors and labourers can be reduced continually throughout the construction phase to keep the project cost within budget</i>

The critical post-contract cost control activities were carefully selected from literature review, which highlights the key areas required for continuous cost reduction during construction. It covered monitoring material, plant, labour and overheads, elimination of unnecessary activities, planning and stakeholders.

Table 4: Kendall's W score for the most critical post-contract cost control activities

	<i>PSL</i>	<i>POM</i>	<i>PEOVER</i>	<i>CVMINI</i>	<i>CPGP</i>	<i>PI</i>	<i>DRR</i>	<i>MESETUP</i>
<i>Kendall's W score</i>	5.02	4.70	4.64	4.52	4.50	4.39	4.30	3.99

From table 4 above, PSL representing overhead cost related to paying suppliers, sub-contractors and labourers can be reduced continually throughout the construction phase to keep the project cost within budget. This is ranked highest with a Kendall's W score of 5.02. POM which is cost of activities related to purchase orders and material deliveries can be reduced continually throughout the construction phase to control the project cost for optimum profit has a Kendall's W score of 4.70. The least critical activity is MESETUP which stands for continual cost reduction of overhead cost of activities related to mobilization and equipment setup will keep the project cost within budget, with a score of 3.93. The Kendall's W score for each of the critical activities for continual cost reduction highlighted the most important activities which cost and project managers have to focus on during construction. The activities were prioritized in order for cost and project managers in small and medium scale construction organizations to address the most important activities which would enable them reduce cost.

Table 5: Kendall's W test for the most critical activities

Kendall's W ^a	.020
Chi-Square	19.077
df	7
Asymp. Sig.	.008

In table 5, Kendall's coefficient of concordance for this analysis is 0.02. This figure is very low and shows that there is almost no agreement between the respondents. Asymp. Sig. is 0.008<0.05 hence, the respondents have a significant association with the critical success factors.

4. Discussion of results

Based on the findings in figure 2, it can be inferred that kaizen costing is a new concept to the construction industry in Nigeria. This may be the case for other construction industries around the world. Although Kaizen costing is used in the manufacturing industry in Nigeria (Olabisi, Sokenfun, & Oginni, 2012), the construction industry needs to adopt this method as major approach for cost maintenance and reduction. Granja, Picchi, and Robert (2005) noted that cost control is not enough during construction, cost has to be maintained on a daily basis and adequately evaluate for waste factors. An allowable cost in construction is the target price minus the target profit (Granja et al., 2005). Therefore, the cost manager has to ensure the allowable cost is maintained. In reality, the forces of demand and supply and other activities on site influence the cost of construction. This is why the major activities which may denigrate the contractor's plans for the construction project have to be evaluated.

Activities on the construction sites were evaluated based on their level of criticality. Overhead cost related to paying suppliers, sub-contractors and labourers can be reduced continually throughout the construction phase to keep the project cost within budget has to be taken into consideration more than any other activity. Olawale and Sun (2013) revealed that the performance of nominated sub-contractor and suppliers affects the final cost of construction projects. The incremental reduction of overheads costs resulting from the activity of suppliers, sub-contractors and labourers will definitely create more profit and value for the contractor and project. In most cases, it is very difficult to monitor the activities of the suppliers because of certain forces in the Nigerian construction industry. Such forces include, collusion with a project team member to inflate the prices of the construction materials, kick back and other vices on the construction site. Inflation, foreign exchange rate and market forces also affect the supplier's and sub-contractors' cost.

Incremental reduction of activities related to purchase orders and material deliveries ranked second in the test. The Kaizen team can focus on this aspect to ensure that the wastage arising transportation of material to site and purchase orders are kept within an allowable cost limit. The cost limits allowed may have a profit and overhead of twenty-five percent plus (25 %+). Most cost managers who are mainly Quantity Surveyors in Nigeria also include this profit and overhead. In some construction companies it is a management function. However, focusing on actions relating to purchase orders and material deliveries will definitely assist the contractor in getting more value for money and client satisfaction.

For most complex projects, equipment and plants are required. “*Continual reduction of plant and equipment depreciation overhead cost throughout the construction phase will keep the project cost within budget*” was ranked third on the scale. The plants and equipment hiring cost, depreciation and maintenance cost is highly important. This aspect is very difficult to maintain and incrementally reduce cost. This aspect is very critical to the success of the project. The final account for the project depends on these factors. Therefore, the cost manager needs to address precise steps which pertain to plant and equipment hiring.

5. Conclusion and further research

The presence of kaizen philosophy is necessary for kaizen costing to be in place during construction. Although this study did not address the presence of kaizen in the management level, the findings revealed that Kaizen is non-existent in the Nigerian construction industry. Cost control during construction has to go beyond monitoring. Maintenance procedures is viewed as monitoring. However, identifying waste and gaps in cost during construction will invariably reduce the cost of construction. The critical activities identified in this paper has to do with external influences such as suppliers, sub-contractors, purchase orders, material handling, equipment and plant hire. These factors are very difficult to control and are critical to a project’s success. Achieving a successful incremental reduction of cost during construction depends on these factors.

The involvement of other stakeholders such as the suppliers, sub-contractors and labourer may also facilitate continual cost maintenance and reduction. A research framework may be designed to provide guidelines for a successful Kaizen costing procedure in the Nigerian construction industry.

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Developing Risk-Based Cost Contingency Estimation Model Based on the Influence of Cost Overrun Causes

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Abstract

Cost overrun on infrastructure projects is widespread and represents significant financial risks to stakeholders. The large number of possible causes makes the planning and management of projects challenging. A survey of 160 project managers of infrastructure projects in Saudi Arabia was conducted to elicit the cost overrun causes. After cluster analysis, the causes were reduced to four dimensions: scope changes, market and regulatory, inadequate planning and control, and unforeseen circumstances. These four dimensions were then used to develop a risk-based cost contingency estimation model (RBCCEM) to improve the accuracy of cost forecasting and then validated using a bootstrapping approach. The accuracy of cost estimation measures was used to compare RBCCEM with fixed cost contingency (10%), reference class forecasting (RCF P50 & P90), and hybrid (it is a combination of RBCCEM & RCF P50). The comparison suggested that the RBCCEM could be more accurate as the error decreased by 10%. Therefore, by considering the actual impact of cost risk of similar projects, the results show that cost contingency was improved and the model delivered a better result compared to RCF.

Keywords: Cost overrun, cost overrun causes, infrastructure projects, classification and cost contingency estimation

1. Introduction

A significant proportion of large infrastructure projects have experienced substantial cost overrun which has led to financial or fiscal distress to project stakeholders and resulted in the deferral or cancellation of other projects (Flyvbjerg, 2014). Cost overruns in infrastructure projects are common around the world, as identified by Flyvbjerg et al (2003). Controlling project cost within budget is important for most if not all projects. The focus on cost performance is even stronger for infrastructure projects because of their high costs. Therefore, it is critical that causes of cost overrun are identified and effectively managed to minimize cost overrun.

Studies have identified a wide range of factors that lead to cost overruns, with two main schools of thought on the causes of cost overrun: technical and strategic causes. Technical causes include mistakes in design, overall price fluctuations, inaccurate estimations, government regulations, project size, quality of the contractor management team, plan changes, priority on construction deadlines, completeness and the project information timelines, the lack of experience of the estimators, certain bidding conditions, project characteristics, and lack of past data on similar types of projects (Koehn et al., 1978; Shash and Al-Khaldi, 1992; Lowe and Skitmore, 1994; Al-Harbi et al., 1994; Flyvbjerg et al., 2002; Memon, et al., 2011). The strategic causes considered optimism bias, which encapsulates the systematic propensity of decision makers to be over-optimistic about the outcomes of planned actions, as the main culprit of cost overruns for infrastructure projects (Flyvbjerg et al., 2002). However, the rhetoric seems to have shifted towards strategic misrepresentation as the main cause of cost overrun, which refers the use of deceptive means in order to win the project or obtain project funding (Liu and Zhu, 2007).

One of the techniques of reducing the impact of project cost overruns is the use of project cost contingencies—usually as a fixed proportion of the project total estimated cost and most recently estimated produced using sophisticated approaches such as reference class forecasting (RCF) or risk-based estimating (RBE) (Liu et al., 2010), but each method has its limitations. By taking into consideration the actual impact of cost risk of similar projects this paper develops and validates a cost contingency estimation model. A cross-sectional survey was conducted in Saudi Arabia to identify the causes of cost overrun of infrastructure projects in Saudi Arabia and the causes identified form the basis of the new cost contingency estimation model.

The structure of the paper is as follows: literature on causes of cost overrun was reviewed and the research design was explained. Cluster analysis is used to classify the causes of cost overrun into clusters. Subsequently, a cost contingency estimation model was developed by regressing project cost overruns on the clusters of causes. The model was then validated using the split sample. Further validation was conducted by comparing the accuracy of RBCCEM with those produced by the fixed cost contingency (10%), RCF (P50 & P90) and hybrid method, respectively. Finally, implications were discussed, future research directions were outlined and conclusions were drawn.

2. Literature review

This section examines the concept of the classification of cost overrun causes. Then, cost contingency estimation in infrastructure projects was also reviewed, followed by a discussion on using a classification approach in a cost contingency estimation model to improve cost contingency estimation accuracy.

2.1. Classification of causes of cost overrun

Cost overrun occurs in infrastructure projects (Memon, et al., 2011), and the causes are various. Classifying or grouping the large number of causes of overrun that may share similar patterns of impact can help manage causes during planning and construction.

Based on a survey of project managers on high-rise construction projects in two Indonesian cities, (Kaming et al., 1997) grouped seven causes of cost overruns into three groups using factor analysis: inflationary increases in material cost, inaccurate material estimating and project complexity. In Vietnam, Le-Hoai et al. (2008) categorized 21 causes of cost and time overrun for the construction industry using factor analysis and identified seven groups of causes: slowness and lack of constraint, incompetence, design, market and estimates, financial capability, government and worker factors. In Malaysia, Abdul Rahman et al. (2013) modelled 35 causes of cost overrun in large construction projects with a partial least squares-structural equation modelling approach and categorized the cost overrun conceptually in seven groups: contractor's site management related factors, design and documentation related factors, financial management, information and communication, human resource, non-human resources, project management and contract administration. These classification attempts have shown that homogenous groups of causes of cost overrun exist which aggregate the effect of causes within the same dimension.

Flyvbjerg has published various widely cited papers on causes of cost overrun for infrastructure projects. Flyvbjerg (2006) proposed a conceptual categorisation of cost overrun based on four main types of explanations that are claimed to account for cost overrun: technical, economical, psychological and political. Flyvbjerg et al. (2003) and Flyvbjerg (2008) acknowledged the technical explanations for cost overrun such as project size and location, but they concluded that the political-economic explanation of strategic misrepresentation and the psychological explanation of optimism bias are the main causes of cost overrun.

In brief, many causes significantly overlap, with relationships between multiple causes contributing to the final cause of cost overruns. There is a need to understand how the diversity of causes share similar patterns and how these causes impact on cost overrun, how causes can be mitigated, and the techniques or tools to ameliorate or eliminate cost overrun.

2.2. Estimation of infrastructure project cost

Accurate cost estimation tools can help reduce or eliminate the uncertainties of cost overrun. Accurate cost forecasting of large project costs is based on the availability and the level of professional

knowledge and the historical cost data quality (Liu and Zhu, 2007). Available information, however, might be limited in the early stage of a large project. This may mean the quantity surveyor must make assumptions about the design; a detail of a project that may not eventuate as the life cycle of the project evolves (Liu et al., 2010).

The most critical feature of effective cost estimation is its potential for accuracy. Classic cost estimates consist of a base estimate, accounting for all physical quantities of materials and labour, and an additional risk contingency quantifying the underlying levels of uncertainty associated with the base estimate (Liu et al., 2010). Accuracy in forecasting costs and risks is valuable for decision makers to make rational decisions. Research has shown that cost forecasting errors are not unique to any specific industry or to project type with estimate inaccuracy in transport (Flyvbjerg et al., 2002), roads (Odeck, 2004), general construction (Liu and Zhu, 2007) and industrial projects (Merrow and Yarossi, 1990). Many studies have found, however, that there has not been noticeable improvement in estimation accuracy despite continued research (Flyvbjerg et al., 2002; Liu and Zhu, 2007).

The dominant methods of cost contingency estimation used in infrastructure projects can be classified into three categories: conventional contingency approach, risk-based estimation (RBE) and reference class forecasting (RCF) (Liu et al., 2010). The conventional contingency approach is to add a percentage, such as 10%, to the most likely estimate of the known works (Burger, 2003) based on the estimator's experience, which may be prone to optimism biases and could lead to cost overrun (Yeo, 1990; Newton, 1992; Mok et al., 1997). The cost contingency technique is acceptable under stable conditions and simple projects, however, it is inappropriate for large and complex projects (Newton, 1992). As a result, it is a less evidence-based approach and a reason for many projects having cost overrun (Hartman, 2000).

The other two methods, RCF and RBE, have been shown to increase the accuracy of cost contingency estimation (Liu et al., 2010). The RBE model is the cost of individual components with base estimates and stochastic or random risk contingencies. Summing the stochastic cost components determines the distribution or probability of the overall project cost (Shaheen et al, 2007). The RBE method identifies inherent risks that directly relate to the internal behaviour of a project; as well as contingent risks derived from external events that may or may not occur (Aspinall and Trueman, 2006). It requires large amounts of expert time and expense (Liu et al., 2010) especially for large and complex projects.

RCF developed by Flyvbjerg, which only takes into account a project's class (the outcome of cost overrun), even when other project factors might impact upon estimate accuracy. RCF utilises a database of previous project performance, from which a subsample of similar projects is selected, and adds a contingency to the total project cost (Liu et al., 2010). As RCF's aim is to mitigate either optimism bias or strategic misrepresentation, it does not specifically address other causes of cost overrun such as technical causes and does not forecast events which may influence the project.

Since cost contingency accounts for the unforeseen cost risks, it is likely the estimating model based on the actual impact of cost risk of similar projects could produce more accurate cost contingency estimates. As a result, in the paper a risk based estimation method was adopted, by including 'cost overrun causes classification scheme', the accuracy of cost estimation could be improved. Supporting

this proposal, (Liu et al., 2010) showed how RBE had excellent predictive validity as 90% projects having an actual cost within the range of the risk-based estimate in which they estimated the risk contingency of every single components of the project but they did include the cost overrun causes of similar projects. Therefore, this study designs and validates RBCCEM for infrastructure projects.

3. Research design

To develop the RBCCEM model, the survey data and the risk factors identified by the authors in a separate paper (Allahaim and Liu, 2015) is used to demonstrate development and validation process. First, the data collection and the identified causes of cost overrun for infrastructure projects in Saudi Arabia were summed up. Then, the use of cluster analysis to reduce the dimensionality of the risk factors was explained in preparation for the subsequent multiple regression analysis. The regression analysis derives the RBCCEM which was validated using bootstrapping analysis. Finally, the estimates produced by RBCCEM was compared those by alternative approaches such as the fixed cost contingency (10%), RCF (P50 & P90) and hybrid (RBCCEM & RCF P50) approaches.

4. Data collection

A survey of infrastructure project managers in Saudi Arabia was conducted to collect data from key infrastructure project professionals in three groups: owners exposed to project cost overrun, consultants supervising the projects, and contractors delivering the projects. The survey asked about the frequency of the 41 causes of cost overrun most frequently identified from 25 selected studies, as shown in Table 1. Respondents used five Likert-scale response anchors to assess the frequency of each cause in Saudi Arabia, based on their own professional experience. For more information about the data collection please refer to the survey data that conducted by the authors in a separate paper (Allahaim and Liu, 2015).

5. Data analysis and results

Based on the clusters identified, the scores for each cluster in each case was derived by aggregating the scores of each cause within each cluster. Subsequently, the cost overruns of projects were regressed on the four clusters identified to develop a risk-based cost contingency estimation model. R project software (version 3.0.2) and IBM SPSS 19 were used for statistical computing and graphics in the cluster analysis, model building and validation of the model.

5.1. Cluster analysis

Cluster analysis was used for dimension reduction (Everitt et al, 2011). The steps in cluster analysis of the data include preparing the data, determining the number of clusters, testing the cluster solution and finally validating clusters.

In Figure 1, there is an extreme “elbow” in the plot suggesting that solutions over four clusters do not have a substantial impact on the total SSE, which indicates that four clusters are appropriate. The next

step tested hierarchical cluster analysis with the selected number of four clusters (Everitt et al, 2011). The Euclidean distance method was used to measure the dissimilarity distance based on the information values and the nature of the variables describing the objects to be clustered. Figure 2 shows the hierarchical cluster (tree) generated from R software, where the cause numbers (C1, C2... C41) refer to the causes listed in Table 1.

In the analysis, 10,000 bootstrap resamplings were used to reduce the error (Suzki and Shimodaira, 20016). In Figure 2, four rectangles have an AU p -value of 99 (0.99), therefore, for a cluster with AU p -value ≥ 95 (0.95), the hypothesis is rejected with significance level 0.01 for one cluster and 0.00 for three clusters, which indicates how strongly four clusters are appropriate as each cluster group contains objects which have a relationship with each other (Figure. 2).

5.1.1. Results – four cluster classification

The four cluster groups were defined based on causes of cost overrun and the literature as scope changes, market and regulatory uncertainty, inadequate planning and control and unforeseen circumstances. Table 1 shows how each of the 41 causes in Table 1 is allocated to one of the four clusters.

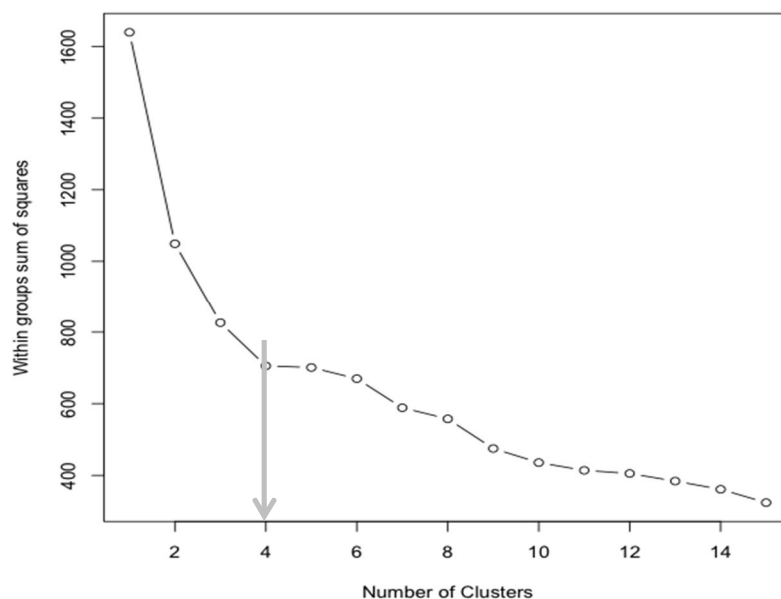
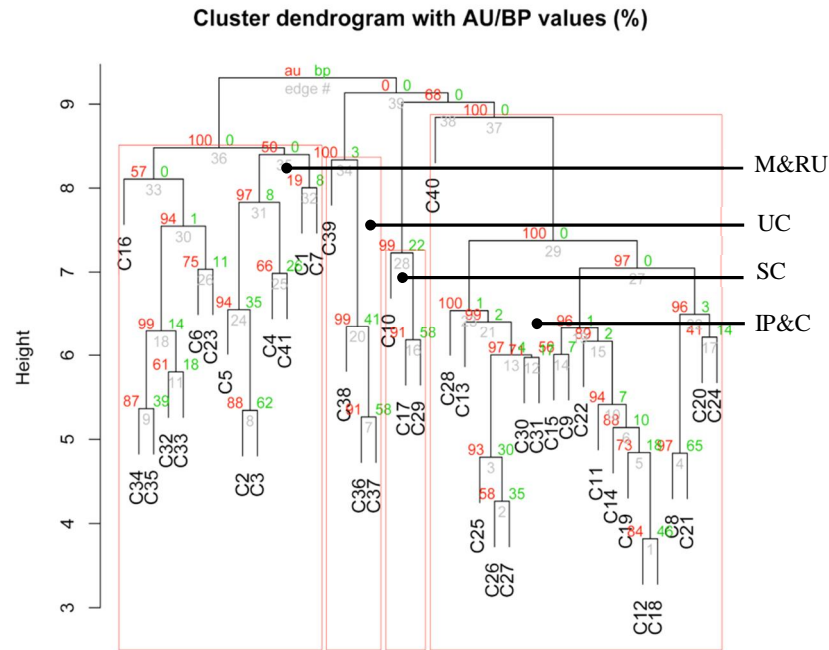


Figure 1: Elbow plot for the cluster determination



Note 1: Values at branches are AU p-values (left-red), BP values (right-green), and cluster labels (bottom). Clusters with $AU \geq 95$ are indicated by the four red rectangles.

Note 2: Inadequate planning and control (IP&C), Market and regulatory uncertainty (M&RU), Scope changes (SC) and Unforeseen circumstance (UC).

Figure 2: Hierarchical clustering with four cluster solution

As shown in Table 1, the first cluster group is scope changes (SC), which represents the causes of cost overrun due to design changes, additional work and rework, and change in the scope of the project. The causes in this cluster are related to time, that is the urgency of the project, namely how much time there is to complete the job. Forcing the project team to take short-cuts or to work on tasks which clash with other tasks and working on concurrent tasks and projects are known to cause delays and cost overrun. The second cluster group is market and regulatory uncertainty (M&RU), which includes causes of cost overrun that relate to the chance or speculation changing costs, whether directly or indirectly. The third cluster group is inadequate planning and control (IP&C), it represents the causes of cost overrun which relate to project planning and control, which comprise the most critical causes of cost overrun in large projects in Saudi Arabia. Inadequate planning and control dimension is referring to the factors that could increase the complexity and thus difficulty of controlling the project cost. The last cluster group unforeseen circumstance (UC). The causes of this cluster relate to environment issues, as well as social and cultural impacts. These issues increase the pressure to find a solution to these problems associated with the project site. For example, the increase of environmental requirements has a significant impact on construction operations, which leads to technical uncertainty that relates to the physical difficulty of completing a project.

Table 1: Four-cluster classification scheme for causes of cost overrun

Classification clusters	Key	Causes of cost overrun	Relationship to cost overrun
Scope changes	C17	Design changes*	Unclear project scope forces project team to take short-cuts, crashing tasks, concurrent tasks/projects, which are known to cause delays and cost overrun (Shenhar and Dvir, 2007).
	C10	Additional work and rework*	
	C29	Change in the scope of the project*	
Market and regulatory uncertainty	C5	Market conditions (materials and labour)*	Increases the volatility of input costs and thus chances of overrun (Pindyck, 1993).
	C41	Practice of assigning the contract to the lowest bidder*	
	C4	Slow payment of completed works*	
	C3	Cash flow during construction	
	C33	Obstacles from government	
	C1	Inflation	
	C35	Laws and regulatory frameworks	
	C16	Failure to price in some risks	
	C2	Monthly payment difficulties from agencies (e.g. contractor, owner)	
	C34	Political complexities	
	C7	Deficiencies in cost estimates prepared by public agencies	
	C32	Fraudulent practices	
	C23	High interest rate charged by bankers on loans	
	C6	Fluctuation in money exchange rate	
Inadequate planning and control	C40	Delays (decision making, in approval of drawings, material delivery)*	Increases the complexity of coordination of parties and tasks, thus making it harder to meet present targets (Baccarini, 1996).
	C21	Design error*	
	C8	Deficiencies in the infrastructure*	
	C20	Changes in material specification and type*	
	C13	Shortage of site workers	
	C18	Incorrect planning and scheduling by contractors	
	C24	Inadequate specifications	
	C14	Unrealistic contract duration and requirements imposed	
	C11	Lack of experience of project manager (e.g. location, type)	
	C28	Lack of constructability	
	C15	Strategic misrepresentation	
	C22	Project size	
	C12	Contractor's poor site management and supervision skills	
	C19	Late delivery of materials and equipment	
	C25	Waste on site	
	C9	Labour, insurance, work security or workers' health problems	
	C27	Poor financial control on site	
	C26	Equipment availability and failure	
	C31	Optimism bias	
	C30	Inadequate modern equipment (technology)	
unforeseen circumstances	C37	Site constraints	Increases the uncertainty of tasks and
	C36	Weather conditions	

	C38	Social and culture impact (e.g. problems with neighbours)	outcome, thus making planning and estimating difficult (Ofori, 1992).
	C39	Heritage material discovery	

Note: (*) ranked in the top ten causes

5.2. Development of the risk-based cost contingency estimation model

To build the model using multiple linear regressions (MLR), as there are 160 cases and 41 causes, the data was randomly split into two data sets with two-thirds of the data as the training set (100 cases=62.5%) for model building and the remaining one-third (100 cases=37.5%) as the test set to ensure more reliable results and also to reduce bias in the validation (Kothari, 1985). For model validation, bootstrap resampling of multiple linear regressions was employed. Then, the estimates by RBCCEM were compared with those produced by alternative models such as fixed contingency and RCF. Error indices such as mean absolute error (MAE), mean absolute percentage error (MAPE), mean square error (MSE) and root mean square error (RMSE) were used to compare the accuracy of estimates produced (Han and Kamber 2006). Then, RBCCEM, fixed cost contingency (10%), RCF (P50 & P90) and hybrid (is a combination of two models which used to increase the accuracy of cost contingency estimation as Liu et al., (2010) identified) were compared based on the distribution of the means of adjusted cost overrun as the smallest dispersion with the shortest distance between the mode and median indicates the most accurate model (Rothwell, 2005; Lawrence, 2007).

5.2.1. Risk-based cost contingency estimation model building

The regression results using the training subsample are reported in Table 2. The results in Table 2 show all four clusters have significant impact on cost overrun. It is worth noting that Table 2 shows that the R-squared is 32% and adjusted R is 30%, which indicates that the four clusters explains about 30% of variance in cost overruns (Chambers, 1992). The interpretation here is that the observed variation in cost overrun is also explained by other factors beyond those captured in the equation. It is not the intention of this paper to delve into which other factors explain overrun, as it focused on the four clusters (p -value < 0.05) as all variations that were categorised based on 41 causes that are frequently identified in the literature are significant. Therefore, the RBCCEM is represented by the equation 1.

$$BCCEM = \%Cost\ overrun = 0.652 + 0.157(scope\ changes) + 0.089(market\ \&\ regulatory\ uncertainty) + 0.047(inadequate\ planning\ \&\ control) + 0.024(unforeseen\ circumstances)$$

Equation 1

Note: the value of inadequate planning and control, market and regulatory uncertainty, scope changes and unforeseen circumstances ranges from 1-5 as 1 has low risk and 5 has major risk.

Table 2: Residuals, coefficients and p-values of regression analysis

Residuals	Min	1Q	Median	3Q	Max
	-2.109362147	-0.515626813	0.00002042	0.47228	1.52539
Coefficients		Estimate	Std. Error	t value	Pr(> t)
	(Intercept)	0.65196	0.08967	2.35254	0.00027***
	Scope changes	0.15733	0.10251	0.46178	0.00452**
	Market and regulatory uncertainty	0.08865	0.11366	0.77998	0.03734*
	Inadequate planning and control	0.04728	0.06818	0.54674	0.05218
	Unforeseen circumstances	0.02431	0.11406	2.13199	0.03558*
Residual standard error: 0.0159 on 95 degrees of freedom Multiple R-squared: 0.3249 Adjusted R-squared: 0.3048 F-statistic: 9.463 on 4 and 95 DF					

Note: $p < 0$ '***', $p < 0.001$ '**', $p < 0.01$ '*', $p < 0.05$ '.'

5.2.2. Models validation

The bootstrapping method was used for validating the RBCCEM. 5,000 bootstrap samples were created to validate the predictive ability of the proposed RBCCEM (multi-linear regression (MLR) model). According to all three measures (Table 3), the coefficient was statistically significant (the default for boot.ci is a 95% confidence interval) as they are centred to the normal, which indicated the model was valid. As reported in Table 3, the mean values of the four regression coefficients estimates from the RBCCEM bootstrapping were close to the proposed RBCCEM (Tables 2 and 3). Also, the standard error values of the four-parameter estimates from the RBCCEM bootstrapping were close to the proposed RBCCEM (Tables 2 and 3). The similarity of estimates of the RBCCEM model from both split samples suggests that RBCCEM is valid and robust.

Table 3: RBCCEM bootstrapping

Ordinary nonparametric bootstrap		Estimate	bias	std. error
	(Intercept)	0.57073	- 0.01413	0.092570
	Scope changes	0.14501	0.00348	0.128087
	Market and regulatory uncertainty	0.07840	- 0.00275	0.101091
	Inadequate planning and control	0.03820	- 0.00481	0.083566
	Unforeseen circumstances	0.03298	0.00148	0.100938
Bootstrap Confidence interval calculations	Level	Normal	Percentile	BCa
	95%	(0.2662, 0.9035)	(0.2243, 0.8637)	(0.2453, 0.8803)

Note: Calculations and Intervals on Original Scale

5.2.3. Models evaluation using estimation accuracy measures

In the models evaluation we used two methods. The first method was by using estimation error (error indices). The second method was comparing the adjusted cost overrun percentage means by using independent samples t-test. The following section will discuss these two methods and the results are delivered.

5.2.3.1. Model evaluation using measures of forecast accuracy (error indices)

To further validate the model, the estimates produced by RBCCEM were compared with alternative methods such as RCF. RCF uses a database of actual performance of comparable past projects within a given reference class to provide an objective reference point for the cost forecast of a current project (Flyvbjerg, 2006). For a particular project, reference class forecasting requires the following three steps (Flyvbjerg, 2006, p. 8): (a) identifying a relevant reference class of past projects as the base, (b) establishing a probability distribution for the selected reference class and (c) comparing the specific project with the reference class distribution.

To compare the models, the accuracy of each model was measured. Forecast accuracy measurements were based on the distributions of absolute errors ($|E|$) or squared errors (E^2), taken over the number of observations (n), which are the most commonly used measures to compare the performance of predictive models (Hyndman and Koehler, 2006). These include mean absolute error (MAE), mean absolute percentage error (MAPE), mean square error (MSE) and root mean square error (RMSE) (Swanson et al., 2011). Table 4 presents MAPE MAE, MSE and RMSE where values of 0 indicate a perfect fit (Singh et al., 2013). Table 4 shows that the RBCCEM has comparable error indices to that of RBCCEM bootstrapping. In contrast, the error indices for RCF are much higher, suggesting RBCCEM is more accurate.

Table 4: The MAE, MAPE, MSE, and MAPE of MLR and error estimates of the four-clusters model: Proposed RBCCEM, RBCCEM bootstrapping and RCF model

	MAE	MAPE	MSE	RMSE	RMSE -MAE
Proposed RBCCEM	0.473786	15.78 %	0.426456	0.653036	0.18
RBCCEM bootstrapping (5,000 bootstrap of test data)	0.428924	14.68 %	0.358026	0.598353	0.17
RCF model	0.872376	25.19 %	1.190669	1.091178	0.22

5.2.3.2. Models evaluation by comparing the means of adjusted cost overrun percentage of the models

As discussed, β_1 to β_4 were estimated based on a sample of 100 and the model was validated using bootstrapping based on the 60 samples, which shows the model was valid and accuracy was improved compared with RCF. In this section, the mean of the adjusted cost overrun percentage of the RBCCEM was compared with those estimated using alternative approaches, such as RCF and fixed contingency (10%), using the split sample. The result in Tables 5 and 6 shows the adjusted cost over. The comparison results reported in Tables 5 and 6 showed that the adjusted cost overrun of RBCCEM results are

significantly lower than adjusted cost overrun of fixed (10%) cost contingency, RCF and hybrid approach.

Table 6 shows that the means of adjusted cost overrun percentage using the fixed cost contingency, RBCCEM, RCF P50, RCF P90 and hybrid (RBCCEM + RCF P50), respectively, are all significantly different from each other (p -value < 0.00). Considering the negative mean (under budget) in the adjusted cost overrun percentage mean of RBCCEM (-0.11451), the results suggested that the mean of adjusted cost overrun percentage using the RBCCEM approach is preferable to that using the RCF P50, RCF P90 and hybrid.

Moreover, Table 6 reports that the adjusted cost overrun using RCF reduce the overrun significantly (p -value < 0.05) as the mean differences for P50 is (0.1049) and for P90 is (0.0140) (Table 5 and 6). Despite the fact that RCF P50 and RCF P90 have lower mean differences, it should be noted that the RCF estimates are subject to the acceptable risk of cost overrun which RBCCEM does not. In addition, the RBCCEM model tends to underrun budget while the RCF model tends to overrun budget. The dispersions of the RCFs are higher than RBCCEM (Figure 3) suggesting RBCCEM produces more consistent results. In sum, using estimates of contingencies by RBCCEM results in slight average cost underruns with more consistent and accurate estimates than that from RCF.

In addition, the variance of adjusted cost overrun percentage using the fixed cost contingency, RBCCEM, RCF P50, RCF P90 and hybrid, respectively, are significantly different (p -value < 0.035) (Table 6). Considering that the variance of adjusted cost overrun percentage using the RBCCEM is lower than those using fixed cost contingency, RCF P50, RCF P90 and hybrid (Table 6), respectively, the results indicates RBCCEM produces the most consistent estimates for cost contingency. Therefore, RBCCEM is the preferable method for estimating cost contingency for infrastructure projects.

Table 5: Descriptive statistics for mean of adjusted cost overrun of two models

	N	Mean	Std. Deviation	Std. Error Mean
Fixed cost contingency 10%	60	0.3319	0.22739	0.02935
RBCCEM	60	- 0.1145[^]	0.15616	0.02016
RCF uplift P50	60	0.1049	0.17155	0.02214
RCF uplift P90	60	0.0140	0.15604	0.02014
Hybrid of RBCCEM and RCF uplift P50	60	-0.0096[^]	0.32646	0.04215

Note: [^] A negative value denotes under and a positive figure indicates over budget.

Table 6: Test results for the equality of means and variances

	Leven's Test for Equality Variance		t-test for Equality of Means				
	f	sig	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Fixed cost contingency 10% vs. RBCCEM	3.289	0.035	6.54	104.52	0.000***	0.44650	0.13561
Fixed cost contingency 10% vs. RCF uplift P50	7.659	0.005	9.174	109.73	0.000***	0.23677	0.03117
Fixed cost contingency 10% vs. RCF uplift P90	7.394	0.006	8.931	104.48	0.000***	0.31795	0.04360
Fixed cost contingency 10% vs. Hybrid of RBCCEM and RCF uplift P95	6.616	0.010	6.650	105.342	0.000***	0.34157	0.05136

Note: Significance codes: p < 0 '***', p < 0.001 '**', p < 0.01 '*', p < 0.05 '.'

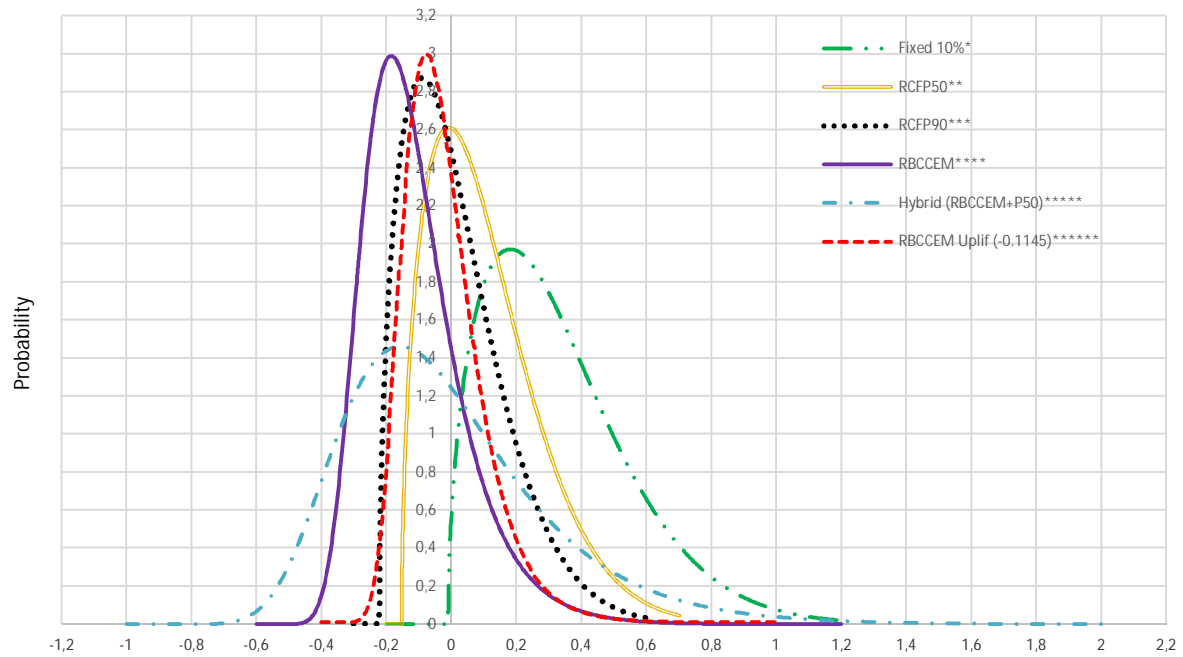
Figure 3 shows the mean distributions fitting to the data. As can be observed that all distributions are skewed to the left and the tails of the distributions are longer in the right. Therefore, the mode is the peak of each distribution, and the median and mean come after it in the right. Furthermore, the distribution of adjusted cost overrun percentage for RCF P50 and P90 are fitted to Weibull distribution as can be observed in the Figure 3 by the orange doubled line and black dotted line, respectively.

In addition, the fixed 10% cost overrun (green long dashed dot dot line) is fitted to Weibull distribution and hybrid (RBCCEM + RCF P50) (blue long dashed dot line) is fitted to exact value distribution. The adjusted cost overrun of RBCCEM distribution (purple solid line) is fitted to exact value distribution which is biased toward under-budget (mean adjusted cost overrun=-0.1145). Comparing the dispersions of the distribution curves presented in Figure 3, RBCCEM has the narrowest dispersion, supporting the above conclusion that RBCCEM produces the most consistent estimates for cost contingency of infrastructure projects.

Further, the small negative mean of adjusted cost overrun of using RBCCEM can be offset by adding an amount equal to 0.1145. As a result, the distribution of RBCCEM +0.1145 (red dashed line) shifted around zero and has the narrowest dispersion compared to the other distributions.

6. Conclusions

Based on a cross-section survey of managers involved in infrastructure projects in Saudi Arabia, cluster analysis was used to reduce 41 causes of cost overruns to four clusters; scope changes, market and regulatory uncertainty, inadequate planning and control, and unforeseen circumstances. Using multiple - regression analysis, the risk-based cost contingency estimation model (RBCCEM) was developed by regressing project cost overrun on the four clusters. Then, validity of the RBCCEM was validated by multiple regression bootstrapping using the remaining split sample (sample size of 60) and by comparing the cost overrun outcomes of using cost contingency estimates from RBCCEM to those of using alternative estimating approaches such as RCF and fixed contingency. The validation analysis



Note: * distribution fitting of fixed % cost overrun (Weibull distribution)
 ** distribution fitting of adjusted % cost overrun based RCF on 50% percentile (Weibull distribution)
 *** adjusted % cost overrun based RCF on 90% percentile (Weibull distribution)
 **** distribution fitting of adjusted % cost overrun based on RBCCEM (proposed model) (Exact value distribution)
 ***** distribution fitting of Hybrid model (RBCCEM + RCF P50) (Exact value distribution)
 ***** distribution fitting of adjusted % cost overrun based on RBCCEM (RBCCEM + uplift (-0.1145) (Exact value distribution)

Figure 3: The fitting distribution curves of fixed cost contingency, RBCCEM, RCF (P50 & P90), hybrid and RBCCEM uplifted (RBCCEM-0.1145)

showed that the degree of dispersion of the cost overrun and the mean of the cost overrun after including the cost contingency is the lowest for RBCCEM, in which it is preferred method of estimation for cost contingency. However, the accuracy of cost contingency could be improved further by offsetting the negative mean of cost overrun using hybrid approach, i.e. by deducting the mean from the cost contingency produced by RBCCEM. Such an adjustment uplifts the means of cost overrun to zero while the degree of dispersion remains unchanged.

To apply RBCCEM, an organization needs to ascertain a comprehensive list of the risks to the cost overrun of similar projects through using questionnaire survey. The questionnaire should be based on the questionnaire used in this study and tailored to the project at hand. Assuming the survey responses of at least 30-40, then the organization can proceed to categorizing the risks by conducting clustering analysis. Subsequently, construct scores can be derived by aggregating the scores of individual risks within each category. Finally, regression analysis of cost performance on risk categories is conducted to drive the cost contingency model which will be used to predict cost contingency for the project. Bootstrapping using a holdout sample is a useful validation of the cost contingency estimation model.

The findings are based on a cross-sectional survey of managers involved in infrastructure projects in Saudi Arabia. Therefore, caution should be exercised when generalizing to other contexts. Future

research needed to develop RBCCEMs in different contexts following the process for developing RBCCEM as in this study. This study is treating RBCCEM as static concepts that have a constant value, rather than dynamic concepts that evolve over time. Past research has suggested that project management practice changes over time due to a growing knowledge-based society which accelerates change in technological, social and economic knowledge (Jaafari, 2003). Therefore, the survey needs to be undertaken periodically and the subsequent processes need to be conducted to update the RBCCEN regularly. Finally, this study has not compared RBCCEM with the risk-based cost estimation approach future research should consider collect data on RBE estimates and compare the two approaches.

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