Keeping the UK Building Safely 2

Prepared for
The PROTECT COVID-19 National Core Study on transmission and environment

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The PROTECT COVID-19 National Core Study on transmission and environment is a UK-wide research programme improving our understanding of how SARS-CoV-2 (the virus that causes COVID-19), is transmitted, and how this varies in different settings and environments. This improved understanding is enabling more effective measures to reduce transmission, save lives and get society back towards 'normal'.

This Keeping the UK Building Safely (KUBS) report is part of the PROTECT National Core study, and explores four themes: transmission risk and perceptions, safety leadership, transmission modelling and wider project delivery and contractual performance in the context of the construction industry and COVID-19 pandemic.

KUBS phase 1 report explored the context at the start of the pandemic with managers and suggested that construction was expected to manage well with safe working due to the existing cultures and structures. This report, 'KUBS 2', was conducted at a much later point in the pandemic, and with a wider range of staff from all levels within construction, allowing us to explore these expectations and the extent to which they were realised.

The report concludes that the full extent of the economic consequences of the pandemic are yet to be known, but early data suggest that the path to recovery will be slow - particularly in the context of global uncertainty arising from the conflict in Ukraine. For people in the UK, inflationary pressures, and the associated increases in the cost of living is likely to lead to greater demand for social housing and by implication, on the house building/refurbishment sector more generally.

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Keeping the UK Building Safely Phase 2

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Key Messages

Transmission

There is evidence of a broad range of COVID-19 transmission mitigation measures in action; these were generally well received by participants, who reported high levels of compliance.

There is evidence of competing requirements of COVID-19 specific and established construction health and safety regulations. For example, and as may be expected, social distancing proved problematic in situations where proximity working is required. Creative measures were used to mitigate risk where social distancing wasn't feasible for example adapting tools and processes or using teams who cohabited.

Whilst participants reported reductions in serious safety incidents on sites, the prevalence of minor incidents increased. For example, face coverings were cited as an inhibitor of effective communication between workers.

The availability of remote working arrangements to some construction workers led to some participants reporting the presence of an 'us-them' culture.

Modelling of transmission

Agent-based modelling (ABM) and Susceptible-Exposed-Infectious-Recovery (SEIR) modelling are viable techniques in simulating the dynamics of COVID-19 transmission.

The integration of ABM and SEIR support the visualisation of COVID-19 transmission dynamics and the identification of high-risk areas in the construction workplace.

Enthusiasm to adopt ABM and SEIR in the participant organisations is high.

Leadership

Safety leadership is positively correlated with safety behaviours, including compliance with COVID-19 safety measures.

The impact of the COVID-19 pandemic and associated mitigations on employee wellbeing was variable, and dependent on the nature of work and/or job role.

We identify examples of robust leadership and communication in the context of mental health and wellbeing more generally.

Interpreting government guidance (simplifying and disseminating) proved challenging. There was evidence of a need to align central government messaging with variations in client, contractor, and worker requirements.

New COVID-19 safety practices soon became integrated with other standard construction safety practices and absorbed within the construction safety culture, although exceptions to this were identified (see Appendix 3).

The wider construction sector

The construction sector has experienced a decade of increasing underperformance; this is a consequence of systemic and entrenched problems that are well documented.

The sector is extremely vulnerable to shocks. Company administrations recorded in February 2022 were highest on record since the onset of the COVID-19 pandemic. There were thirty-one administrations recorded, the largest on record since early 2000.

Construction supply-chains are exposed to significant uncertainty. Our research uncovers evidence of construction materials price quotes expiring after 24 hours because of inflationary concerns arising from COVID-19 and the war in Ukraine.

Digitalisation and technological innovation are key to improving productivity, but entrenched structures, fragmentation and ‘ways of working’ in and across the construction industry present significant transformation challenges.

People and technology are equally important considerations in the presumption towards Modern Methods of Construction (MMC).

On major construction works, the project ‘front-end’ is crucial; research shows that decisions made at this stage are highly influential on culture, safety leadership and efficiency.

The construction sector is characterised by high degrees of complexity; a system approach is therefore crucial to tackling these challenges.

Executive Summary

Introduction

This KUBS2 report explores four themes: transmission risk and perceptions, safety leadership, transmission modelling and wider project delivery and contractual performance in the context of the construction industry and COVID-19 pandemic (Figure 1). KUBS 1 explored the context at the start of the pandemic with managers and suggested that construction was expected to manage well with safe working due to the existing cultures and structures. KUBS 2 which was conducted at a much later point in the pandemic, and with a wider range of staff from all levels within construction, allowed us to explore these expectations and the extent to which they were realised.

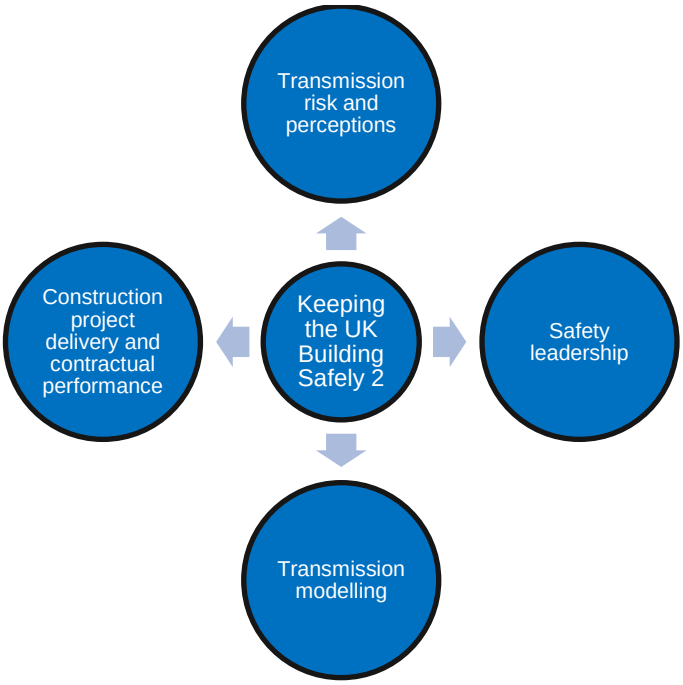

Figure 1: Keeping the UK Building Safely 2; thematic areas of investigation

Transmission risk and perception

This report evidences how understanding of risk and mitigation management practices across the construction value chain were implemented in the wider context of the hierarchy of controls, technology, and COVID-19 related testing/vaccine practices.

Perceptions of risk in the initial phases of pandemic were framed by high degrees of unknowns; factors affecting risk perception included temporality, legislative and regulatory change, media messaging and behaviours of those in government. After an initial relaxing of rules, risk perception appeared to reduce.

Construction sites are unique workplaces, this presented larger organisations with challenges when implementing rules and guidance across different areas of the nation with differing rules.

There was a perception that working outdoors reduced the risk of transmission and infection. Our evidence that suggests that participants understood the risks of proximity working but often found it difficult or impossible to find workable solutions. Examples of workarounds included extended tools to carry heavy items and projecting a two-metre light on the ground to ensure people worked apart. Where a workaround was not possible, and the job required two workers in an enclosed space a bubble was used or created where possible.

Families or flat mates working together were useful as they formed a natural bubble of contained risk. The hierarchy of controls shows that elimination is the best control, and all companies immediate response was for staff to work from home.

Substitution was achieved by maintaining remote working where possible; however, this had a range of impacts. Some felt at greater risk because they had to go in rather than being able to work from home, some felt at greater risk working indoors than those outdoors, and there were risks to mental health for those working remotely.

Ventilation was the next best control and evidence showed that the perception of risk was reduced when working outdoors, which helped workers feel safe. Ventilation in offices had varying success depending on the season. There was evidence of organisations aiming to improve ventilation with air filtration and purification devices being used introduced for the first time or used more frequently.

Safe working practice is where the industry focused most mitigation measures such as cleaning and contact tracing. Training was limited.

There was also significant use of administrative controls such as social distancing, bubbles (small, contained work groups), staggered timing and changes to layout and use of shared facilities.

Changes to processes meant they took longer or required additional workers to complete tasks than pre-pandemic and this meant there were additional costs to all suppliers. Some tier 2 companies reported passing the cost on to the client, where

the measures were insisted on by the client. Some tier 2 companies did not incur significant additional costs and were able to deliver to original costs. Tier 1 organisations reported that they were absorbing additional costs within their company but maintained delivery of all key jobs to schedule.

Safety leadership

Employee wellbeing in construction during COVID-19 was variable, and often dependent on the context of work and job role. Most employees in construction thought they were coping well, but a small percentage reported they were struggling with dealing with problems during the pandemic.

People working from home in the construction industry had a wide range of experiences both negative and positive. There were risks to mental health for all but in particular those working from home. Organisations recognised this and responded with a wide range of support mechanisms from routine check-in calls through to specially organised events. On occasion there was perceived to be an ‘us-them’ culture between those working remotely and those working on site.

Compliance with site rules was reportedly high although there were a wide range of examples of non-compliance. In some instances, compliance required reminders, (such as sending people home who should be self-isolating), and on other occasions required enforcement, although this was reportedly not common. The most difficult rules to encourage workers to comply with were related to social distancing and many suggested this was because of a culture of close working and looking after your workmates which is prevalent in the construction industry. Perceptions were that compliance reduced over time through the pandemic.

Research participants suggested that they perceived the key effective leadership attribute was leading by example. Being visible was perceived as important, in particular at tier 2. Confident encouragement and enforcement were important in relation to managing safety compliance.

Two-way communication between employer/manager and employee/worker was vital to managing the remote workforce. Regular check ins and empathy were key to supporting mental health and wellbeing. Communication had to be targeted at distinct levels of audience. H&S and managers played an interpreting role based on government guidance (simplifying and disseminating). There was evidence of a need for alignment of messaging between government, client, contractor, and workers. Consistency was vital for strong messaging. Some felt government messaging was clear and helpful and others did not. Confusing differing advice across different nations of GB impacted large companies or individuals working across borders which is common in the industry.

Views on remote working varied with some perceptions that working remotely increased productivity and others suggesting that productivity was decreased for those working remotely. Working remotely on tasks which required shared access to visual stimuli (such as site drawings) was particularly difficult.

From a management perspective there was some difficulty in maintaining targets while people were working from home. Participants suggested in interviews that working from home was frowned upon before the pandemic but is now more broadly accepted.

Microsoft Teams was a useful tool for communicating remotely and used widely.

Generally, new COVID-19 safety practices soon became integrated with other normal construction safety practices and absorbed within the construction safety culture, although exceptions to this were identified (see Appendix 3).

There were complex relationships identified between transmission risk, leadership and outcomes.

The role of H&S was vital and had overlap with the HR role as people were unsure where to access the support they needed as this was an unprecedented situation. The H&S department usually became the interpreter between government advice and organisational communication.

Safety leadership was also positively correlated with safety behaviours in the workplace, including compliance. Constructive safety leadership in a work context was associated with lower perceptions of vulnerability to COVID-19 infection in the workplace.

Perceptions were that levels of compliance were broadly high. Where perceptions of risk were low and adhere low then there was a perception that higher levels of encouragement and enforcement required from management.

There was evidence of a range of impacts on traditional health and safety reported by health and safety managers.

It was broadly reported that major safety incidents on site were reduced (in correlation with reduced activity and staff on site). However, there was some rise in minor incidents often due to compliance with safety measures. For example, face coverings often made communication difficult and on occasion caused a safety risk.

Whilst there was minimal evidence for the rise in minor incidents, there was some suggestion these may have been situations arising from safety challenges in meeting COVID-19 safe practices. For example, one health and safety manager in tier 2

reported at least 3 incidents directly related to people trying to lift and move things on their own because they were too nervous to ask for help in case they came into too close contact with other people.

Decreases in safety incidents were reported by some participants in the initial stages of the pandemic, followed by an increase in safety incidents as workers returned to site when rules were relaxed. There was some suggestion that compliance fatigue contributed to an increase in incidents over time.

Transmission modelling

We investigate the use of simulation and modelling techniques as a means to support transmission risks management of infectious diseases, such as COVID-19, on construction sites as a proof-of-concept using agent-based modelling (ABM) and Susceptible-Exposed-Infectious-Recovery (SEIR) approaches. ABM and SEIR provide an appropriate set of methods to simulate the dynamics of COVID-19 transmission and the epidemiological effects of various protective control measures, including social distancing, face covering, vaccinations rate, ventilation, and isolation. This also enables the consideration of population heterogeneity (e.g., age, vaccination status and household size), duration of contacts and site layout.

To achieve repeatability and flexibility in deployment, an interactive and user-friendly interface is demonstrated. In addition, it also highlighted how to use the model and platform for estimating the transmission risk and identifying high-risk work areas on a typical construction site. In particular, the work enables users to select the level of compliance with different protective control measures, to create different scenarios as well as visualise the impacts of such scenarios on COVID transmission dynamics and identification of high-risk areas. As a result, users can identify the scenario (i.e., combinations of compliance levels for different protective control measures) that offers the optimal balance between operational requirements and controlling the spread of diseases.

An engagement workshop held with professionals from construction firms generated positive comments on all the evaluation criteria (i.e., usability of the platform, structure and layout, ease of integration with other platforms, and representativeness and relevance of captured information). Participants declared their interest in utilising the model and integrating it with their existing occupational safety and health management systems.

Construction project delivery and contractual performance

The impact of the COVID-19 pandemic on the construction sector, from a project delivery and contractual performance perspective is characterized by seven key themes:-

Strategy

The COVID-19 recovery strategy '***Build Back Better: Our Plan for Growth***', describes "*a **transformational** approach, tackling long-term problems to deliver growth that creates high-quality jobs across the UK and makes the most of the* strengths *of the Union."*

The strategy sets out three core pillars of growth, one being infrastructure, and recognises the broader socio-technical challenges facing the construction industry.

> *"Accelerating and improving delivery through wide-ranging Project Speed reforms including streamlining the planning system; improving the way projects are procured and delivered; and greater use of cutting-edge construction technology."*

The strategy also emphasises the role of technology in delivering growth, this is also evidenced in Transforming Infrastructure Programme (TIP) Roadmap to 2030. This document articulates the role of technology in delivering societal needs, including platform approaches to construction.

Sector vulnerability

Insolvencies recorded in February 2022 alone were the highest on record; 31 administrations were recorded, the largest monthly total since early 2000. During the period 2021Q1-2021Q4 there was an increase in the rate of insolvencies in the domestic building sector; this is potentially significant in the context of the house-building and affordable housing supply. Homes England's annual report for 2022 states that it supported the delivery of 26,953 affordable homes in the year to end March 2022 against a target of 34,349-home target. The report identifies labour and material shortages as a concern for schemes approaching completion.

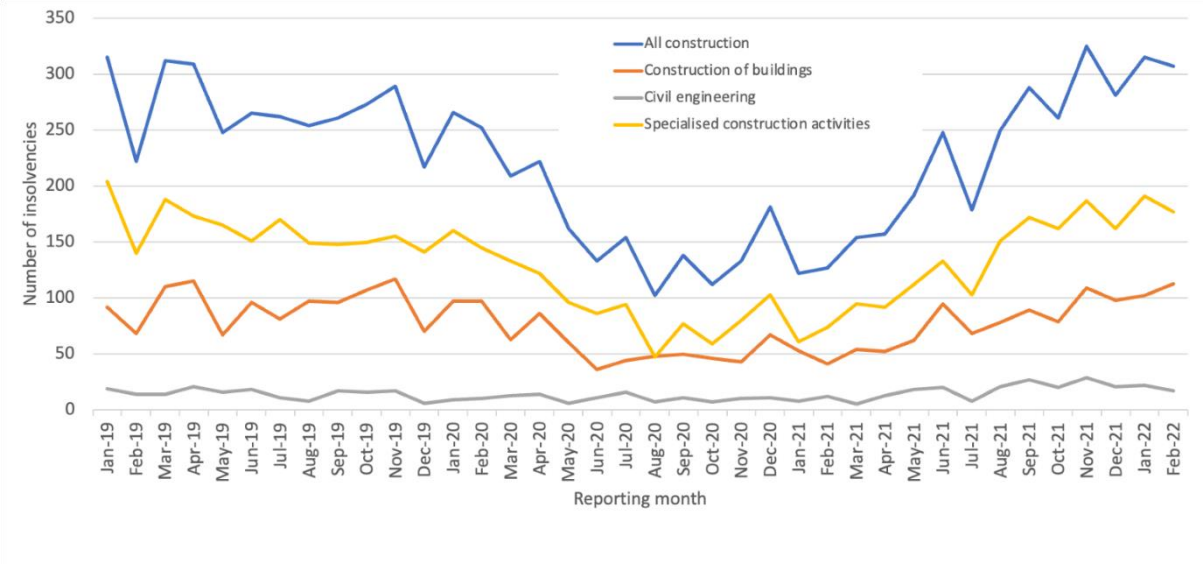

Figure. 2: Company Insolvencies in the Construction Sector Jan 2019-March 2022 (source: ONS)

The rate of insolvency across the construction sector is shown in Fig 2. Data from The Insolvency Service reported in the industry magazine 'Building' shows that there were 307 administrations in February 2022, a 142% increase on the previous year.

Supply-chain uncertainty

In July 2022, the consumer price index was 9.4% (Bank of England target rate is 2%). The inflationary pressures are evidenced in some situations whereby construction firms are required to agree materials price quotes within 24hrs. Larger organisations, typically those described as Tier 1, tend to insure against material price escalation by 'banking' materials or developing strategic relationships with suppliers. Small-to-medium sized organisations tend to source their materials from local suppliers and are therefore exposed to higher levels of price volatility, and therefore, are more likely to experience cash flow problems.

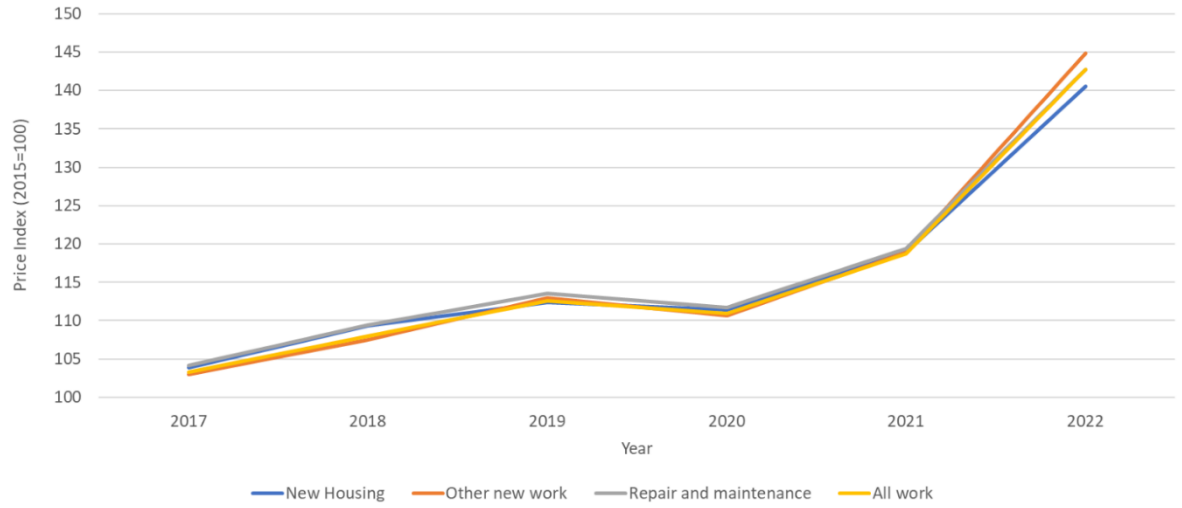

Figure 3. Construction Building Materials Price Indices; consecutive February's between 2017 and 2022 (source: ONS)

The materiality of the construction process

Construction is a 'performative' process whereby the skill of trades has intrinsic value. This is often referred to as 'materiality and the '*Restoration and Renewal Programme*' at the Palace of Westminster provides a good illustration of this. The strategic outline business case is due in 2023 but debate surrounding the governance of the programme remains unresolved as the programme approaches a critical juncture. In a recent Public Accounts Committee report, parliamentarians report that '*every week of delayed repairs to crumbling Parliament was costing the taxpayer another £2 million'.* In October 1943, Winston Churchill recognised the importance of materiality in a speech to Parliament on his Government's plans for the rebuilding of the House of Commons following catastrophic war damage;

> *"…we have now to consider whether we should build it up again, and how, and when.* ***We shape our buildings and afterwards our buildings shape us****. Having dwelt and served for more than 40 years in the late Chamber, and having derived fiery great pleasure and advantage therefrom, I, naturally, would like to see it restored in all essentials to its old form, convenience and dignity…"*

People and technology are equally important considerations in the presumption towards Modern Methods of Construction (MMC).

The IPA's 'construction pipeline' of 528 projects, programmes and other investments indicates that 27% will be delivered through MMC. This includes digital design to off-site and volumetric construction and represents a total investment of £79bn. IPA estimates that > 425,000 workers will be required, annually on average, over the

period 2021/22 to 2024/25 to deliver the £200bn of planned investment within the pipeline.

ONS data shows that despite the rate of growth slowing in December 2021 to February 2022, most industries recorded increases in the number of vacancies. The rate of quarterly growth is variable across the UK; the fastest rates of growth are in the education sector at 21.2% and construction industry at 17.3%. Strangely, electricity, gas, steam, and air conditioning supply work showed the largest negative growth of 13.8%. This is odd in the context of the growing demand for construction and the associated mechanical and electrical work that service most buildings.

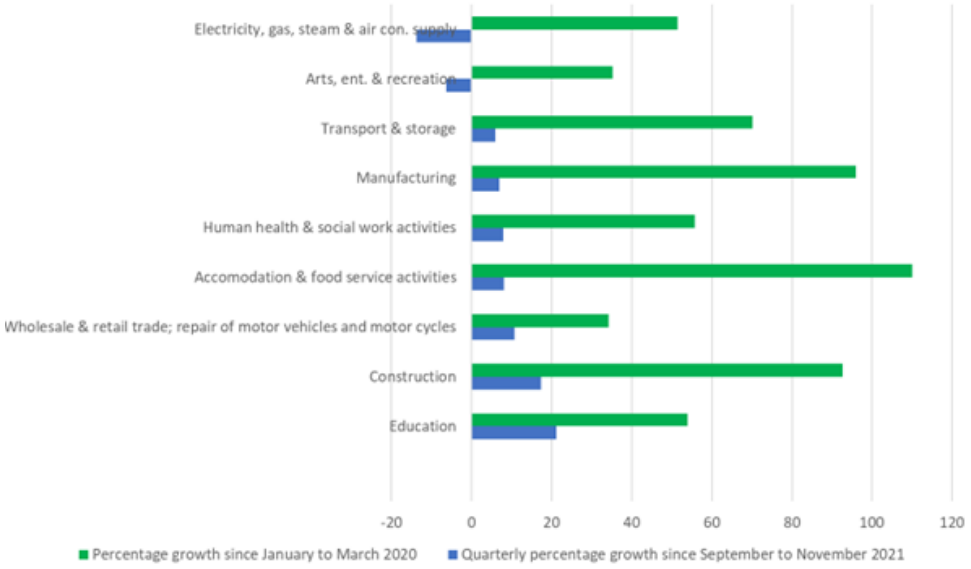

Figure. 4: Despite the rate of growth slowing between September 2021 to November 2021, most sectors recorded increases in number of vacancies, including construction (source; ONS)

On major construction projects, the project 'front-end' is crucial

Research shows that decisions made at the early stages of a construction project are highly influential on performance, culture, safety leadership and the delivery of wider benefits. For major infrastructure and construction projects, which account for £236bn whole life cost and £349bn of forecasted monetised benefits (36% of all major government projects) important 'front-end' considerations include:

- *Procurement* – 'setting the scene' for safety in the pre-contract phase

- *Contractual environment* – responsible contractual behaviour through the use of appropriate contracts to allocate risk, resolve disputes quickly and ensure timely payment

- *Outcomes* – a focus on societal value

Social value and complexity

The Public Services (Social Value) Act came into force on 31 January 2013, but it is only recently that government departments were mandated to use the 'social value model' to assess suppliers on the wider benefits achieved through public contracts. The elements of the social value model point to some of the most challenging and systemic issues facing the construction sector:

- Enabling post COVID-19 recovery, particularly in local communities
- Reducing economic inequality, including creating new businesses, jobs and skills, and increasing supply chain resilience
- Tackling climate change and reducing waste
- Driving equal opportunity, including reducing the disability employment gap and tackling workforce inequality Improving health and wellbeing and community integration

A note on methodology

This report is comprised of five packages of work; each characterised by a distinct methodological approach. For clarity, the relevant methods and methodology are described separately in each of the main sections of the report.
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Contents

Transmission risk, perception and safety leadership

Introduction

In the first section of this report, we evidence how understanding of risk and mitigation management practices across the construction value chain were implemented in the wider context of the hierarchy of controls, technology and COVID-19 related testing/vaccine practices.

In the methods section we outline the process for the work undertaken in literature review, quantitative and qualitative research. This includes a brief timeline to contextualise the findings in relation to both the previous KUBS1 project and the timeline of development of the COVID-19 pandemic.

The findings are presented against 6 key research questions covering transmission risk and perception and safety management within the construction context. Further sections reflect on how behaviours changed through the pandemic and highlight the key differences between the KUBS1 and KUBS2 reports.

Finally, the conclusion reflects on the overall learning from the findings which can be usefully translated to the construction context for action or further research.

Methods

This section outlines the methods of data collection and analysis used in each of the stages of literature review, quantitative survey data and qualitative interview data. The combination of the mixed methods adds validity to the process through triangulation.

We considered peer reviewed papers published on ScienceDirect and Emerald Insight. Inclusion criteria were papers containing variations of combinations of the terms ‘Construction’ and ‘COVID-19’ (COVID-19) and ‘risk minimisation’ and published since 2020. A Boolean search technique was used. The literature review followed the methods outlined in the following PRISMA diagram (Fig 5.).

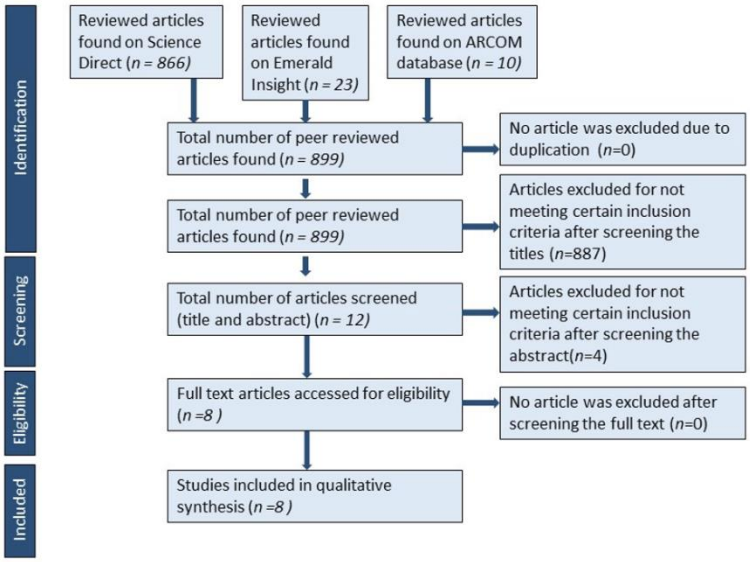


Figure. 5: PRISMA diagram of literature review methods

In total 8 papers were considered in-depth and included in the literature review findings presented.

An updated systematic approach to reviewing the literature provided a grounding for empirical data collection. The research team adopted a mixed-methods approach drawing on the strengths of integrating both quantitative and qualitative methods to give insight into the complex sociocultural situational context of construction work through the COVID-19 pandemic.

Quantitative data was collected from an online survey between November 2021 and January 2022. Both strategic and opportunistic sample approaches were taken to ensure a wide range of participants. Invitations to participate in the survey were distributed through a HSE newsletter and cascaded through 3 major tier 1 construction companies to their employees at all levels and to subcontracting firms.

The inclusion criteria for participation were people working in any roles in a construction company during the COVID-19 pandemic. A response rate is not valid since the survey was participation by open invitation. The quantitative survey collected a total of n= 590 responses. On analysis a number (n=93) were found to be less than 4% complete and removed prior to analysis. The full number of survey responses analysed is n=497. There were 84% male and 15% female participants (1% not stated). A total of 71% were in full-time employment, 3% part-time employment, and 26% self-employed: 47% with main contractors, 40% with subcontractors or suppliers (13% other). A total of 41% had supervisory responsibilities.

Participants were from a wide range of roles and organisations across the construction sector. Data was analysed using a range of statistical approaches using the software SPSS. The quantitative data collected gives broad insights into what happened across the sector which can be generalisable.

The qualitative data was collected through online interviews using MS Teams or Zoom through November 2021 to January 2022. The same inclusion criteria applied as above. Invitations to participate were cascaded through 3 major tier 1 construction companies to their employees at all levels and also to subcontracting firms.

The qualitative interviews were undertaken with 22 participants representing a wide range of roles and organisations. 23% (5/22) were female and 77% (17/22) were male. Participants represent a total of 11 organisations (3 x Tier 1 and 8 x subcontracting forms) and represent 7 health and safety roles and 15 others ranging from ‘on the tools’ roles such as ganger, through office roles such as planner and up to associate director.

Qualitative data analysis was undertaken using a thematic approach using NVivo for coding. 8 global themes emerged and within each of these three overarching organising themes. Beneath the organising themes are a range of 5-10 sub-themes.

The global and organising themes are presented in Fig. 6.

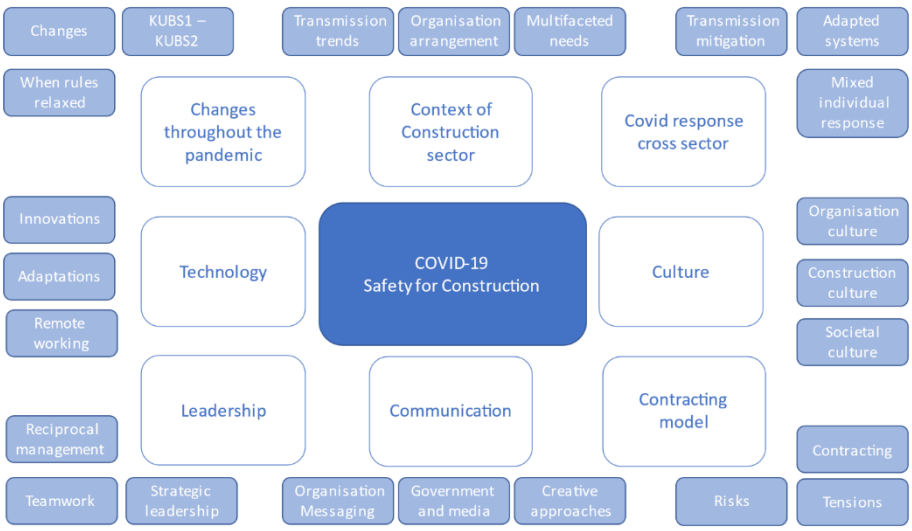


Figure 6: Thematic analysis summary of qualitative data collected in KUBS 2 WP2

The survey findings (n=497) are triangulated with qualitative interview data (n=22) affording the team an opportunity to explore diverse perspectives and relationships that exist in the layers of the multifaceted research questions.

Timeline

Table 1: COVID-19 pandemic timeline and 'Keeping the UK Building Safely' research stages.

Note: England used as basis of timeline with acknowledgement of variance by home nation in GB

Date	COVID-19 Pandemic*	KUBS Research
January 2020	Pandemic reported in China First 2 cases of COVID-19 in UK	
February 2020	23 cases of COVID-19 in UK (0 deaths)	
March 2020	Total UK cases of COVID-19 >10k Total UK deaths from COVID-19 1,789 **First national lockdown**	
April 2020	First national lockdown	
May 2020	Those who cannot work from home encouraged to return (but avoid public transport)	
June 2020	Phased re-opening of schools Non-essential shops re-open	
July 2020	Local lockdowns (Leicester) Powers to enforce social distancing	
August 2020	Eat out to help out More restrictions eased (theatres)	
September 2020	Rule of 6 Return to working from home	
October 2020	Second national lockdown	
November 2020	Second national lockdown	
December 2020	Second national lockdown (Tier 4 restrictions) Vaccine launched	KUBS 1 data collection
January 2021	Third national lockdown	Interviews and scoping review
February 2021	Third national lockdown Roadmap to recovery published	Interviews and scoping review
March 2021	Rules relaxed Children back to school	KUBS 1 reporting
April 2021	Rule of 6	

Date	COVID-19 Pandemic*	KUBS Research
May 2021	Indoor venues reopen	
June 2021	Vaccine accelerated	
July 2021	All restrictions lifted	
August 2021		
September 2021		
October 2021		
November 2021	Omicron variant	KUBS 2 data collection
December 2021	Government announces Plan B Face coverings compulsory	KUBS 2 data collection
January 2022		KUBS 2 data collection
February 2022	**End of all COVID-19 restrictions**	KUBS 2 data collection
March 2022		KUBS 2 data analysis and writing
April 2022		KUBS 2 data analysis and writing
May 2022		KUBS 2 reporting
June 2022		Close of KUBS

***Data from https://www.instituteforgovernment.org.uk/sites/default/files/timeline-lockdown-web.pdf / https://www.instituteforgovernment.org.uk/charts/uk-government-coronavirus-lockdowns**

Research questions

- RQ1: To understand the transmission risk perception and good / best risk management practice across different construction sites and activities

- RQ2: To understand the role of hierarchy of controls and testing / vaccination regime in effective transmission risk mitigation and in ensuring H&S outcomes

- RQ3: To develop insights into effects of COVID-19 and related risk management measures on employees' mental health, wellbeing, and safety compliance

- RQ4: To identify leadership attributes and good/best practice related to management of COVID-19 risks, managing the workforce remotely, and supporting employees' mental health, wellbeing, and safety compliance

- RQ5: To identify relationships between COVID-19 transmission risk perceptions (relative to other non-work-related activities), safety leadership and health & safety outcomes (e.g., safety incidents, wellbeing)

- RQ6: To develop insights into the impact of bio secure management on traditional H&S

- RQ7: To work alongside other researchers to identify and gather appropriate data to inform technology application and modelling

Findings & Discussion

Findings

Our findings generate further insights to those gathered in ‘Keeping the UK Building Safely; a scoping study’ particularly in relation to transmission risk and perception and safety leadership. Overall, our findings are broadly consistent with our earlier findings

This works adds significant value as a more in-depth and wide-ranging view of the construction industry as the pandemic changed over time. Where KUBS1 interview participants were broadly in H&S roles in Tier 1 companies the insights given into the early pandemic were from one particular position. The wide range of participants in KUBS2 both in the survey and the interviews enables a deeper look. The timing of the KUBS2 research allowed participants to reflect on a changing landscape of the pandemic.

The KUBS2 participants gave experiential insights into what worked, and what didn’t. Some participants described instances of practices far from the espoused best practice and these insights give useful learning opportunities. Participants shared their experience of working in the construction sector and told us that along with a culture of safe working are many sub-cultures which can support or constrain the safety process. There were some notable tensions in the relationship between tier1 (clients) and tier 2 organisations, between those working in site office and on site, and those who could work from home versus those whose job required them to physically go to work.

KUBS2 also offered interesting insights into the impact of government and media messaging, and societal behaviours, on workplace behaviours and safety. There were many contradictions between what people were asked to do for work and their behaviour off-site, increasing as restrictions were eased.

Literature Review

A table giving an overview of the main characteristics of each of the academic peer-reviewed papers is included in the literature review (see Appendix 1). Conducting the literature review identified a small number of studies relevant to this area, and an even smaller number based in the UK construction context – this identified a clear gap for the KUBS research.

The main findings of the papers reviewed have some clear overlap with the findings presented from the empirical data in the report. This included similarities with the

types of transmission mitigation approaches and their varying rates of success. Most examples of best practices were outside the UK and our work identifies the ways in which the UK contribute to global understandings of the cutting-edge work done in the construction industry during the pandemic.

Empirical data

Part A - Broad findings construction context

Within the broad construction context, different activities presented differing challenges. For example, there was perception of a big difference between risks between office-based site staff and 'on the ground' staff and between indoor / outdoor context. There was overall a perception of a lower level of risk in the outdoors but a higher level of potential control indoors.

The data showed that many working in construction, both indoors and on site, had to work closely to others despite the social distancing recommendations. Survey data showed high levels of working in close proximity, in particular in indoor environments. 66% of respondents (n=309) confirming they worked in close proximity in an indoor working environment and 52% (n=228) confirmed working in close proximity in an external working environment**.** There were many examples of distinction between different types of trade – some trades require closer working and present different challenges. Several participants noted the problem of lifting and carrying heavy items which required two people to be close together. Several participants noted difficulty in maintaining social distance at fitting out stage of project. Other participants remarked on the need to work in close proximity in noisy environments. Several participants remarked that the culture of site-based work in construction relied on team members being close by to look after one another, which was a hard habit to break.

Based on analysis of the survey data, there was a significant difference in perceptions of transmission risk based on working in close proximity (<2m) indoors ($t = 4.0$, $p < .001$), but no significant difference for those working in close proximity outdoors. There was also no significant difference in perceptions of transmission risk based on remote working vs onsite, or type of employer.

Based on analysis of the survey data, there were no significant differences in perceptions of safety climate, or safety leadership, based on working in close proximity (<2m) indoors, or outdoors. However, there were significant differences in safety climate perceptions based on remote working from home vs onsite, and type of employer (main contractor vs subcontractor / supplier). Those who worked remotely from home reported significantly higher safety climate perceptions (across

all scales on the survey) than those working onsite indicating they perceived a more positive safety working environment. Furthermore, those working for main contractors reported significantly higher safety climate perceptions than those working for subcontractors / suppliers (except for immediate supervisor subscale, where there was no significant difference). However, there was no significant differences in safety leadership based on remote working, or type of employer.

For wellbeing, the survey analysis showed that there were no significant differences based on close proximity of working indoors or outdoors, remote working, or type of employer.

Many participants explained the ways they adapted procedures to ensure they continued to work safely. Some participants suggested that procedures were rewritten to enforce the transmission mitigation measures whilst maintaining usual processes. Participants with responsibility for organizing work/staff groups on site reported on ways they adapted to controls using social distancing, cleaning and bubbles. Participants working in health and safety roles remarked on how their job role had to adapt to incorporate COVID-19 safety.

As outlined, there were a range of efforts at adapting systems and processes. The biggest problem identified by several participants was adapting processes to incorporate social distancing. This often required more space that was not available, or took more people to do the job, and therefore the job took longer and therefore cost more. On occasion this presented the challenge of being cost effective -vs- safe.

There was a distinction between the experiences of organisations operating at different ‘tiers’ of the construction industry and their adaptations. Tier 1 organisations manage sites but do not employ (many) staff who work directly on the (site) ground. Tier 2 organisations are sub-contracted to manage the work activities directly on the ground for Tier 1 (the client). Tier 3 and beyond are subcontracted to Tier 1 or 2 to directly deliver construction activities. Experiences varied between tiers. Those working in tier 1 companies suggested that best practice existed at the top tiers, reducing down, due to the availability of resources and expertise. As Tier 1 organisations work more remotely from the construction site there is evidence of their staff returning to site later than others. The risk related to the proximity to work sites therefore varied by tier of operation. Those working in Tier 2 organisations felt that they responded first with transmission mitigation measures and additional layers caused additional confusion or in one case, transmission risk. Those in management roles at tier 2 expressed some frustrations and regret at not returning to site work sooner recognizing this caused some resentment from those returning back to site more quickly.

Part B - Transmission mitigation approaches

There was evidence of a wide range of transmission mitigation approaches used by construction companies operating during the pandemic which are explored in this section. This includes both quantitative and qualitative data. Table 2 outlines the hierarchy of controls which we reflect on in this section of the findings.

Hierarchy of controls (Common terms)	**Description** (Usual application as part of a safety system)	**Control measures** (Application in relation to Covid)
Elimination	Physically remove the hazard	Not possible
Substitution	Replace the hazardous situation with a less hazardous situation	Remote working for office staff
Engineering control	Develop a solution to control hazard/ Isolate people from the hazard	Enhanced ventilation
Safe work practices	Develop strong rules and procedure	Enhanced cleaning regime Enhanced hand washing facilities Testing on site Vaccination on site
Training	Skills and knowledge reduce the likelihood of mistakes	Communication Adaptions to procedures and processes
Administrative control	Change the way people work	Social distancing Formation of work team bubbles Reduction of number of workers for specific tasks Staggered start and finish times Access restrictions to canteen, site, changing facilities Changes to shared accommodations
Personal Protection	Personal Protective Equipment	Face coverings

Table 2: Hierarchy of controls in construction COVID-19 context

The industry quickly moved to substitution measures. This primarily meant working from home where possible. Survey data showed an even split in that 49% of participants were able to work from home and 51% were not. Of those who were working from home, 34.3% reported it was a very low percentage of their overall time at work and 20.6% worked from home for a low percentage of the time whereas 20.6% worked from home for a high percentage of the time and 24.5% worked at home for a very high percentage of their time.

This demonstrated varying levels of ability to work from home reflecting the range of roles and activities and need for many people to be on site at least for part of the time.

This outlined the potential for a wide range of varied and often conflicting experiences by those working in different roles or locations in the same organisations. Working from home had a range of impacts with some feeling at greater risk because they had to go in rather than being able to work from home. There were also impacts on those working from home, and those managing remote workers.

Engineering Controls relates to the solutions devised to control the hazard or isolate people from the hazard. This focuses on approaches to enhance ventilation. Survey data showed that amongst our participants around half worked indoors for half of the time or less and half for more than half of their working time. Despite being potentially the most successful control measure only 38% of survey participants reported enhanced ventilation on site. This could be due to a number of those completing the survey were working from home, or already working in the open air. Interview participants accepted ventilation as important. Ventilation was recognised as important in all shared spaces, not just office spaces. Measures varied from opening windows to enhanced air conditioning through to investment in expensive new air filtration or purification systems. Some participants explained some difficulties to maintain ventilation in shared office environments. Ventilation, along with face coverings and social distancing, were reported as the most common mitigation measure. There was some concern about the benefits or risks of air conditioning systems. Some of the participants expressed an interest in understanding the air transmission model for COVID-19, to understand the validity of the hierarchy of controls.

Safe Work Practices relates to the rules and procedures designed to keep people safe at work. This includes cleaning, testing and vaccination. There was evidence of early, enhanced cleaning employed at all sites and this approach was maintained throughout. Many reported employing more cleaning staff and expecting all staff to be responsible for cleaning their own space whilst at work. There was evidence of provision of additional cleaning for those sharing tools and equipment outside the office. Many reported additional cleaning and hygiene responsibilities and tracking. Several participants reported a ‘touch point’ scheme identifying key points likely to be touched by multiple people and therefore identified for enhanced cleaning. There was evidence of provision of hand sanitisers for staff at all sites and for those on the move. One participant suggested that although sanitiser was offered to staff it was not always used.

There was evidence of contact tracing and support for COVID-19 testing as an approach to safe work practices. Several tier 1 and tier 2 companies reported

contact tracking in order to be able to contact trace in the event of an outbreak. Some organisations reported that contact tracing was reactive and helped them to understand transmission patterns. There was evidence that companies did not use the government track and trace but used their own systems. Individuals also resisted use of the government track and trace system.

Most organisations offered free lateral flow tests at the workplace. There was no evidence of compulsory testing apart from at airport facilities. There was evidence of mass testing in response to an outbreak that was successful in identifying further cases and was believed to have prevented more widespread transmission. This was a short-term mitigation measure used on two occasions in response to rising cases. Interview participants often represented the view that that cleaning, testing and contact tracing worked successfully as mitigation measures to make working practices safer.

Most interview participants were vaccinated (20/22) but a small number had chosen not to be vaccinated, some were willing to share their reasons and others preferred not to. There was evidence of companies encouraging all workers to be vaccinated by offering time off and information. Some interview participants discussed additional restrictions placed on those not vaccinated. Several participants spoke about the difficulties in tracking vaccination status of workers. There was a perception of some resistance / many site-based workers choosing not to be vaccinated and commitment to vaccines waning over time.

Training relates to the skills and knowledge gained and used to reduce the likelihood of mistakes. Survey data gave an interesting overview about safety management and training. This demonstrated a broadly positive reaction to training about safety issues. However, it is interesting to note the counter position that 17.6% did not agree that training covers situations workers encounter in their jobs, 20% did not agree that workers have sufficient access to training and 22% did not agree that workers receive comprehensive training in workplace health and safety issues. There was limited data about specific training initiatives in the qualitative data. Health and safety teams interpreted arising information and disseminated it through the company using a range of methods. Many interview participants referred to adapting standard health and safety communication methods to incorporate COVID-19 safety information rather than specific training.

Administrative controls relate to the solutions devised to change the way people work in order to keep them safe. This includes social distancing, work bubbles, staggered timings and shared accommodations. Although social distancing was in practice, the actual success rate reported was variable. Interview participants described creative use of bubbles for unavoidable close working. This included families and flat mates working in bubbles together and workers creating a bubble

with the machine they used. Some interview participants reported examples of transmission within bubbles. One interview participant described a large tier 1 company who were not working with bubbles as they believed it sent the wrong message. There was evidence of tier 1 organisations splitting office workers into teams working in bubbles in order to allow site-based office work to continue even in the event of an outbreak. Some sites tried to stagger timings. Many interview participants reported examples from their workplace of successful approaches such as staggering use of shared facilities and timings of breaks. Staggering start and end times for workers was implemented less widely and was more problematic. Although many organisations tried it at the start of the pandemic, it was dropped by all before the end of the research. Some sites could not move start and end times due to the location of the job. Managing staggered start times required additional security or marshalling staff. There was evidence of changes to shared facilities – along with the staggered timings outlined above there was evidence of additional space provision and changed processes for use.

All organisations used a range of face coverings and policies to encourage and enforce wearing of face coverings, in particular in shared spaces.

Some tier 2 organisations were more relaxed about wearing face coverings than tier 1 (clients). Some participants suggested that encouraging people to wear face coverings was difficult in outdoor contexts and could even comprise health and safety in some contexts. Some participants suggested that encouraging people to wear face coverings was difficult when societal rules relaxed. There was varied evidence about individuals' choice in relation to wearing face coverings with some choosing to always wear them, other choosing to never wear them and a range in between.

A number of transmission risks emerged which fell outside the workplace hierarchy of controls but represent significant learning measures. This includes commuting and travel and taking a dynamic approach to changes throughout the pandemic. Regardless of transmission mitigation measured undertaken at the workplace, most participants reported commuting as the major transmission risk during their working day. This was especially true of those working in London with limited alternatives to public transport. The nature of construction means that staff are frequently travelling to multiple sites and regularly across GB national boundaries which causes confusion when there are different rules in different countries. Working from home was utilised by all companies in response to the pandemic work from home order in March 2020.

As mentioned previously the rate at which workers returned to site depended on their organisational tier and role in the organisation. There was evidence of a dynamic response at each stage of the pandemic. In the first stages of the pandemic most organisations had to close down, then have as many people as possible working

from home, returning to site work as soon as possible as measures relaxed. Some organisations felt they took maximum precautions in the early days of the pandemic. Some organisations felt they could have done more. Measures were adapted as societal measures changed and relaxed. In the early stages of the pandemic there was evidence of creative problem solving and co-production of adaptation ideas at site level.

In relation to transmission perception, the evidence relates to adherence, outbreaks and perceptions of safety at work and relative changes throughout the pandemic. Adherence to work rules was reported by all organisations as generally high but weakening as rules relaxed later in the pandemic. Adherence is explored in further detail in relation to safety management and compliance later in the report. Evidence showed most interview participants felt safer at work than other places (in particular shopping, pubs and travel/holidays). However, there was a broad acceptance that nowhere is totally safe. There was evidence of a broad perception by most participants that transmission mitigation measures had been effective in preventing workplace transmission of COVID-19.

Table 3: Summary of data against hierarchy of controls

Elimination	Not possible.
Substitution	Working from home is possible for some but has affordances and constraints. Some work well and are productive but the reverse is true for others. Remote working can cause resentment due to the nature of onsite work required. Working from home can negatively impact mental health.
Engineering controls	Ventilation perceived as important and effective. Air purification and filtration used as well as opening windows and doors.
Safe working practices	Cleaning was embraced and effective. Cleaning enhanced at all sites and this approach maintained post-pandemic. Contact tracing and site spread; mass testing was effective but used minimally.
Training	Training was limited but significant evidence of using a range of methods of communication depending on situation with health and safety departments in an important interpreting and disseminating role.
Administrative controls	Most of the workplace adjustments were made in this category. Bubbles were helpful to contain transmission (but there was evidence of spread within bubbles). Split bubbles enabled continuation of construction projects in event of transmission. Some sites tried to stagger start and end times but with little success.
Face coverings	Use of face coverings in general mirrored use in general population, difficult to enforce and depending on changes in cultures.

There are significant correlations between safety climate subscales and the COVID-19 risk control measures, such that positive safety climate perceptions were

associated with reported use of the risk control measures. The use of face coverings, enhanced cleaning regime, enhanced handwashing facilities, hand-sanitisers, enhanced ventilation, reduced number of workers, and remote working for office staff, were all associated with perceived safety climate across all subscales.

The strongest correlations were between the perceptions of management safety values and management safety systems and the use of enhanced cleaning regimes. However, perceived safety climate was not associated with the use of work bubbles and vaccination onsite.

Of the safety climate subscales (correlation values in parenthesis):

- Management values correlates with all risk control measures (.10 to .25) except formation of work bubbles, testing onsite, and vaccination onsite.

- Immediate supervisor correlates with all risk control measures (.13 to .18), except social distancing, work bubbles, staggered times, and vaccination onsite.
- Communication with all risk measures (.12 to .23) except work bubbles, testing on site, and vaccination onsite.

- Training with all risk measures (.12 to .20) except work bubbles and vaccination onsite.

- Safety systems with all risk measures (.11 to .27) except work bubbles and vaccination onsite.

Similarly, safety leadership correlates positively all with risk control measures (.16 to .27), except the use of work bubbles and vaccination onsite. The strongest correlation was between safety leadership and an enhanced cleaning regime.

There are significant positive correlations between safety behaviours, for both safety compliance (.10 to .29) and safety participation (.10 to .26) for all risk control measures, except vaccination onsite, and work bubbles for compliance only. Safety behaviours (both compliance and participation) were most closely associated with the use of hand sanitisers.

Wellbeing correlated significantly with COVID-19 risk control measures (.11 to .19), except social distancing, formation of work bubbles, remote working of office staff, and ventilation onsite. The correlations with wellbeing (.11 to .19) were generally weaker than with safety-related variables. Wellbeing correlated most strongly with enhanced ventilation, use of face coverings, and enhanced cleaning regime.

Part C - Transmission perception

Table 4: Table of survey participants risk perception

Place	Percentage of respondents answering QUITE or VERY likely to the question 'how likely do you think it is for you to get infected with COVID-19?'
Generally	34.5%
At work	31.7%
At home	6.4%
On commute	29.7%
On public transport	55.2%
Social events	59.9%
Indoors	54.5%

Around a third of participants felt they were at risk of infection generally and a similar number felt a risk of infection at work. The lowest level of risk was recorded at home (6.4%) with more than half of participants feeling at risk of infection indoors (54.5%), on public transport (55.2%) and at social events (59.9%).

In relation to transmission perception in interview data, the evidence relates to adherence, outbreaks and perceptions of safety at work and relative changes throughout the pandemic.

Adherence to work rules was reported by all organisations as generally high but weakening as rules relaxed later in the pandemic. Adherence is explored in further detail in relation to safety management and compliance (research questions 3-5).

In relation to perception of construction as a COVID-19 safe working place, evidence showed the majority of interview participants felt safer at work than other places (in particular shopping, pubs and travel/holidays). However, there was a broad acceptance that nowhere is totally safe. There was evidence of a broad perception by most participants that transmission mitigation measures had been effective in preventing workplace transmission of COVID-19. This reinforced the perception of construction as a COVID-19 safe workplace by those working there. Fear was high at the start of the pandemic and reduced over time. There was evidence that transmission trends changed from early pandemic (limited spread) to later (wider spread). There was some evidence of changing perceptions later in the pandemic, in particular in relation to the spread around Christmas 2021 and the omicron variant. Many participants reported higher levels of spread and a perception that at this point in the pandemic it was somewhat unavoidable and lower risk than previous perceptions.

Organisation, construction and societal cultures all have impact on safety behaviours

Summary of response to Research Questions 1 & 2

RQ 1 – Understand transmission risk perception and good / best risk management practices across different construction sites and activities.

At the start of the pandemic there were many unknowns and across the board perception of risk was high. In the general population and some employees this waned over time. Outside factors impacting risk perception included growing knowledge as time passed by, changing government rules for society, media messaging and behaviour of those in government. After an initial relaxing of rules risk perception seemed to lower and stay lower.

Different sites in different areas of the GB nations required different rules which was difficult for large organisations to manage and enforce.

There was a perception that working outdoors in open air presented less risk than working indoors.

Everyone understood the risks of working closely but it was often required for the job to be completed. There were attempts at workarounds, such as using extended tools to carry heavy items, and projecting a two-metre light on the ground to ensure people worked apart. Where a workaround was not possible, and the job required two men in an enclosed space a bubble was used or created where possible. Teams of families or flatmates working together were useful.

RQ2 – Understanding the role of hierarchy of controls and testing/vaccination regime in effective risk mitigation and ensuring H&S outcomes

The hierarchy of controls lists elimination as an important transmission control measure, however in the context of Covid elimination is not possible.

Substitution was achieved with all companies' immediate response being for some staff to work from home, and by maintaining remote working where possible; however this had a range of impacts. Some felt at greater risk because they had to go in rather than being able to work from home, some felt at greater risk working indoors than those outdoors, and there were risks to mental health for those working remotely.

Ventilation was perceived as the next best control and there was evidence that the perception of risk was less working outdoors which helped workers feel safe.

Ventilation in offices had varying success depending on season. There was evidence of air filtration and purification devices.

Safe working practice is where the industry focused most mitigation measures such as cleaning and contact tracing. Training was limited.

There was also significant use of administrative controls such as social distancing, bubbles, staggered timing and changes to shared facilities.

Safety measures often cost additional money as they often took longer or required more people. Some tier 2 companies reported passing the cost on to the client, where the measures were insisted on by the client. Some tier 2 companies did not incur significant additional costs and were able to deliver to original costs. Tier 1 companies reported that they were absorbing additional costs within their company but maintained delivery of all key jobs to schedule.

D - Safety, working from home and mental health

This section relates to safety leadership and wellbeing of employees in relation to mitigation measures. This includes the needs of those working from home and overall compliance.

Survey data provided interesting insights into the general wellbeing of those working in the industry. The data demonstrates a workforce where the majority feel they have been dealing with problems well (70%) and thinking clearly (76%) most or all of the time. However, 16.5% have only been dealing with problems well about half the time and 3.1% feel they never deal with problems well.

In relation to working from home participants reported an increase in mental health support needs (potentially due to a lack of coping mechanisms in workforce population). There was widespread organisational emphasis on mental health and wellbeing for all with targeted support for those working from home. There were lots of examples of practical mental health approaches which are explored further below. On occasion there was an us-them culture between those working from home and those on site. Some people had negative experiences of working from home and others very positive experiences.

Compliance with site rules was generally high with some participants reporting no resistance and full adherence. There were examples of non-compliance (usually isolated incidents). Some reported non-compliance by their workforce in relation to the pandemic and vaccinations broadly. Most compliance required gentle reminding rather than enforcement. There was most difficulty in enforcing compliance on measures which reduced socialisation. Compliance waned over time. There was difficulty with compliance when reintroducing measures later in the pandemic after they had been eased. There was a suggestion compliance was higher in higher tiers. There was evidence of some creative approaches to buy in and compliance.

E - Leadership attributes and best practices

This section relates to leadership attributes and best practices in construction during COVID-19. This includes the needs of those working remotely and overall compliance.

Survey data gave an interesting overview about safety management with elevated levels of agreement that management emphasise and prioritise health and safety. This translated to direct safety support by supervisors, although at a slightly lower

rate than management. Data is broadly positive. There was some outlier evidence of supervisors not implementing best practice – for example 14% believe that their supervisor does not care how their work is done if there is no accident and 9.8% do not get positive feedback from supervisors for working safely.
There was evidence that some people work well from home and others do not therefore requiring differing levels of support. Different tasks such as working collaboratively on drawings were problematic. Many used MS teams and commented on how the pandemic sped up the transmission to digital working and especially meetings using Teams. This had impacts in terms of increased numbers of meetings, increased people attending meetings, increased attendance and punctuality. There was evidence that people used attending meetings on Teams as a way of being 'seen' to do their job. There was some evidence of flexible working after the pandemic to support emotional wellbeing based on evidence that showed people can work from home effectively.

There was evidence that some people felt their productivity increased when working from home. Some participants suggested an uptake in productivity for remote workers. Output efficiency was consistent or improved. It was faster to get responses. Decision making was easier with smaller teams / less people involved. Conversely there was some argument that productivity was negatively impacted when working from home depending on circumstances.

Participants suggested in interviews that working from home was frowned upon before the pandemic but is now more broadly accepted. Working from home enabled autonomous working but made teamwork more effort. Lack of face-to-face experiences impacted working as a team. There was evidence that some felt working on site was optimal, and presence important but it was difficult to quantify. This was especially relevant in the culture of the construction sector. There was evidence of specific support for people working from home. From a management perspective there was some difficulty in maintaining targets while people were working from home.

In terms of leadership approaches, leading by example was important. Leading by example was cited as the most important leadership approach by interview participants from each tier and type of work. Management, in particular those working in tier 2, recognised the importance of being visible on site. An important leadership role in both tiers related to the ability to be an enforcer of rules where necessary.

Clear regular and honest communication was a vital leadership skill. Many participants, both managers and other roles, suggested a need for a strong, supportive work network and to understand personal circumstances. Visibility in prioritising people and wellbeing at the top level of the organisation was perceived as

an important leadership role. There was evidence of positive feedback collected by organisations from staff about their mental health support.

There was evidence of a wide range of measures to support mental health of staff in all types of organisations. Many staff in tiers 1 and 2 were offered and used Employer Assistance programs. There was evidence of some creative approaches to support men working on site such as use of motivational speaker and male influencers which were very successful.

Managers were alert to issues and organisational messaging was delivered by and through managers. A personal response, listening and flexibility were important. Many had weekly check-ins with staff. This was specifically to address pandemic concerns and for most a significant change or increase from pre-pandemic practices. There were individual case study examples of how the pandemic had impacted individuals' mental health and the types of leadership support needed.

As previously highlighted, compliance was achieved through a combination of communication, setting examples and reinforcement. Enforcement was rarely needed but used where required. The sector wide safety culture in construction supported adherence.

F - Relationships between transmission risk, leadership and outcomes

There were complex relationships identified between transmission risk, leadership and outcomes, which was reflected in both the qualitative and quantitative data.

The role of H&S dept was vital and had overlap with HR role as people were unsure where to access support they needed and as this was an unprecedented situation. The H&S department usually became the interpreter between government advice and organisational communication.

As previous sections highlighted, all participants emphasised the need to lead by example. Visibility and clear communication were vital. Survey data gave an interesting overview about safety management and communication. This demonstrated an overall positive and open approach to communication about safety issues.

There were some challenges in managing remote workers. Regular contact and openness and a people first empathic approach was important. The leadership role had an increased focus on wellbeing and sense of community. At the same time leadership had responsibility for enforcement and adherence. Compliance levels were broadly high.

As highlighted in sections A & B there were a range of efforts at adapting systems and processes. The biggest problem identified was adapting processes to incorporate social distancing, which required more space that was not available, took more people to do the job, took longer and therefore cost more. This presented the challenge of being cost effective -vs- safe.

Survey data gave an interesting overview about safety procedures. Whilst most agreed with positive statements and around 80% or more felt there were sufficient safety procedures, it is interesting to note the 15-20% who did not agree that procedures and practices were safe. By contrast there was evidence that a high proportion of individuals felt their own practices were safe (more than 90% in response to 3 questions). Furthermore, a high proportion actively promoted safety at work.

There was a natural elevation in sickness levels (pay) because of COVID-19 and isolation requirements. There were varying levels of other types of sickness than normal. Some workers were perceived to take advantage of sick pay for isolation.

There was evidence of a range of impacts on safety incidents reported by health and safety managers. It was broadly reported that major incidents were reduced but there was some rise in minor incidents. Whilst there was minimal evidence for the rise in minor incidents, there was some suggestion these may have been situations arising from safety challenges in meeting COVID-19 safe practices. For examples one health and safety manager in tier 2 reported at least 3 incidents directly related to people trying to lift and move things on their own because they were too nervous to ask for help in case they were coming into distance with people. Some suggested a decrease in safety incidents initially but an increase in safety incidents when numbers on site increased and also when rules relaxed (linear). There was some suggestion that compliance fatigue contributed to an increase in incidents over time.

Generally, new COVID-19 safety practices soon became integrated with other normal construction safety practices and absorbed within the construction safety culture, although exceptions to this were identified (see Appendix 3).

Analysis of the survey data showed that the perceived likelihood of being infected with COVID-19 was significantly correlated with all work safety climate subscales. Correlations were -.14 to -.22 across subscales ($p<.001$), the strongest correlation with safety training subscale. There were also significant correlations with getting COVID-19 compared to other persons with all work safety climate subscales (-.10, $p<.05$, to -.15, $p<.01$), with the strongest correlations being safety training and immediate supervisor subscales. There were no other significant correlations with questions about the likelihood of being infected with COVID-19. Thus, having a positive work safety climate was associated with perceptions of lower likelihood of infections at work (but this did not extend to getting COVID-19 infection, at home, or in other situations) and, in comparison to others. Example correlation tables are included in Appendix 2.

Similarly, positive safety behaviour, specifically participation (rather than compliance), was also significantly negatively correlated with getting infected at work (-.14, $p<.01$), compared to others (-.13, $p<.01$), and on the commute (-.10, $p<.05$), but no other infection questions. There were no significant correlations with safety compliance behaviours.

The survey data also highlighted the significant role of safety leadership in relation to perceived likelihood of COVID-19 infections. The analysis showed that there were significant correlations with getting COVID-19 at work (-.21, $p<.001$) and compared to others (-.16, $p<.001$), but no other questions. Thus, constructive safety leadership in a work context was associated with lower perceptions of vulnerability to COVID-19 infection in the workplace – again, this reflects a specific work context, and does not extend to infections in other situations (such as generally, or at home). Safety leadership was also positively correlated with safety behaviours in the workplace, including compliance (.62, $p<.001$) and participation (.67, $p<.001$).

Wellbeing had significant negative correlations with perceived likelihood of getting COVID-19 at work (-.11, $p<.05$) and indoors vs outdoors (-.14, $p<.01$), but no other infection questions. This indicates that better wellbeing is associated with lower perceived risk from COVID-19. Wellbeing was also positively related to safety leadership (.38, $p<.001$), compliance (.34, $p<.001$) and participation (.35, $p<.001$).

G – Culture and communication

This section provides insights into culture and communication during the COVID-19 pandemic and how they impacted work in the construction sector.
There was widespread evidence, amongst a wide range of participants, but in particular those in health and safety management roles, of a perception of a strong safety culture in the construction sector and that COVID-19 measures built on the existing safety culture. Some suggested risks were dependent on the type of work undertaken within construction with those needing to work in close contact at the highest perceived levels of risk.

Organisational culture was also important. Tier 1 participants reported they felt a safe culture due to the expertise and investment at their level of operation. COVID-19 safety required planning and leadership. Existing organisational safety practices, behaviour management training and approaches were useful background to build COVID-19 practices upon. COVID-19 safety became integrated into new ways of working, especially in tier 1 but also in tier 2. COVID-19 safety became normalised within routine safety practices. There was evidence of a reciprocal approach with organisations mostly taking ‘people first’ approaches. These included open conversations and including lower tier staff in decision making – co-production of new processes / adaptations. There were challenges to enforce compliance using either reward or enforcement or a combination of both. Respect and potential personal impact were used as drivers of compliance. There was some effort at monitoring. Other aspects of culture of working in construction were discussed including ‘male’ culture, a drinking and social culture, working away from home and an ‘old-fashioned’ culture, all of which impacted on measures and success. Compliance was often linked to wider challenges of societal culture.

Communication was vital during COVID-19 and impacted on safety leadership. Communication had to be targeted at different levels of audience. H&S and managers played an interpreting role based on government guidance (simplifying and disseminating). There was evidence of a need for alignment of messaging between government, client, contractor and workers. Consistency was vital for strong messaging. Some felt government messaging was clear and helpful and others did not. Confusing advice / leadership impacted large companies or individuals operating in more than one GB nation. Some blamed changing government guidance for society noncompliance which filtered into working practices. Leading by organisational messaging was important and it was important that communication was reciprocal between workers and management. A wide range of communication techniques were used including briefings, newsletters, videos, infographics and messaging on company systems / phones / apps. There was evidence of two-way

communication – both from the middle up to seniors (and shareholders), and also from middle management down to ground. Communication was cascaded through managers (black hats) and traditional safety mechanisms such as toolbox talks. Techniques such as visual representation and signage were useful. Balance was required – it was important not to bombard / over-brief, too many meetings / too many lines of communication. Sometimes communication was perceived as reactive rather than proactive.

Summary of response to Research Questions 3-6

RQ3: To develop insights into effects of COVID-19 and related risk management measures on employees' mental health, wellbeing, and safety compliance

Employee wellbeing in construction during COVID-19 was variable, and often dependent on context of work and job role. Most employees in construction thought they were coping well, but a small percentage admitted they were struggling with dealing with problems during the pandemic.

People working from home in the construction industry had a wide range of experiences including both negative and positive. There were risks to mental health for all but in particular those working from home. Organisations recognised this and responded with a wide range of support mechanisms from routine check-in calls through to specially organised events. On occasion there was perceived to be an 'us-them' culture between those working remotely and those working on site.

Compliance with site rules was reportedly high although there were a wide range of examples of non-compliance. In some instances, compliance required reminders, (such as sending people home who should be self-isolating), and on other occasions required enforcement, although this was reportedly not common. The most difficult rules to encourage workers to comply with were related to social distancing and many suggested this was because of a culture of close working and looking after your workmates which is prevalent in the construction industry. Compliance reduced over time through the pandemic.

RQ4: To identify leadership attributes and good/best practice related to management of COVID-19 risks, managing the workforce remotely, and supporting employees' mental health, wellbeing, and safety compliance

Research participants suggested that they perceived the key effective leadership attribute was leading by example. Being visible was perceived as important, in particular at tier 2. Confident encouragement and enforcement were important in relation to managing safety compliance.

Communication, in particular reciprocal, was vital to managing the remote workforce and regular check ins and empathy were the key to supporting mental health and wellbeing. Communication had to be targeted at different levels of audience. H&S and managers played an interpreting role based on government guidance

(simplifying and disseminating). There was evidence of a need for alignment of messaging between government, client, contractor and workers. Consistency was vital for strong messaging. Some felt government messaging was clear and helpful and others did not. Confusing advice impacted large companies or individuals operating in more than one nation in GB, which is common in the industry.

Views on remote working varied with some perceptions that working remotely increased productivity and others suggesting that productivity was decreased for those working remotely. Working remotely on tasks which required shared access to visual stimuli (such as site drawings) was particularly difficult. From a management perspective there was some difficulty in maintaining targets while people were working from home. Participants suggested in interviews that working from home was frowned upon before the pandemic but is now more broadly accepted.

Microsoft Teams was a useful tool for communicating remotely and used widely.

Generally, new COVID-19 safety practices soon became integrated with other normal construction safety practices and absorbed within the construction safety culture, although exceptions to this were identified (see Appendix 3).

RQ5: To identify relationships between COVID-19 transmission risk perceptions (relative to other non-work-related activities), safety leadership and health & safety outcomes (e.g., safety incidents, wellbeing)

There were complex relationships identified between transmission risk, leadership and outcomes.

The role of H&S dept was vital and had overlap with HR role as people were unsure where to access support they needed and as this was an unprecedented situation. The H&S department usually became the interpreter between government advice and organisational communication.

Safety leadership was also positively correlated with safety behaviours in the workplace, including compliance. Constructive safety leadership in a work context was associated with lower perceptions of vulnerability to COVID-19 infection in the workplace.

Perceptions were that levels of compliance were broadly high. Where perceptions of risk were low and adhere low then there was a perception that higher levels of encouragement and enforcement required from management.

RQ6: To develop insights into the impact of bio secure management on traditional health and safety

There was evidence of a range of impacts on traditional health and safety reported by health and safety managers.

It was broadly reported that major safety incidents on site were reduced but there was some rise in minor incidents often due to compliance with safety measures. For example, the wearing of face coverings often made communication difficult and on occasion caused a safety risk.

Whilst there was minimal evidence for the rise in minor incidents, there was some suggestion these may have been situations arising from safety challenges in meeting COVID-19 safe practices. For example, one health and safety manager in tier 2 reported at least 3 incidents directly related to people trying to lift and move things on their own because they were too nervous to ask for help in case they were coming into distance with people.

Some suggested a decrease in safety incidents initially but increase an in safety incidents when numbers on site increased and also when rules relaxed. There was some suggestion that compliance fatigue contributed to an increase in incidents over time

H – Technology

This section is predominantly provided as contextual data to support further work in technology and modelling but also to underpin the data reported on transmission mitigation measures. A range of technologies were reported during interviews, summarised in the Table 5. These include technologies for social distancing, contact reduction, ventilation and remote working.

Social distancing	• Proximity apps / watches • 2-meter light projectors
Contact reduction (touch points)	• Temperature gauge / gun on sign in • No touch (sensor) hand wash sinks • Colour change bacterial clean door handles • PDAs / no touch technology • Retails to fully online process • Converting fingerprint to facial recognition for sign in
Ventilation	• Air filtration and purification devices
Remote working	• Teams / online tools • Phones / apps / portal • Video headsets / virtual site tours

Table 5: Technologies were reported during interviews

Recommendations

From the research undertaken and responses given by participants about their experiences of working in construction during COVID-19 we can make some broad recommendations specifically relating to COVID-19 but also relevant to the management of potential future pandemics. While these may not be applicable across the whole industry, they provide useful insights and potential for experiential and vicarious learning.
We can make the following recommendations in relation to transmission mitigation measures and risk perception:

- Emphasise the existing culture of safe working in construction and link COVID-19 risk controls to existing safe working guidelines.

- Recognise the potential for tension and differences in working practices between different tiers and provide clear guidance to employees of safe working in the context of COVID-19 risk.

- Acknowledge different risks between indoor/outdoor working and home/onsite and give guidance in relation to such risk and working practices as applicable

- Acknowledge and address areas where close working and social distancing is difficult to maintain / enforce.

- Allow and encourage employees to report concerns and promote best practice and potential solutions as applicable.

- Build on the safety and ‘looking after each other’ culture that exists on site and emphasise the need to do this in relation to COVID-19 rules as well as traditional safety rules.

- Draw on and share examples of best practice across organisations / tiers to build knowledge of what worked / didn’t work.

- Ventilation is perceived as important, ensure good messaging is provided about ventilation measures in different activities / sites as appropriate.

- As above for cleaning, testing, contact tracing.

- Acknowledge concerns of employees relating to risk outside of the workplace and provide good guidance (e.g., from external sources) on risks and risk mitigation measures being implemented, for example in public transport.

- Understand that compliance to rules will change over time and is linked to general perception of risk overall. Reinforce messaging as appropriate to maintain focus on risk in workplace and the need to ensure this risk is being managed.

- Appreciate that risk control measures can be associated with safety climate perceptions and wellbeing. This reinforces the need for explicit risk controls and good messaging, communication etc.

We can make the following recommendations in relation to safety leadership:

- Continue to place emphasis on mental health support, and target it appropriately to different groups, e.g., working from home / on site.

- Continue with provision of mental health support shown to be engaged with, e.g., EAPs.

- Understand the need to lead by example and show visible leadership to influence compliance with safety rules.

- Be aware that regular and honest communication from leaders is important to get employee buy in.

- Consider creative messaging to engage with groups / subcultures where compliance may be lower, e.g., through the use of motivational speakers / male influencers.

- Keep good levels of contact with employees to monitor compliance and wellbeing.

- Understand the likelihood of compliance fatigue over time and design messaging and support to emphasise the need to ‘protect each other.’ Explicitly address and discuss compliance fatigue and the implications of this with employees.

- Integrate COVID-19 safety with existing construction safety practice to normalise the required ways of working at any given time.

- Recognise that good safety leadership is essential with regard wider compliance.

- Design and implement communication methods for targeting at different groups as appropriate.

- Seek to simplify and disseminate clear organisation rules based on government guidance, where possible make messages short and easy to understand.
- Ensure communication methods are two-way and allow for back-and-forth communication.

Conclusions

In conclusion the experiences of those working in the construction context during the COVID-19 pandemic offer useful and interesting insights and lessons to be learned for the future.

A wide range of transmission mitigation measures were used to prevent outbreaks of COVID-19 at work, and these were broadly well received, and compliance was high. The perception of risk was very high at the start of the pandemic and reduced over time.

Safety leadership employed a range of tactics to support the workforce, both on site and those working remotely. The construction industry quickly adapted to allowing more flexible working which for many is a benefit that will remain beyond the pandemic. There were a wide range of examples of strong leadership and communication and in particular support for mental health and general wellbeing with a focus on putting the people first.

A range of technologies were employed for social distancing, contact reduction, ventilation and remote working.

Broad recommendations were made based on the data collected from the experiences of those who worked in this unique context.

The KUSB2 research project contributes a rare insight into the COVID-19 pandemic through the eyes of the construction industry workers in the UK.

Transmission modelling

Introduction

In ‘Keeping the UK Building Safely: A scoping study,’ we established that the construction industry faces significant challenges in accurately identifying the high-risk transmission areas of COVID, and several evidence-based control measures have been implemented to alleviate the risks. This was buttressed by the fact that all the sampled contractors showed evidence of regular acquisition of COVID-19 related data (e.g., test results, number of positive cases, and contact tracing) and construction site data (e.g., the scale of the site, site layout, and work schedule through data captured in Building Information Modelling (BIM)), as well as trying different epidemic prevention measures on construction sites. However, simulation and modelling techniques had not been widely used to systematically analyse the collected data, make predictions about the high-risk transmission areas, and identify the most effective combinations of measures to manage the transmission risks. As a result, the industry found it challenging to optimise its decision-making processes regarding the management of COVID-19 control measures. The main reasons for the lack of uptake captured during interviews with sector representatives during KUBS1 were insufficient skills and knowledge, and cost concerns. However, the sampled contractors still recognised the potential benefits of simulation and modelling for managing the transmission risk. They also indicated their willingness to widen the application of simulation and modelling techniques, provided that such techniques were cost-effective, visual, interactive and easy to use. In addition, based on the literature review conducted during KUBS1, the potential integration of agent-based modelling (ABM) and Susceptible-Exposed-Infectious-Recovered (SEIR) model was identified as a means to incorporate population heterogeneity, duration of contacts and site layout into the modelling work.

Aims

Considering the challenges and needs of the industry, the study aims to build capacity and knowledge for the industry on how to effectively use simulation and modelling techniques to manage the transmission risks of infectious diseases on a construction site. To achieve this aim, the study developed and tested a proof-of-concept model to showcase the potential of integrating ABM and SEIR modelling approaches in an interactive and user-friendly manner, to simulate the dynamics of COVID-19 (delta variant) transmission and the epidemiological effects of various protective control measures, including social distancing, face covering, vaccinations rate, ventilation, and isolation with the consideration of population heterogeneity (e.g., age, vaccination status and household size), duration of contacts and site layout. Yet, the model does not aim to provide absolute transmission risk estimation. All the variables used in the model can be modified based on the unique site control

measures, demographics, layout as well as the transmission rates of different variants.

Methods

This section was divided into the following five parts (A-E):

- Part A provides a brief overview of the concepts of SEIR and ABM modelling.
- Part B defines the various components of the integrated ABM-SEIR model as well as their interactions.
- Part C illustrates how primary (from real-life construction sites) and secondary (based on well-established parameters within academic literature) data were collected. This part also describes details of the exact types of data, their quantities and justifications for selection of individual classes, so as to facilitate the creation of representative components, environments and their interactions within the integrated model.
- Part D details the modelling platform.
- Part E details the control scenario selected to run the model
- Part F describes how the created integrated model was shared with industry professionals to evaluate its utility

Part A: An overview of SEIR and ABM

SEIR (Susceptible-Exposed-Infectious-Recovered)

SEIR (Susceptible-Exposed-Infectious-Removed) models are widely used epidemic models for depicting the transmission dynamics of infectious diseases. It is a mathematical modelling technique in which the disease status of the population is assigned to compartments of Susceptible, Exposed, Infectious, or Recovered. The flow patterns of how people progress across the different compartments are indicated in the order of the labels SEIR, as shown in Fig. 7 Consequently, people are initially at the susceptible (S) stage which designates the fraction of a population that can contract the disease. This stage is then followed by being exposed (E), representing the fraction of the population that has become infected but is still not infectious. The infectious (I) stage accounts for a fraction of the population that is capable of spreading the disease. Finally, the recovered (R) stage denotes the fraction of the population that has recovered from the disease, thereby returning to the susceptible (S) stage after the immune period. Considering that the epidemic included multiple waves over several years, with new variants of the virus frequently emerging, previous infection to an earlier variant may only convey partial immunity, Therefore, people who have recovered are likely to become susceptible again after a period of time. Many studies within the existing body of knowledge have developed or adapted SEIR model to estimate the reproductive number, understand the pattern of epidemic spread, and predict the magnitude and duration of a pandemic [9-15]. However, those equation-based models are often used for large populations (e.g., countries and cities) and have the drawbacks of not being able to incorporate population heterogeneity into the individual level (e.g., age, gender and vaccination status), compliance with different protective measures (e.g., social

distancing and face covering) and variation of contact duration, which are essential for estimating the spread of COVID-19.

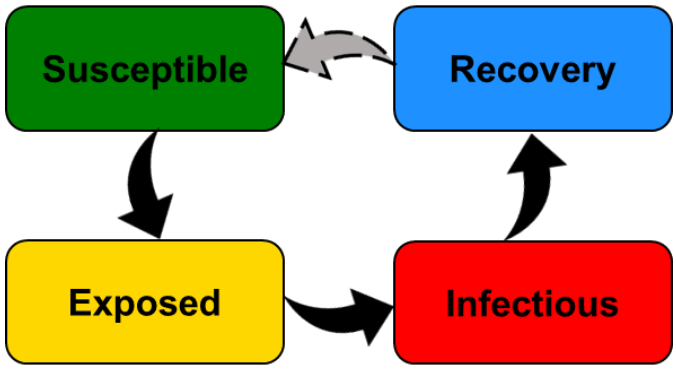


Figure 7: SEIR model flow

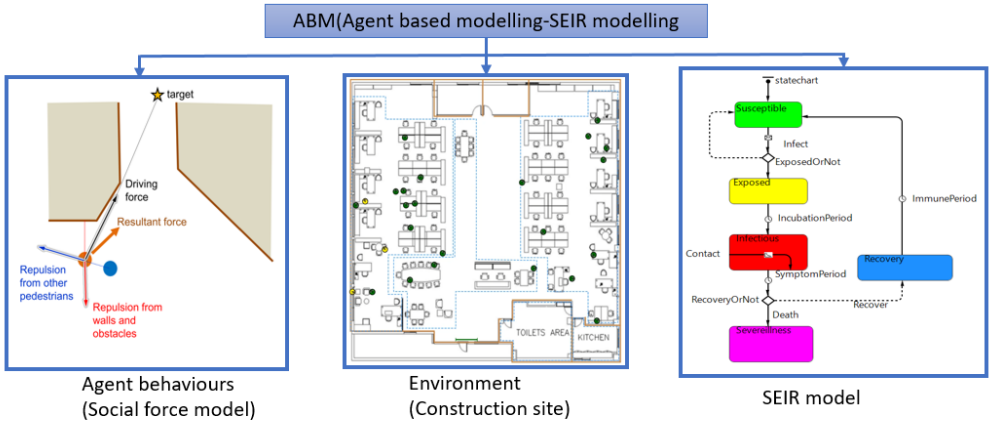
Agent-based modelling

Agent-based modelling (ABM) is a computer simulation technique that allows the creation, disappearance, and movement of a finite collection of interactive individuals or agents with unique attributes regarding spatial location, physiological traits, and/or social behaviours. ABM functions on a bottom-up basis, with population-level behaviour emerging from the interactions between individuals and their environment. ABM could be used to predict the spread of COVID-19 in time series and then evaluate the impact of different interventions on epidemic outcomes (e.g., [16], [17]). As a result, it could help identify the most effective interventions as well as optimise various combinations to support decision making. Although ABM has been widely used for construction industry-related research, such efforts have been mainly directed towards the premise of simulating actual construction activities (e.g. [16] and [17]). The key advantages of ABMs are that they can stimulate complex social interactions, individual and collective behavioural adaptation, and different intervention measures [18]. In addition, the agents' interactions and outputs of those interactions can be easily adjusted and visualised by users.

The integration of ABM and SEIR

Since WP3 aims to simulate the transmission risk on a typical construction site with about 250 workers, this size and scale are relatively small when compared with the differential equation based SEIR compartmental modelling at a country or city level. When using SEIR compartmental models for large populations at a country or city level, the individual differences (e.g., age, gender, household size and vaccination status), contact history, and the physical boundary could be less critical to the transmission risk as those differences could offset each other due to the size of the population. Therefore, using SEIR compartmental models to model the transmission of a large population may be sufficient, although it assumes that the population is

homogeneous in the individual level (e.g., age, gender and vaccination status) and physically or geographically static (i.e., no change in contacts). However, this assumption is difficult to justify when modelling a small population such as those on typical construction sites, owing to individual effects not easily offsetting one another due to significantly smaller population sizes. Under these circumstances, ABM, an individual-based simulation model, was chosen and used in WP3 as the core technique. Yet, to incorporate how individuals migrate across the different transmission stages of COVID-19, each individual is modelled according to their own "SEIR" state in terms of severity and time spent in that state. Furthermore, the model simulates how individuals interact with each other (i.e., contact duration and frequency), based on work schedules and social distancing rules, which makes the individuals physically or geographically dynamic (i.e., change in contacts) in the model. The individual SEIR state is changed accordingly (refer to section 3.3.4 for details). To sum up, WP3 created an integrated ABM and SEIR model to simulate the transmission risk on a typical construction site. Fig. 8 summarises the described integrated modelling approach adopted here.



Agent behaviours (Social force model) | Environment (Construction site) | SEIR model

SEIR	ABM-SEIR	How to
Large population	Small population	The transmission of Covid-19 is determined based on contact. Specifically, infectious agents can infect others only within a certain distance (e.g., 2 meters)
Homogeneous	Heterogeneous	The agent properties such as age, gender, vaccination, household size, number of children that may have an impact on Covid-19 transmission will be included into the model.
Static	Dynamic	Social force model, agent daily schedule and physical boundary are included to simulate agent behaviour in a certain physical space(e.g., a construction site)

Figure. 8: An integrated ABM and SEIR model

Part B: Model components and their interactions

The integrated ABM-SEIR model includes three elements: 1) agents, 2) interactions between agents, and 3) interactions between agents and their environment.

Agents

Agents represent the construction workers working on site. Based on the previous studies [19, 20], worker attributes including age, gender, household size and number of children within each agent's family, vaccination state and whether wear a face covering were incorporated into the model, owing to their established effects on COVID-19 transmission risk.

Environment

The environment is a construction site that includes the main building site (i.e., ground floor) and welfare facilities (e.g., toilets, meeting rooms and clock rooms) outside of the main building site (as shown in Fig.8). The rationale behind selecting the ground floor and welfare facilities as the primary focus for this model is based on the fact that all workers on the construction site must pass through the ground floor to reach their respective workplaces on other floors, as well as need to use the welfare facilities at some point during their shifts. This research assumes that workers are sparsely spread when working on other floors and it is more likely that the COVID-19 transmission takes place when workers are gathered on the ground floor (due to close proximity). This research mainly depicts the capability and potential of the proposed modelling method; thus, the environment has been simplified in the model. It is however worth mentioning that the model was developed such that new information at varying levels of complexity can be easily incorporated as they become available.

Transmission between agents

The COVID-19 transmission dynamic was simulated through interactions, i.e., contacts, between agents. There are three main worker behaviours that could affect the transmission risk: 1) maintaining social distancing [21], 2) wearing face coverings [21], and 3) getting vaccinated [22]. To prevent the spread of COVID-19, social distancing refers to maintaining a prescribed level of physical distance between people [21]. For example, individuals need to keep two meters apart. A face covering is something that safely covers the nose and mouth (e.g., wearing a mask) [21]. The COVID-19 vaccines currently approved for use in the UK are: Moderna, Oxford/AstraZeneca, Pfizer/BioNTech, vaccines. Research [22] has shown that vaccines help reduce the risk of getting seriously ill or dying from COVID-19, the risk of catching or spreading COVID-19, and protect against COVID-19 variants. Different types of vaccines have similar effectiveness, but different number of doses (i.e., 1 dose, 2 doses, a booster dose) have a great impact on the vaccines' effectiveness [20, 22-25] The data used in this study were mainly drawn from reports on the Delta variant, because it was the most prevalent at the time of study.

Interactions between the agents and the environment

Agents (i.e., construction workers) move around different parts of the construction site, based on their work schedules under pre-pandemic working conditions. Site areas (i.e., specific working zones and welfare facilities) are very prone to clustering,

which brings favourable conditions for transmission of the virus. Therefore, site areas need to be carefully considered in the model. Isolation strategies have also been considered in the model. According to previous studies [26, 27], ventilation affects the spread of disease to a large extent. Therefore, availability of ventilation on the site was also mimicked in the model. More extensive details about ventilation and isolation are provided in Part C

Part C: Model development and data collection

Definition of the simulation environment

The construction site information considered for this study is the site size, site layout, and ventilation state.

Site size and layout

The representation of the construction site in the model (i.e., ground floor of the main building and 3-floor welfare building) is shown in Fig. 9. The site is a construction project site in the United Kingdom. The size of the site is about 110 metres × 85 metres and as shown in Fig. 9, the solid brown line represents the walls, while the blue dotted line represents the specific working areas. In general, the solid green line represents the entry and exit but more specifically, the solid green line at the corner represents the entry and exit of the construction site. However, the solid green line in the centre of the building represents the entry to and exit from other floors in the main building. Light green marks represent specific functional modules. The L-shaped welfare building has three floors, to simplify the representation, three identical blocks are displayed at the front of the site. Because the building is still under construction, only the exterior and load-bearing walls inside the building were modelled.

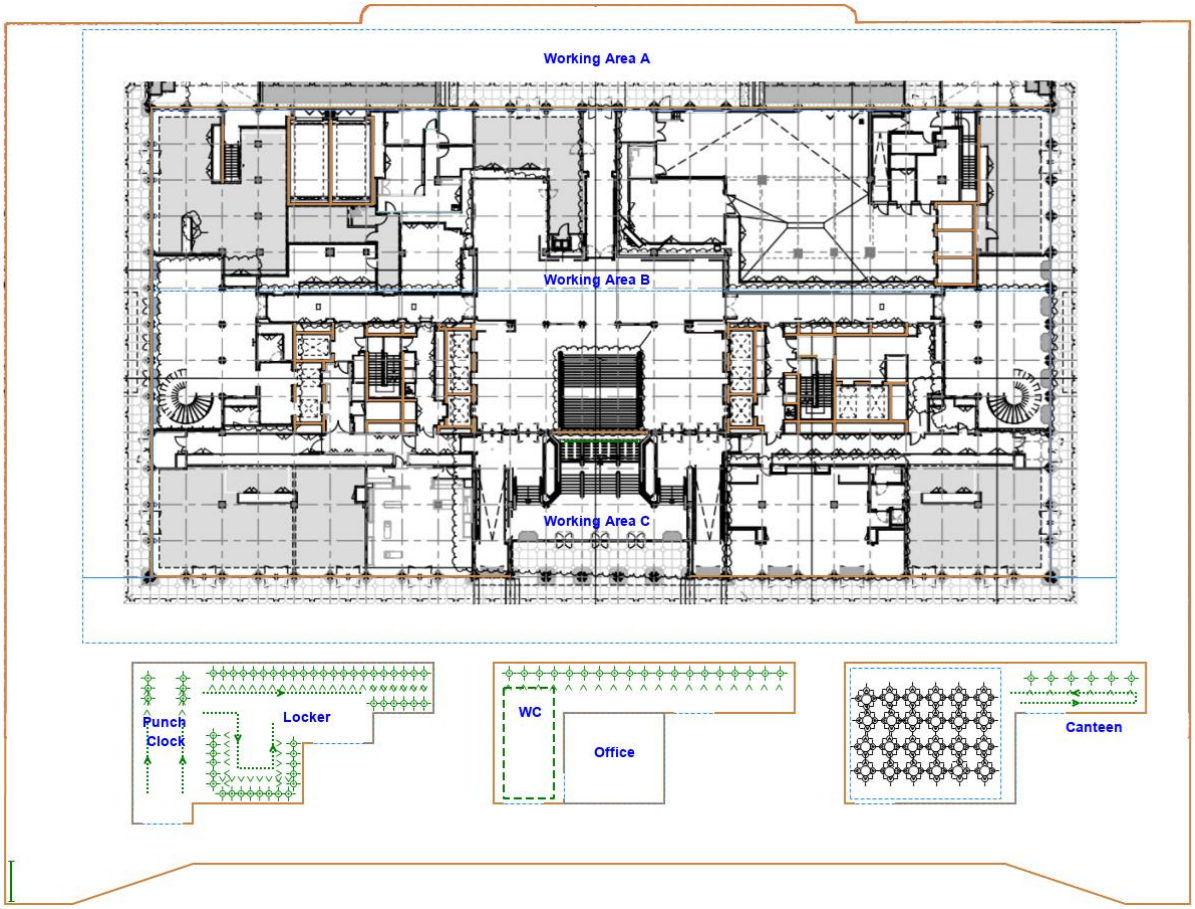


Figure. 9. Construction site layout in model

Site areas

The ground floor of the main building was divided into three working areas, named A, B and C according to the work schedule provided by the contractor. Several site areas were placed on the three floors of the L-shaped welfare building, including punch clock, locker, office, WC, and canteen.

Ventilation state

The model considers several different ventilation conditions, including outdoor, indoor with ventilation and indoor without ventilation. The parameter named weight for ventilation state is introduced in the model to modify the virus transmission ability in different ventilation environments. In this model, the ventilation state is simplified into two states, good ventilation (100-350 m3/h per infector and 1200-4000 m3/h per infector for 0.25 h and 3 h of exposure, respectively) [26, 27] or bad ventilation (nearly no ventilation), and affects the entire construction site.

Defining the properties of the agent

To define the agent properties used in the model, an online survey was deployed at one of the construction sites of the industrial partners in February 2022, with a return of 175 valid responses from a population of 250 workers. The outcomes of the responses were then used to update the values of the agent properties within the model. Table 6 summarises the agent properties including the total number of agents, age, gender, household size and number of children within the families of individual agents, vaccination status, previous COVID-19 infection status and the use of face coverings.

Table 6. Properties of agents

Properties of Agents	Distribution	Value
Total number	-	100
Age (Youngest, Mode, Oldest)	Triangular	(20, 34, 60)
Gender (Male%: Female%)	Bernoulli	(95: 5)
Household size (Min, Max, Mean, Shift, Stretch)	Poisson (truncated)	(1, 10, 3, 0, 1)
Number of children in family (Min, Mode, Max)	Triangular	(0, 0, 10)
Infection status (Infected%: Not infected before%)	Bernoulli	(5: 95)
Vaccination (None%: 1 dose%: 2 doses%: 3 doses%)	Discrete probability	(27: 5: 31: 37)
Face covering (Wearing%: Not wearing%)	Bernoulli	(73: 27)

Note：Information in the table were based on self-reported survey of construction workers in Feb 2022

Defining the interaction rules

The interaction rules were guided by the process-centric model related to the work schedule, the social force model embedded in ABM, the isolation strategies and the interactions between agents (individual SEIR model) are described as below

Work schedule

Based on the four-week work schedule obtained from the participating contractors for February 2022, a process-centric model has been developed to simulate the logic of workers' behaviour and movements, as shown in Table 7. In addition to the work schedule provided by the contractor, we have made some reasonable assumptions based on the general working conditions across most construction sites in the UK. For instance, our model depicts that workers are onsite between 9 am to 5 pm every day and take their lunch breaks from 12 pm to 1 pm. The work schedule also indicates 100 workers on the site (including workers within the interior and exterior site locations). More specifically, there are 10 workers each in areas A and B; 9 workers in area C; 5 workers in the office areas. The remaining 66 workers are engaged in different activities across the other floors of the building. In general, workers are required to visit the clock and locker rooms as soon as they arrive on

site, prior to the commencement of any construction tasks. Workers will randomly choose a workplace (including area A, area B, area C, office in welfare facility, and workplaces on other floors) at the beginning of each working period, and continue to work from 30 to 60 minutes as one working period. Every worker is assumed to have a 25% chance of needing a short comfort break for toilet (typically lasting for 1-20 minutes per break) after every working period. If workers choose not take short toilet breaks, they will continue to work for another working period. After taking a short toilet break or long lunch break, workers will continue to work for another working period until the end of stipulated working time (i.e., after 5 pm). The summary of time spent within each site area is shown in Table 7, while the logic flow chart of workers' actions and movements on site is shown in Fig. 10.

Table 7. Duration at work locations

Work Locations	Distribution	Duration (Minutes)
Working Areas	Uniform	30-60
Office	Uniform	30-60
Punch Clock	Uniform	1-3
Locker	Uniform	2-15
WC	Uniform	1-20
Canteen (ordering and queueing)	Uniform	2-10
Canteen (eating and drinking)	Uniform	20-40

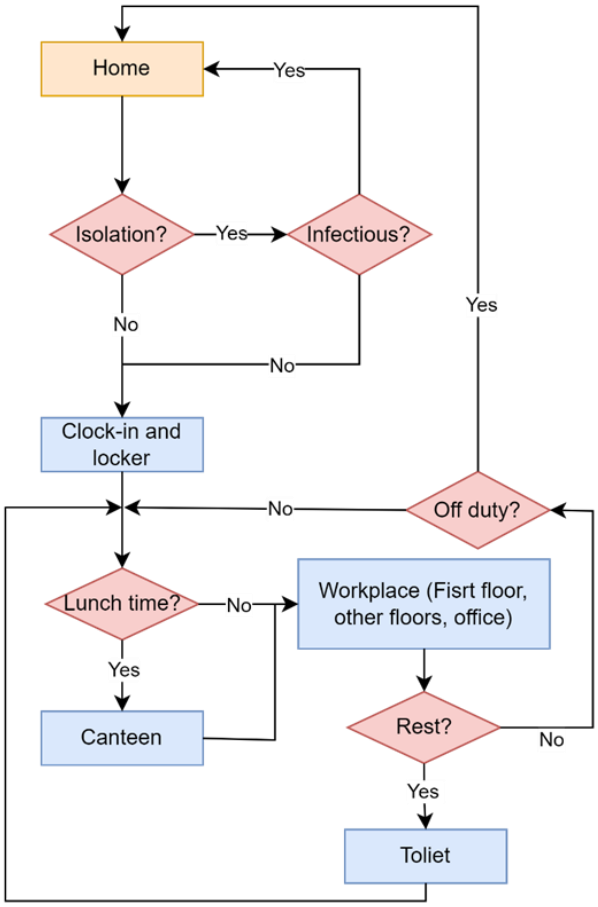


Figure. 10. Logic flow chart of workers' actions and movements on site

Social force model

The social force model (SFM) depicted below was embedded in ABM to guide the movement of agents against obstacles such as walls and other people as well as reaching target destinations within the shortest possible distances. Although the original literature [20] around SFMs is based on the term pedestrians, we have replaced pedestrians with agents in this study for the purpose of better inclusivity and uniformity. The concept of SFMs was first proposed by Helbing and Molnar [28] to represent the motion of agents. SFM indicates that the movement of agents can be represented as if they were experiencing certain "social forces" which are not necessarily caused by their personal environments, but rather, a representation of the internal drives of the agents to execute specific actions related to their movements around predefined areas. The physical force vectors that drive such movements are referred to as social forces [20]. The concepts and representations of social forces are well-established but in order to enhance the understanding of this report without necessarily consulting additional literature, a summary of the three force vectors is also shown here as the driving force $\vec{f}_i^0$, inter-agent force $\vec{f}_{ij}$ and boundary force $\vec{f}_{iw}$. According to Newton's second law of motion, the corresponding expression of each agent i is shown in Equation (1) and the diagram is shown in Fig 11:

$$m_i \frac{d\vec{v}_i(t)}{dt} = \vec{f}_i^0 + \sum_{j(\neq i)} \vec{f}_{ij} + \sum_w \vec{f}_{iw} \quad (1)$$

Where m_i is the mass of agent i, and $\vec{v}_i(t)$ is the walking velocity at time step t.

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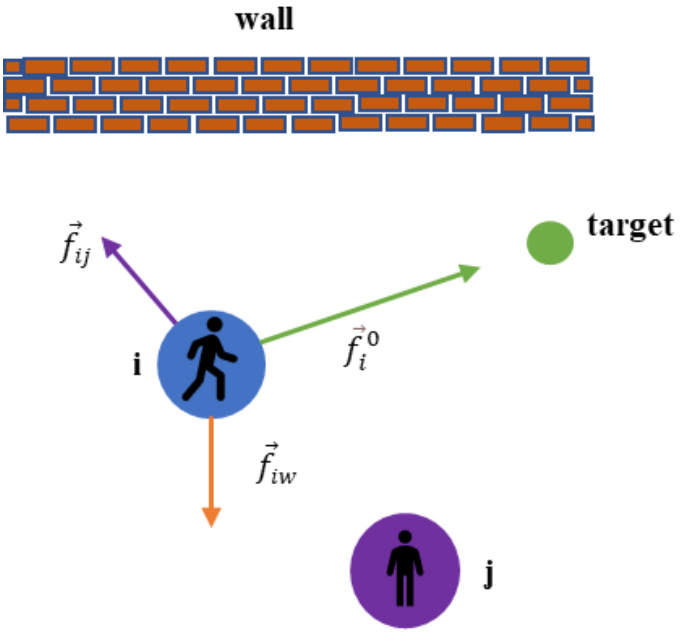


Figure 11. Diagram of the social force model

a) Driving force

The driving force $\vec{f}_i^0$ indicates the intention of the agent to reach a target, based on the desired speed v_i^0 and desired direction $\vec{e}_i^0$. The driving force is represented in Equation (2):

$$\vec{f}_i^0 = m_i \frac{v_i^0(t)\vec{e}_i^0 - \vec{v}_i(t)}{\tau_i}, \qquad (2)$$

where $\vec{v}_i(t)$ is the agent velocity at time step t, and τ_i is a characteristic time scale that reflects the reaction time.

b) Inter-agent force

Inter-agent force is comprised of socio-psychological force $\vec{f}_{ij}^s$ and physical force $\vec{f}_{ij}^p$. The socio-psychological force describes the psychological tendency of two agents to keep a certain safe distance between each other, while the physical force indicates the physical contact between agents within crowded environments. The corresponding expressions are shown in Equations (3) and (4):

$$\vec{f}_{ij}^s = A_i \exp\left(\frac{r_{ij} - d_{ij}}{B_i}\right)\vec{n}_{ij}, \qquad (3)$$

$$\vec{f}_{ij}^p = kg(r_{ij} - d_{ij})\vec{n}_{ij} + \kappa g(r_{ij} - d_{ij})\Delta v_{ji}^t \vec{t}_{ij}, \qquad (4)$$

where A_i, B_i, k , κ are constant parameters. $\vec{n}_{ij}$ is the unit vector pointing from agent j to agent i. $\vec{t}_{ij}$ is the unit tangential vector and orthogonal to $\vec{n}_{ij}$ and $\Delta v_{ji}^t = (v_j - v_i) \cdot t_{ij}$ is the tangential velocity difference.

c) Boundary force

T
he boundary force is similar to the physical force of inter-agent and the mathematical expression is shown in Equation (5)

$$\vec{f}_{iw} = A_i \exp\left(\frac{r_i - d_{iw}}{B_i}\right)\vec{n}_{iw} + kg(r_i - d_{iw})\vec{n}_{iw} + \kappa g(r_i - d_{iw})\Delta v_{wi}^t \vec{t}_{iw}\,, \qquad (5)$$

where d_{iw} is the distance between the centre of agent i and the surface of walls. The specific parameters of the SFM considered in this study are specified in Table 8.

Table 8. Parameters of the social force model.

Parameter	Symbol	Value
Agent radius	r	0.25 m
Strength of social repulsive force	A	2000 N
Characteristic distance of social repulsive force	B	0.08 m
Coefficient of sliding friction	k	240000 kg m^{-1} s^{-1}
Body compression coefficient	κ	120000 kg s^{-2}
Agent reaction time	τ	0.5 s

Isolation strategy

Isolation strategy is another protective control measure applied in the integrated model. The isolation strategy within this model places a checker point before a worker goes to work daily. If a worker is adjudged to be in an infectious state, based on the outcomes of the individual SEIR model calculations (refer to Section 3.2.4) before the commencement of the day, then such an agent must remain in an isolation state within their home for 14 days. Those workers who enter the infectious state from the exposed state in the middle of their work will continue to work on site until the next day, so as to simulate the real-life self-examination strategy of workers before the next day's work.

Individual SEIR model

The SEIR model for individual agents was developed based on specific attributes, especially the duration of interactions and workplace protective measures. Hence, the completion of the SEIR stages by each agent is bound to be different as further clarified by the following explanations:

The susceptible state consists of agents who may become infected. The exposed state is however characterised by agents that have received a certain load of the pathogen but not yet infectious or symptomatic. On the contrary, the infectious agents are those currently afflicted with the disease and can infect other agents; while agents in the recovery stage have overcome the disease and gained some levels of immunity. The modified SEIR model is shown in Fig 12, which is also a representation of the transitions between different states for an individual (S→E→I→R).

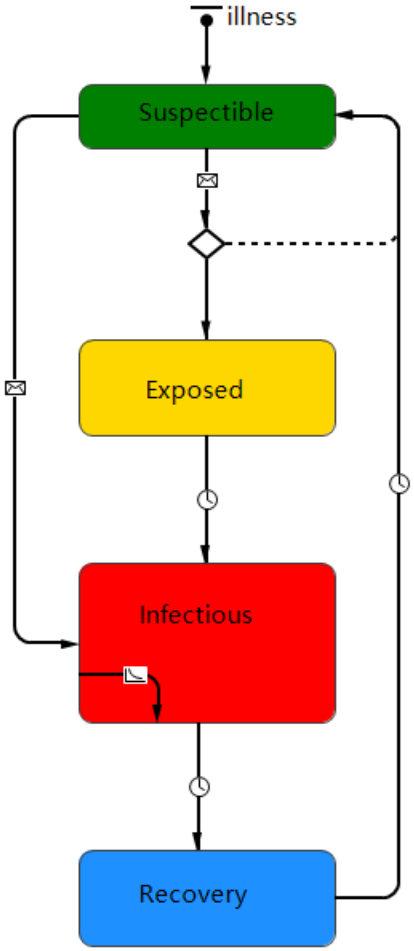


Figure. 12. The state chart of SEIR model

S → E: The state transition from susceptible to exposed happens when a susceptible agent comes into close contact with an infectious agent. Each infectious agent has an infection range, and if another agent comes within their infection range, then they are in close contact. The state transition from S to E is considered based on the transmission probability β. Hence, the probability of disease transmission β_{ij} from agents i and j is influenced by agent properties, behavioural attributes, and environmental attributes represented by Equation (6) and the list in Table 9.

$$\beta_{ij} = \beta_0 \prod_{n=1}^{6} a_n^i + \beta_1 \prod_{n=5}^{7} a_n^i \, a_8 \quad (6)$$

The equation of transmission probability of each contact is comprised of two components- agent background and close contact. Agent background describes the vulnerability of an agent towards COVID-19 before entering the workplace. For instance, an elderly person from a high-density community, or a multi-children family without vaccination is regarded as a highly vulnerable agent. Each time he/she will have a higher probability of getting infected when in close contact with an infectious agent. Close contact represents the probability of getting infected when in close contact with an infectious agent. The probability of close contact is a function of the resistance to a virus (e.g., vaccination state, face-covering).

Table 9. Properties of disease

Parameter	Description	Initial value	Range	Relevant Reference
β_0	Local infection rate	0.0568		[29]
a_{i1}	Weight for age	1	0.37 – 1	[19]
a_{i2}	Weight for gender	1	1 – 1.2	[19]
a_{i3}	Weight for household size	1	1 – 2.23	[19]
a_{i4}	Weight for number of children	1	1 – 2.58	[19]
a_{i5}	Weight for vaccination status	1	1 for not vaccinated, 0.67 for 1 dose, 0.15 for 2 doses, 0.06 for 3 doses	[22, 24, 25]
a_{i6}	Weight for infected or not before	1	0.8 – 0.93 for infected, 1 for not infected before	[30]
a_{i7}	Weight for face covering	1	0.174 for face covering, 1 for non-face covering	[21]
β_1	Workplace transmitting rate per minute of contact	0.5	can assume a range between 0 to 1	[31]
a_8	Weight for ventilation state	0.29	0.001 – 1	[26, 27]
σ	Incubation period	4 days	4 days – 6 days	[32]
γ	Symptom duration	10 days	8 days – 24 days	[32]
ξ	Immune duration	3 months	3 months –	[33]

	13 months

E → I: The state transition from exposed to infectious upon the completion of the incubation period σ of the disease, starting from the instance of exposure.
I → R: The state transition from infectious to recovery upon the completion of the symptom duration γ.
R → S: The state transition from recovery to susceptible happens upon the completion of the immune duration ξ.

With specific reference to the model, agents at the infectious (I) stage will continue to send out one “infection” message per minute to all agents that are within a 2-meter radius. Although messages are sent to all the agents that are within close proximity of the infectious agent, however, only agents in the susceptible (S) state will react to the messages by transiting into the exposed state, which is based on the probability of β that is estimated as depicted in Equation (6). Fig.13 illustrates examples of the transitions between S to E.

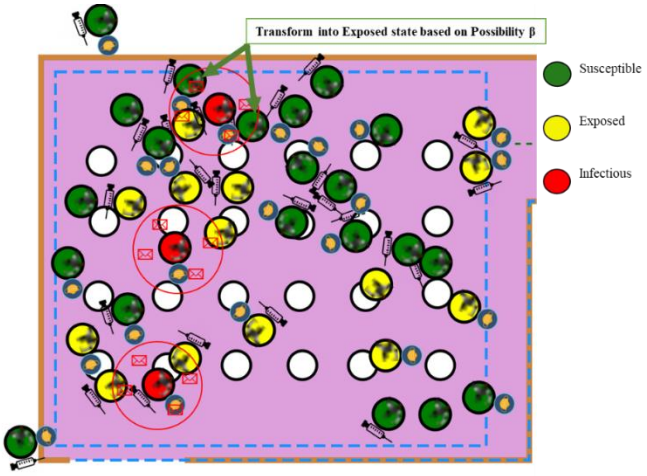


Figure. 13. The COVID-19 transmission mechanism

Part D: Modelling platform

The ABM-SEIR model was constructed using AnyLogic platform (version 8.7.10). It is a multi-agent modelling software for creating a professional virtual prototyping environment and simulating discrete, continuous, and mixed behaviour of complex systems.

The user interface of the ABM-SEIR model for simulating COVID-19 transmission risk on a construction site is presented in Fig. 14. A safety control measure (SCM) panel was integrated into the interface to allow users to pre-set the SCM scenario according to their needs.

Figure. 14. The user interface of the proposed ABM-SEIR model.

Figs 15-17 illustrated the graphical user interface (GUI) of the proposed ABM-SEIR model comprised of 3 components: 2D model, 3D model and activity flowchart. Fig. 15 was the main 2D interface of the proposed model, Fig. 16 presented the 3D animation of the simulation and Fig. 17 showed logic flow chart of the agent activity. A navigation bar was designed at the top of each component for users to switch

between the components and the model total running time was integrated into the bar as well.

The CAD drawings of the construction site (i.e., ground floor layout) were designed at the left top of the main interface as shown in Fig. 15. The green, yellow, red and blue dots represent the agent in susceptible, exposed, infectious and recovery states, respectively. (COVID-19 state transformation was explained in Section 3.2.4) Agents with face covering or vaccinated got corresponding icons as shown in the bubble. As an indicator of the high-risk area, the population density was also considered when simulating the COVID-19 transmission risk. Areas or work zones are in green or pink to represent low-risk or high-risk area, respectively. The colour changes from green to pink if the room density is higher than the pre-set density threshold and vice versa. From top to bottom, the graphical outputs on the right side were the number of agents in different SEIR states, the exposed agents based on different SCMs and the density of each room on the construction site, respectively. The control panel was embedded, allowing users to interact with the model during running. Apart from the SCM panel, the properties of COVID-19 were also allowed to adjust to fit other infectious diseases and therefore maximise the generalisation capability of the proposed ABM-SEIR model.

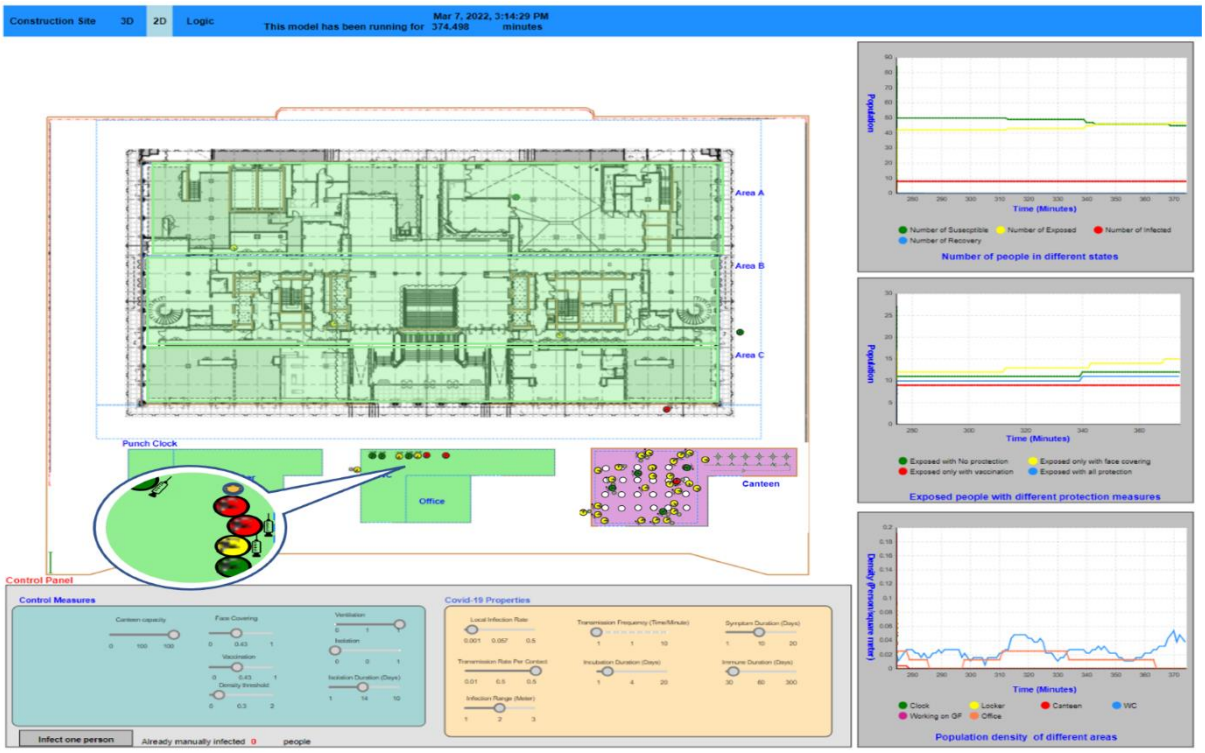


Figure. 15. The main 2D interface of the proposed model

The 3D animation of the simulation illustrated in Fig. 16 enabled the user to develop an intuitive and straightforward understanding of the interaction among agents as well as between agents and environment. A coloured dot was assigned to each

agent to imply his/her Covid state and a face covering, or injector icon would appear if the agent was with face covering or vaccinated, respectively.

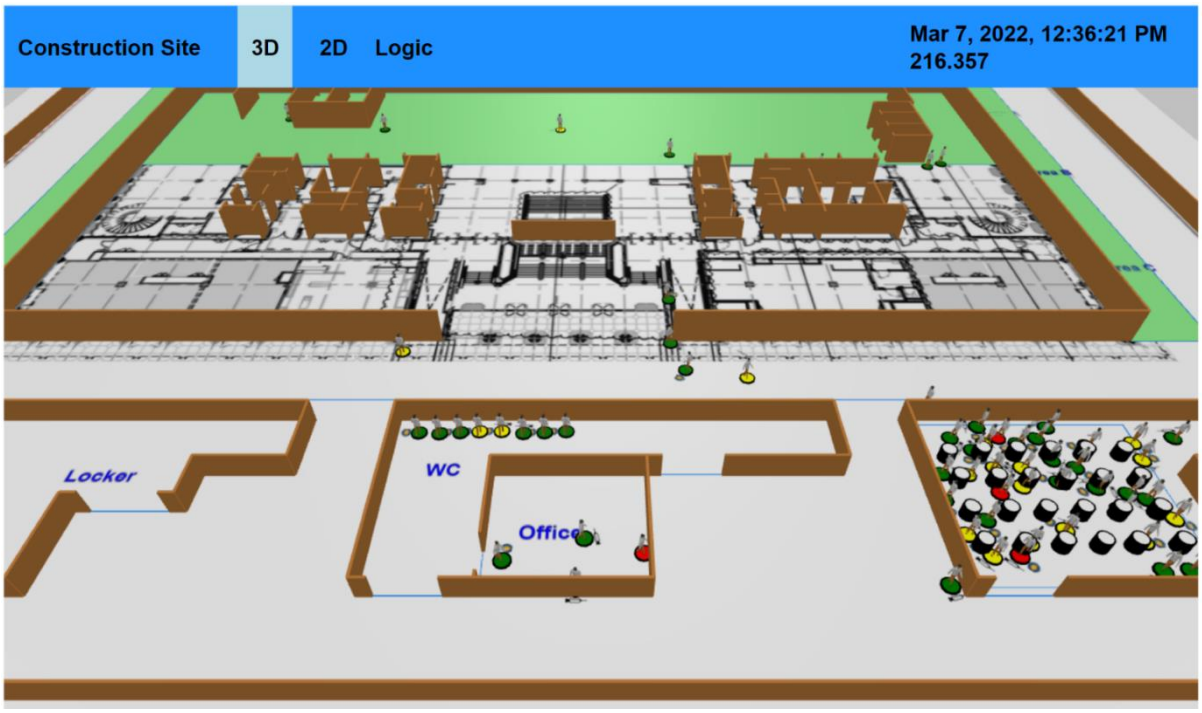


Figure 16. 3D animation of the simulation

The logic flow chart in Fig. 17 not only indicated the work schedule of the agent, but it also functioned as a counter of the traffic of each room. As shown in the speech bubble, each green block recorded the number of people entering and leaving this block as well as the current population in the block.

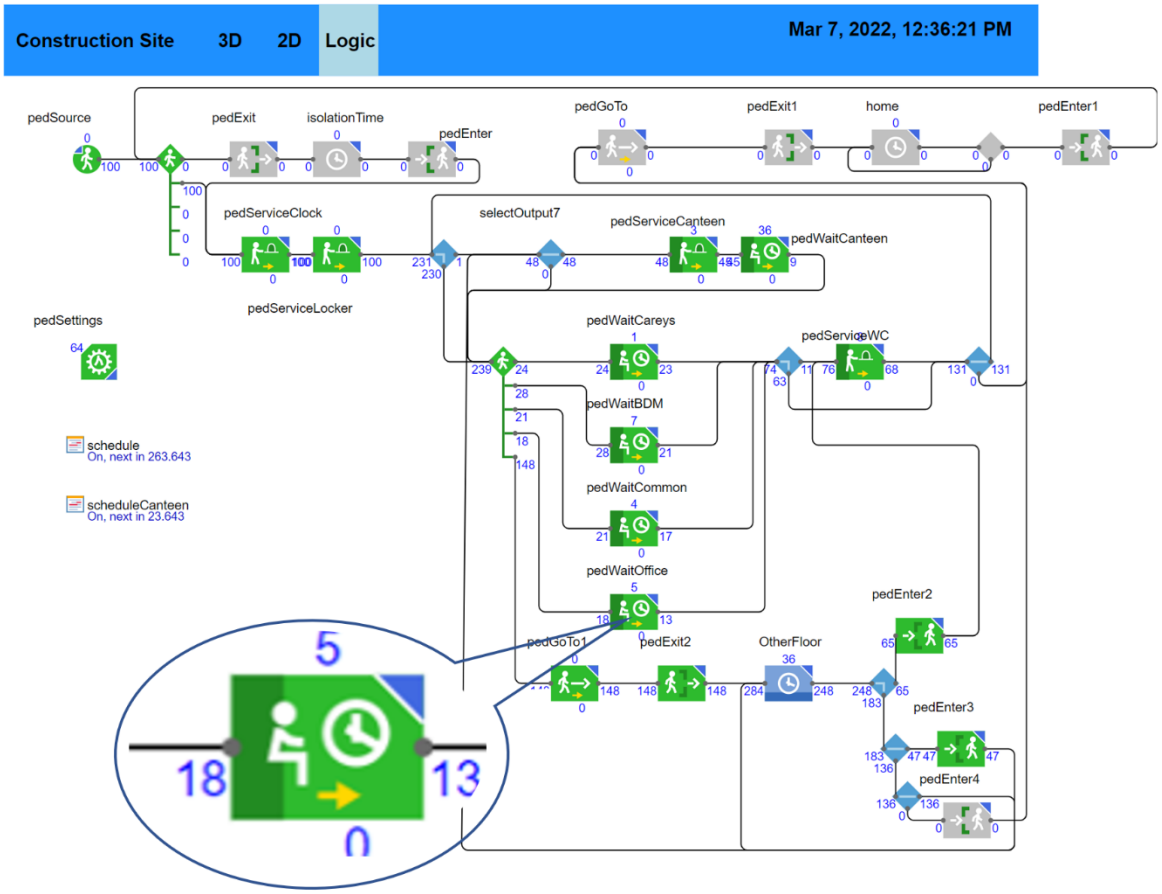


Figure 17. the logic flow chart of the agent activity

Information about individual agents was provided during simulation running period. In the proposed model, the user can get access to the state chart and property of each agent as depicted in Fig.18. The state an agent is currently in was highlighted with red box.

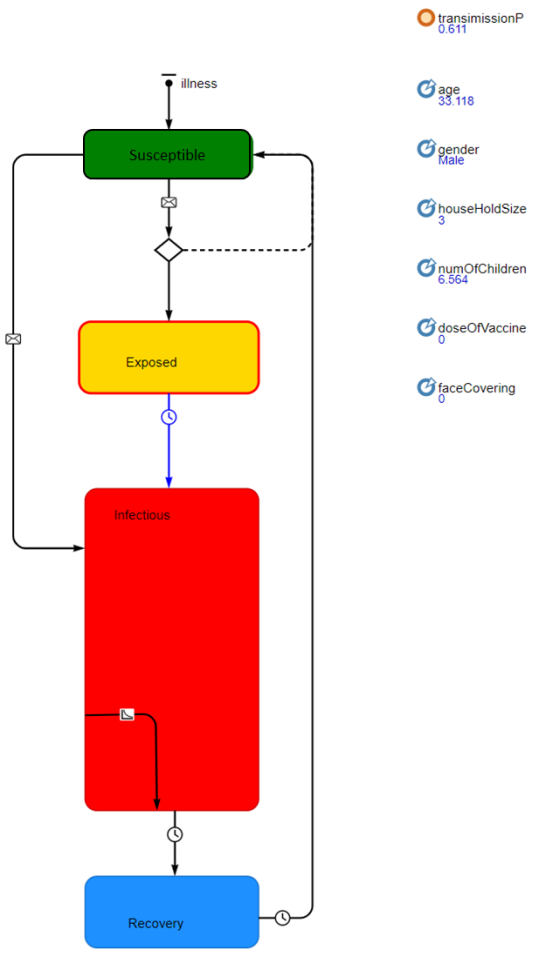


Figure 18. Agent state chart and property

Part E: Safety control measures scenarios

With the five safety control measures (SCMs) (i.e., percentage compliance with wearing face-covering usage (SCM1), percentage compliance with vaccination (SCM2), percentage compliance with social distancing (SCM3), site ventilation (SCM4) and isolation (SCM5) in the model, there are a total of 108 scenarios generated as shown in Table Appendix-4. We first picked up three SCMs scenarios of 108 as the baseline ones. Each baseline scenario stands for three different levels of compliance on those five SCMs. Specifically, scenario 1 (NSCM) represents a total lack of or no compliance with SCMs 1-5 (i.e., zero compliance with face coverings; zero compliance with vaccination; zero compliance with social distancing guidelines; no site ventilation and no compliance with isolation strategies). Scenario 2 represents moderate compliance with most SCMs (MSCM), implying that approximately 50% of the agents comply with all SCMs except that no isolation rules will be implemented. Scenario 3 assumes a full compliance on SCMs 1-5 to (FSCM). For FSCM, all agents are required to always comply with face-covering and get vaccination protocols. Additionally, the site ensures that all agents are always socially distanced, provision of good ventilation and strict implementation of isolation rules. In addition to three baseline scenarios, we picked up additional seven scenarios from the 108 scenarios to understand on how the compliance of individual SCM could play a role in the transmission speed and number of exposed and infected agents: 5 new scenarios which only considered a single

SCM were conducted. Then, for MSCM, one new scenario replaced ventilation with isolation instead of choosing ventilation. The last new scenario was similar to FSCM where only isolation was ignored, considering isolation is not an achievable option for some construction site. Table 10 summarised the selected SCM scenarios.

Table. 10 Summary of different SCM scenario

Scenario	[Fc, Sd, Va, Vc, I]
NSCM	[0, 0, 0, 0, 0]
FcSCM	[1, 0, 0, 0, 0]
SdSCM	[0, 1, 0, 0, 0]
VaSCM	[0, 0, 1, 0, 0]
VeSCM	[0, 0, 0, 1, 0]
ISCM	[0, 0, 0, 0, 1]
MSCM (No isolation)	[0.5, 0.5, 0.5, 1, 0]
MSCM (No ventilation)	[0.5, 0.5 0.5, 0, 1]
FSCM (No isolation)	[1, 1, 1, 1, 0]
FSCM	[1, 1, 1, 1, 1]

Part F: Model Validation with the Industry

In order to evaluate the likelihood of deployment to the model to the industry, it is necessary to understand the views of occupational safety & health (OSH) professionals within the construction industry. After demonstrating the functionalities of the model, an expert panel was convened to provide feedback on their overall views on the model.

The members of the expert panel included a health and safety director, a safety health environment advisor, and a safety health environment and quality administrator.

Selection of study participants

The expert panel session was conducted through MS Teams platform and lasted for approximately 60 minutes. The first 40 minutes were used to fully demonstrate the features and capabilities of the model to the participants, while the remaining 20 minutes were dedicated to the acquisition of feedback from participants. Based on

information available within the existing body of knowledge [34-37] related to the criteria used to evaluate the readiness of computer-based simulation systems for the industry, the 4 most widely applied criteria were then selected. Table 11 shows the selected criteria and their descriptions, while Table 16 provides the comments offered by the participants against the different criteria.

Table 11. Assessment criteria and their descriptions

Codes	Criteria Titles	Criteria Descriptions	References
C1	Usability of the platform	C1 refers to the proficiency of the system to support the efficient and effective completion of specified tasks. It focuses on whether the platform meets all of the user's functional requirements.	[26-29]
C2	Structure and layout	C2 mainly refers to the overall appearance of the platform and the convenience with which users can navigate the different aspects.	[27, 28]
C3	Ease of integration with other platforms	Most organisations would have already invested substantial funds into systems that enable them to monitor compliance with rules and regulations. Therefore, C3 measures the difficulty of integrating the model with other existing OSH monitoring and control platforms or systems.	[26-28]
C4	Representativeness and relevance of captured information	C4 is a measure of how well the recorded information and assumptions reflect real-life scenarios.	[26-29]

Results

This section includes the results of safety control measures scenarios and model validation with the industry.

Safety control measure scenarios

For each of the scenarios, the modelling duration was set to 1 month (i.e., from 26th April to 26th May) to adequately account for all the stages of COVID-19 (i.e., Susceptible-Exposed-Infectious-Recovery). The time granularity was based on 1 minute. Once it reaches 10 minutes (model virtual time), 10 messages were randomly sent to the agents on the construction site to transform their COVID-19 states from susceptible to infectious, as well as allowing such agents to further spread the virus to nearby agents. The number of agents at the different COVID-19 states was then recorded on an hourly basis. In order to guarantee model robustness and representativeness of results, each safety control scenario was run 10 times and the average value of results was considered as the final outcome.

The number of agents at the different COVID-19 states, based on different SCM scenarios are presented in Figs 19-22. As shown in Figure 19, despite being unable to prevent the agent from getting infected, MSCM can postpone the time of susceptible agents from transforming to the exposed stage by 52 hours compared with NSCM. When implementing FSCM, an obvious plateau was observed from 27th -29th April owing to the implementation of isolation strategies that ensured that all infectious agents were absent from the workplace. Meanwhile, it was noticed that nearly 50% of the agents remained in the susceptible state throughout the simulation process, which implies the FSCM scenario is the most effective scenario to curtail the transmission of COVID-19 on a construction site.

In terms of the population of agents in the exposed state, Figure 20 shows that MSCM reduced the peak of exposed population by 17 and delayed the peak by 30 hours, compared to NSCM. A significant reduction of exposed population was found in the FSCM scenario, with peak value of 26 exposed agents. The relative flatness of the FSCM curves in comparison with the other two scenarios also further highlights the impact of FSCM in controlling and preventing the spread of COVID-19.

With regards to the population of agents in the infectious state, Figure 21 depicted that despite the implementation of MSCM scenario, there was no tangible reduction in the peak number. It to a certain extent alleviated the COVID-19 transmission by delaying the peak for 53 hours compared with NSCM. Hence, the best results were still associated with the FSCM scenario, whereby the peak population was only 41 and the peak appeared 69 hours later than that of NSCM.

Similarly, Figure 22 illustrated that the results of recovery under the NSCM scenario had a sharp rise in the recovery rates of agents compared with other scenarios. This shows that NSCM was unable to prevent the spread of COVID-19 on the construction site.

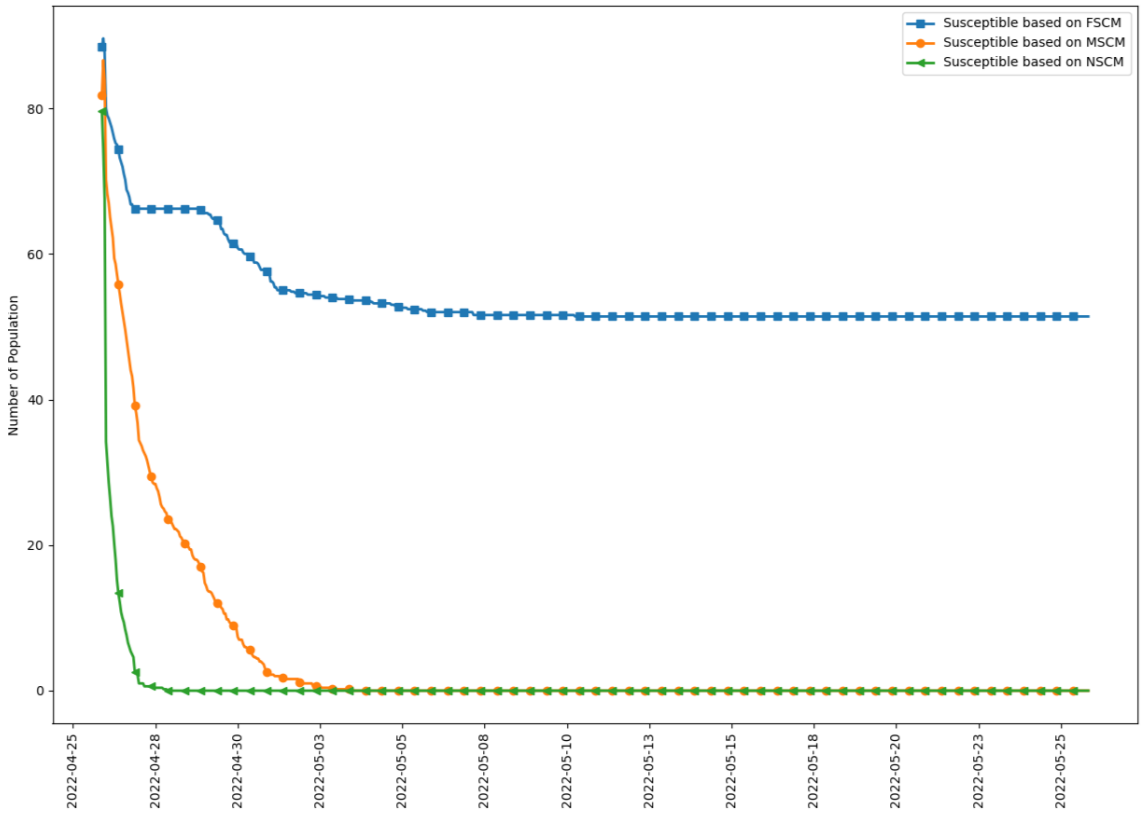


Figure. 19. The number of susceptible agents based on different SCM scenarios

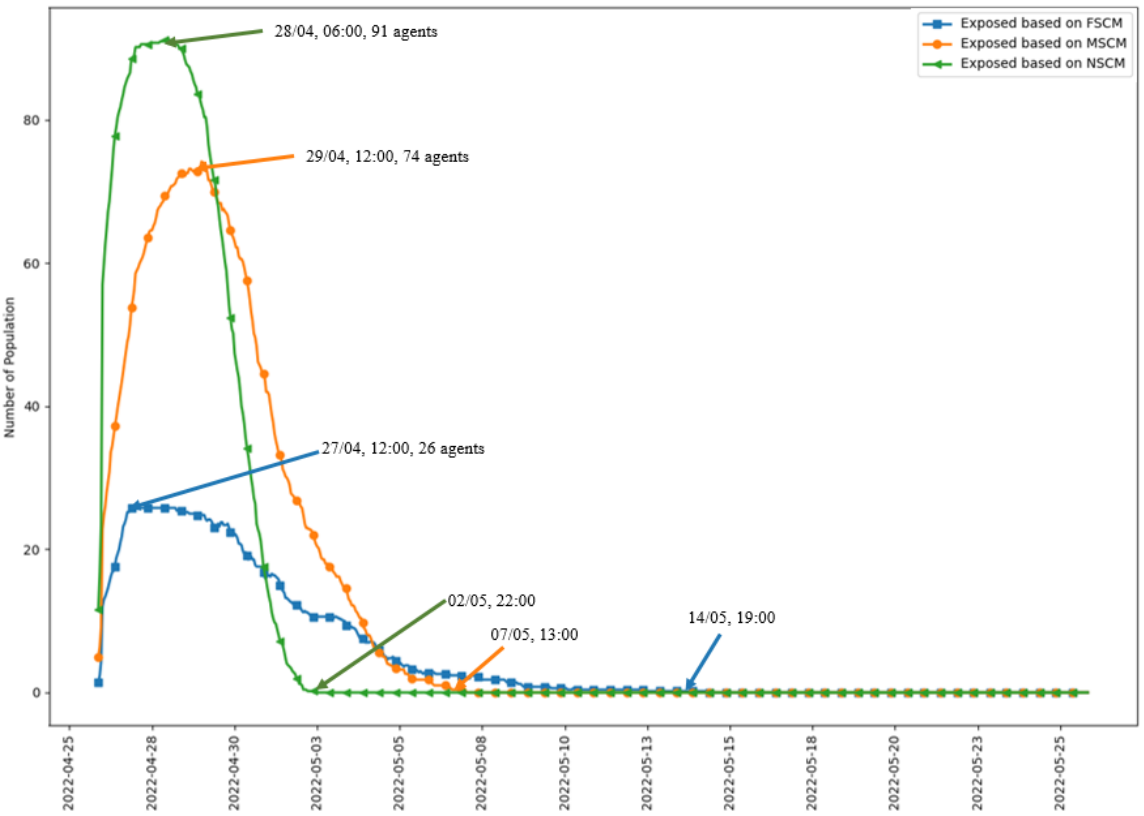


Figure. 20. The number of exposed agents based on different SCM scenarios

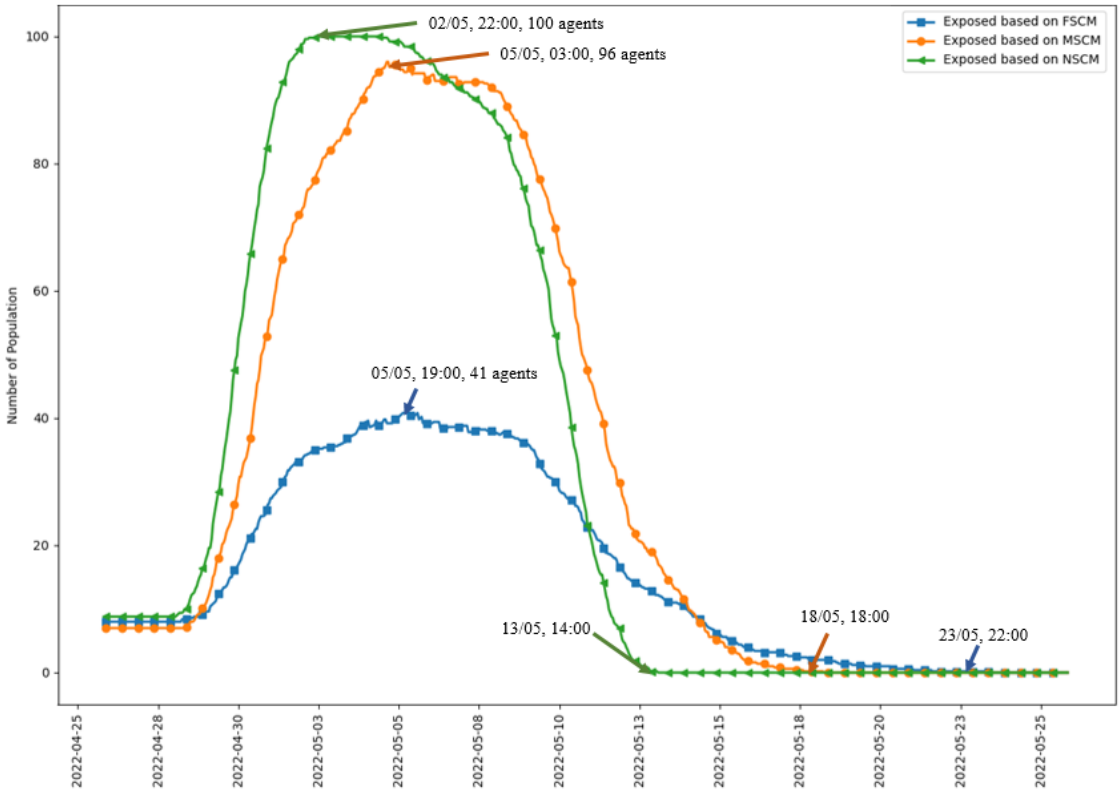


Figure. 21. The number of infectious agents based on different SCM scenarios

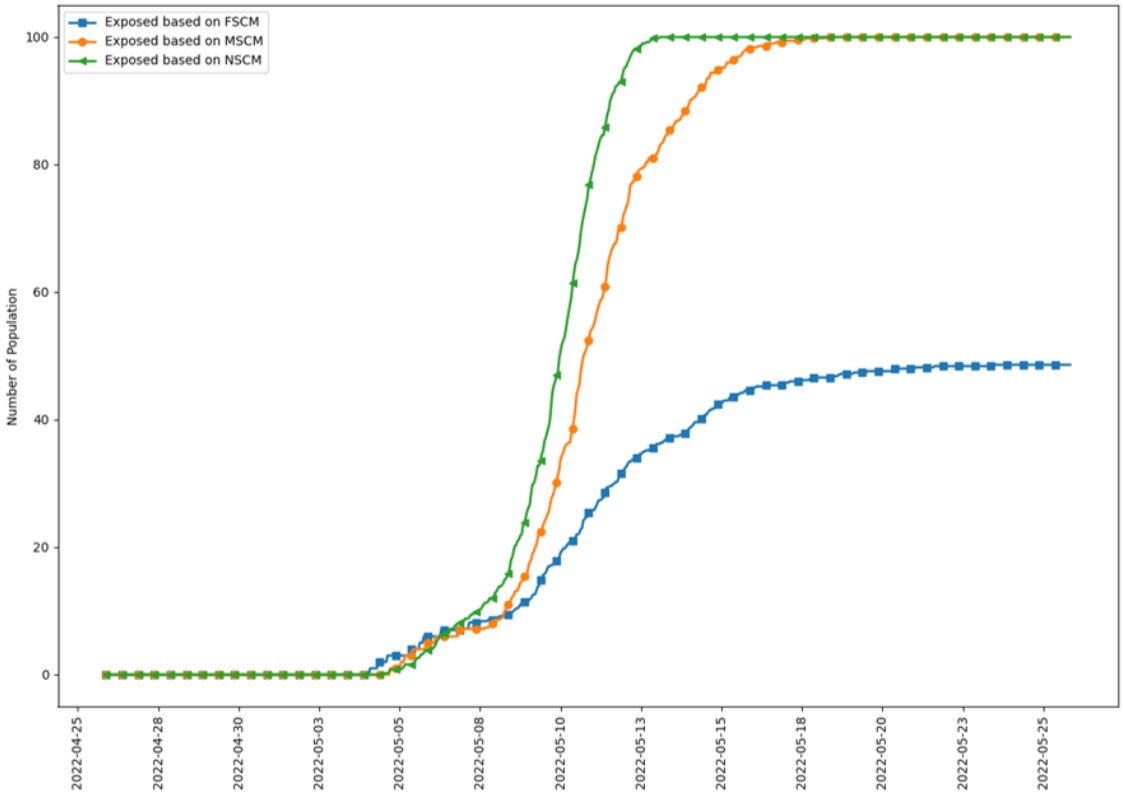


Figure. 22. The number of recovery agents based on different SCM scenarios

In addition to the three baseline scenarios (i.e., NSCM, MSCM, and FSCM), Table 12, Figures 23 and 24 summarised the results of all the ten selected scenarios. It is noticed that for SCMs who implemented isolation on the construction site, an obvious plateau in terms of the exposed population was observed in Figure 23. It is perhaps because once an agent transformed into an infectious state, he/she was not allowed to work and therefore the agent was not able to infect another agent anymore.

When only considering single SCM, as shown in Figure 23, making sure all the agents are fully vaccinated was the most effective measure in both reduce the peak value and time of the exposed population. All other single SCM failed to curb the transmission of the COVID-19. An obvious alleviation in COVID-19 transmission was found in MSCM (No isolation) and MSCM (No ventilation). However, it should notice the former scenario was more efficient. The main reason is that the objective of isolation is excluding the COVID-19 virus from the construction site while the ventilation works by replacing the inside contaminated air with outside fresh air which therefore the inside agents still have chance exposed to COVID-19 virus.
Two fully compliance scenarios FSCM (No isolation) and FSCM were conducted, the results implied that FSCM was the best of all 10 scenarios in preventing the COVID-19 transmission on construction site. However, it may not always be achievable for stakeholders to implement isolation especially for the labour-intensive construction industry. FSCM (No isolation) showed a significant effectiveness in terms of keeping agents from the threat of COVID-19.

Table 12. Summary of the effectiveness of different SCM scenario (unit of time is hours)

Scenario	[Fc, Sd, Va, Ve, I]	Peak value (Exposed)	Peak time (Exposed)	End time (Exposed)	Peak value (Infectious)	Peak time (Infectious)	End time (Infectious)	Final recovered
NSCM	[0, 0, 0, 0, 0]	91.2	49	158	100	158	414	100
FcSCM	[1, 0, 0, 0, 0]	91	45	189	100	189	454	100
SdSCM	[0, 1, 0, 0, 0]	90	42	160	100	260	418	100
VaSCM	[0, 0, 1, 0, 0]	91.2	51	167	100	167	422	100
VeSCM	[0, 0, 0, 1, 0]	83.8	66	216	98.8	216	472	100
ISCM	[0, 0, 0, 0, 1]	88.4	24	241	99.2	193	482	99.8
MSCM (No isolation)	[0.5, 0.5, 0.5, 1, 0]	74.2	76	269	96	211	538	100

MSCM (No ventilation)	[0.5, 0.5 0.5, 0, 1]	63	57	494	84.6	220	696	90.8
FSCM (No isolation)	[1, 1, 1, 1, 0]	56.2	100	339	90.8	271	609	99.8
FSCM	[1, 1, 1, 1, 1]	25.8	24	443	41	227	662	48.6

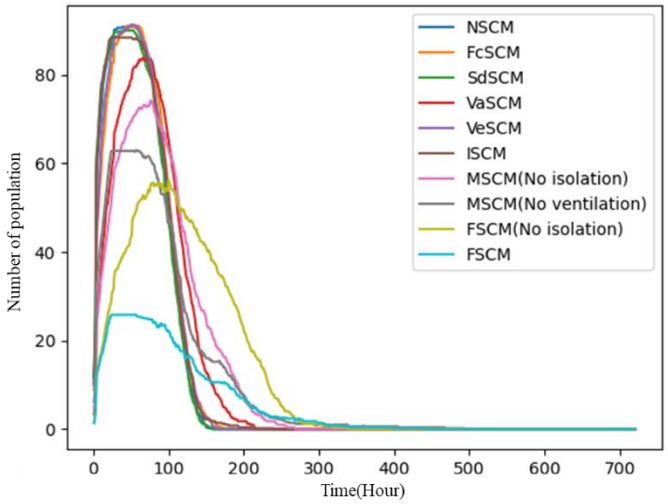


Figure. 23. The number of exposed agents based on the 10 SCM scenarios

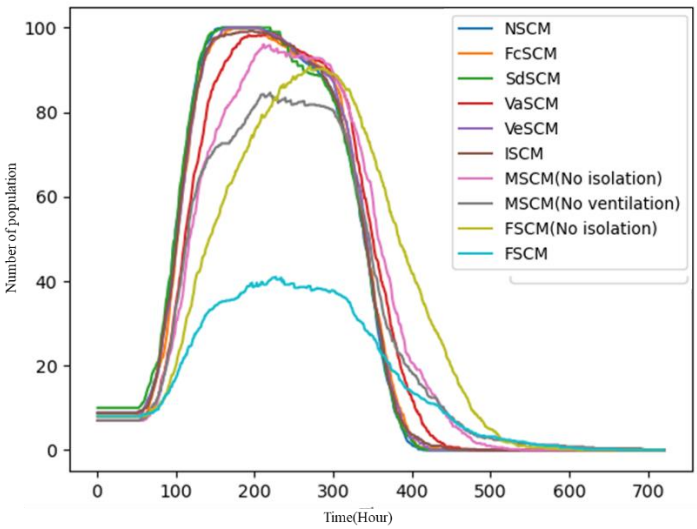


Figure. 24. The number of infectious agents based on the 10 SCM scenarios

Furthermore, the average duration of each agent remained in susceptible state and the number of messages each agent received before transforming into exposed state are two pivotal metrics when assessing COVID-19 transmission risk on

construction sites and verifying the effectiveness of SCMs in the model. These are shown in Figure 25, Figure 26 and Table 13. Without any SCM (NSCM), all the agents were exposed to an extremely dangerous environment and would transform into exposed state once they are exposed to the virus for on average 6.3 hours. The transmission was to some extent alleviated (up to 11.17 hours) when fully compliant with single SCM and vaccination was the most effective amongst the five SCMs. When it comes to MSCM, the duration each agent remained in susceptible state was 21.88 hours (No ventilation) and 14.92 hours (no isolation). The best result was achieved when fully compliant with all 5 SCMs (118.41 hours remained in susceptible state) and a significant outperformance was observed from FSCM implementation compared to full compliance without isolation. The results regarding isolation suggest that the implementation of isolation as the only safety control measure did not lead to an improvement in preventing COVID-19 from spreading. In fact, a significant improvement was achieved by combining isolation with other SCMs compared with SCM scenarios without isolation. The reason might be associated with the fact that it is difficult to isolate exposed agents from the construction site in practice. For example, an effective track and trace system and related company policies and compensation need to be in place in order to make it work.

In terms of the number of messages received (as shown in Figure 26), implementing isolation worked by removing infectious agents from the workplace and therefore reduced the number of messages. For SCMs (ventilation, face covering and vaccination), by increasing agents' resistance towards COVID-19, the agent was able to be exposed to COVID-19 more times without transforming into exposed state. It is noticed that SdSCM did not work in preventing COVID-19 spreading, which is perhaps due to the majority of contacts between agents occurring during lunch breaks where social distance protocols are not entirely followed.

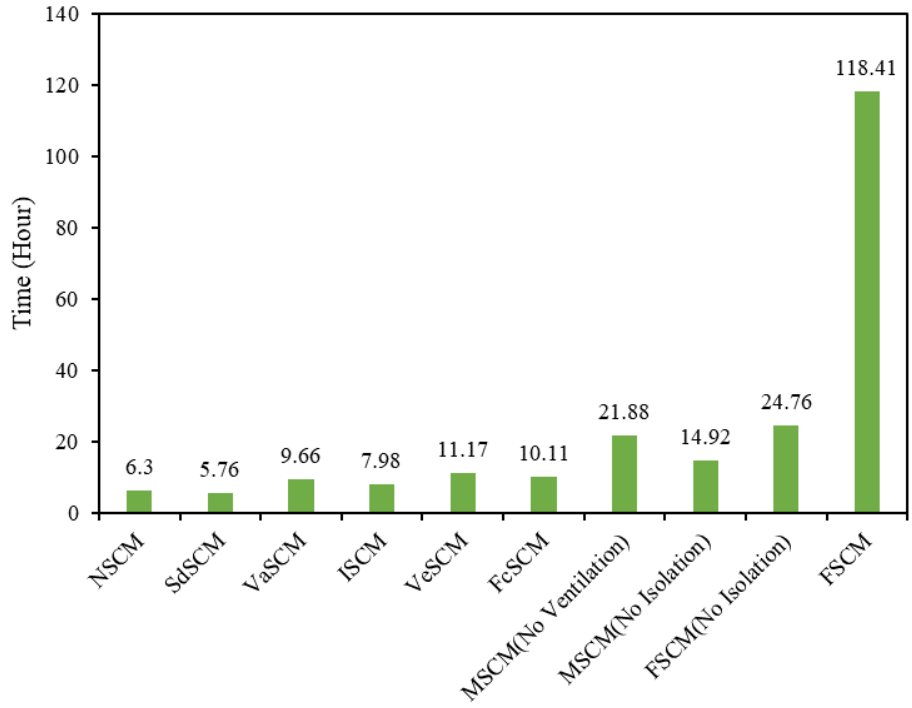


Figure. 25: Average duration of each agent in susceptible state

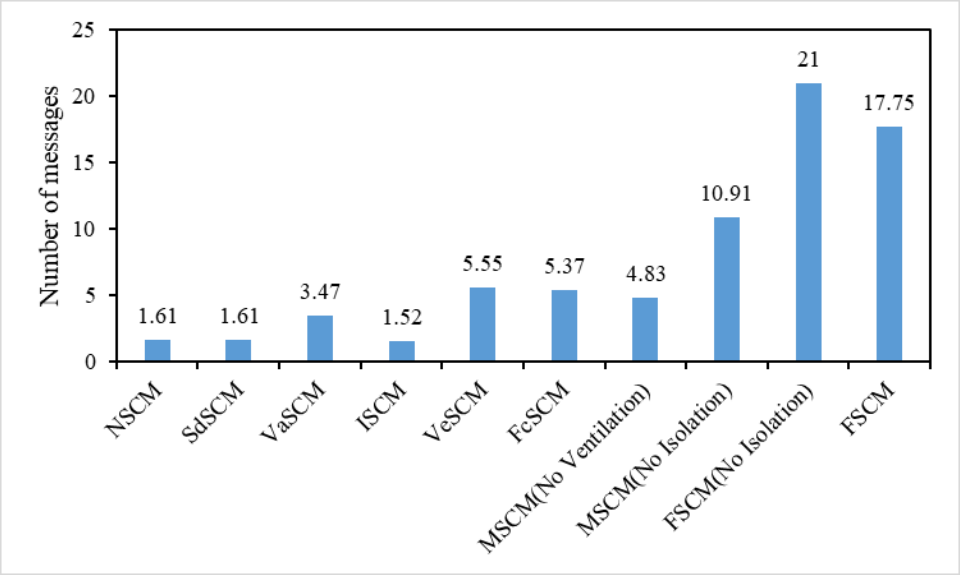


Figure.26: Number of messages each agent received before transforming into exposed state

Additionally, an estimate of the amounts of contacts (all contacts including contacts between healthy agents as well as between healthy and infectious agents) that occurred during the study period (one month) was obtained via the messages sent by the agents in each state as shown in Figure 27 and Table 14. The results further strengthened the effectiveness of isolation as one of the means of preventing COVID-19 spread on the construction site. However, other SCMs did not depict any significant difference in terms of outcomes. The results may be due to the fact that despite workers were sparsely spread on the construction site, there were occasions when they were closely gathered (i.e., lunch break) A considerable number of contacts happened during lunch break and caused the relatively high contact number in several safety control scenarios without isolation.

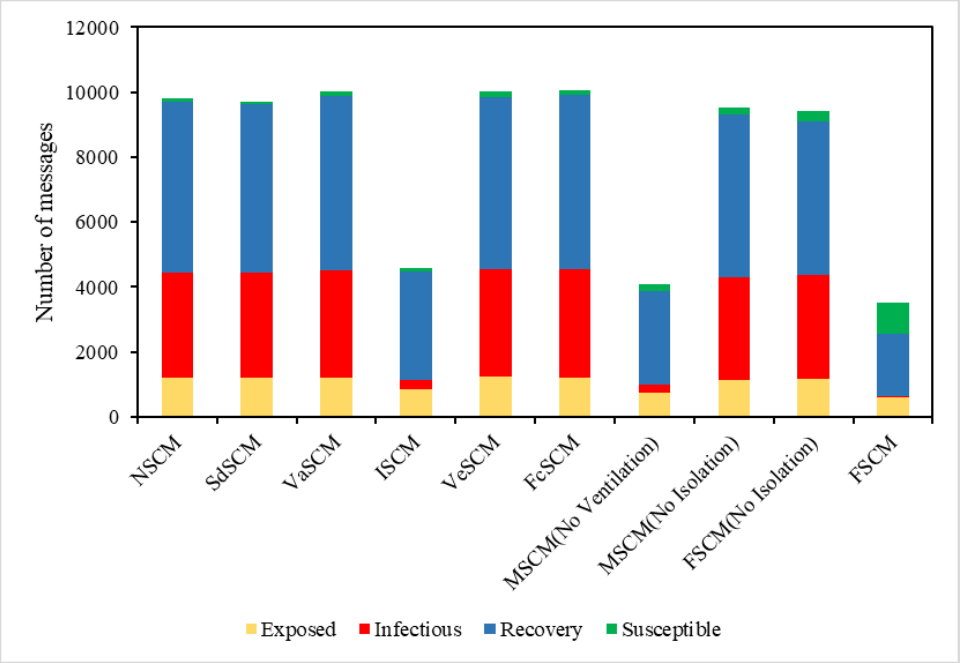


Figure. 27: Number of messages each agent spread during each state of SEIR

Table 13. Summary of COVID-19 prevention effectiveness based for the selected 10 scenarios

SCM	Average duration in susceptible state	Message received
NSCM	6.3	160.6
SdSCM	5.76	160.8
VaSCM	9.66	346.8
ISCM	7.98	151.8
VeCSM	11.17	555
FcSCM	10.11	536.8
MSCM(No Ventilation)	21.88	482.6
MSCM(No Isolation)	14.92	1091.2
FSCM(No Isolation)	24.76	2099.8
FSCM	118.41	1774.6

Table 14. Number of messages sent by each agent during each SEIR state

SCM	Susceptible	Exposed	Infectious	Recovery	Total
NSCM	98	1221	3229	5250	9798
SdSCM	85	1189	3265	5167	9705
VaSCM	143	1211	3284	5384	10022
ISCM	115	856	295	3321	4587
VeSCM	174	1248	3293	5304	10019
FcSCM	152	1222	3319	5377	10071
MSCM(No Ventilation)	236	735	260	2872	4104
MSCM(No Isolation)	211	1149	3162	5017	9539
FSCM(No Isolation)	353	1170	3184	4728	9434
FSCM	953	602	46	1900	3501

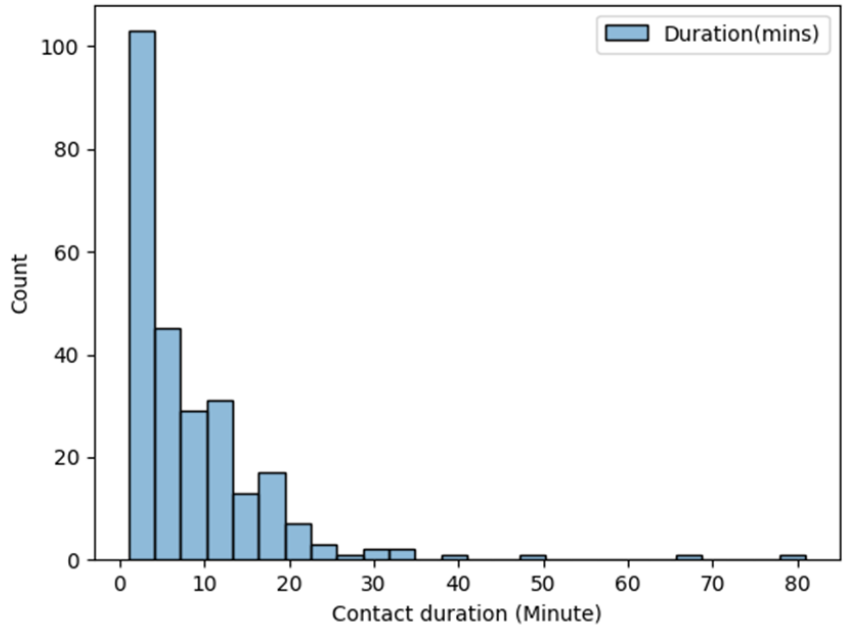


Figure. 28: The average contact duration of NSCM

Figure 28 further shows the average contact duration of infectious agents in the first 24 hours based on NSCM. the result reveals an exponential distribution of the average contact duration, and it is noticed that the majority of the contact lasts less than 30 mins.

Result of the model validation workshop with the industry

The experts' comments were crucial to improving the functionality and application of the model. Based on the feedback from the industry engagement work detailed in Table 15, the industry partners have positive comments on all the evaluation criteria. Indeed, they are interested in utilising the model and integrating it with the existing systems.

Table 15. Feedback template on the four criteria set to evaluate the model

Assessment Criteria	Comments	Improvements and suggestions
C1 Usability of the platform	*"It's very plug and play, very interactive."* *"I think on the basis of what you've presented so far, taking away those logic pieces and quietening down the screen to have those functions of adding in or taking out control*	*"We would probably need to see what it would look like in its final user usable state."*

	measures, would be pretty functionally usable. As long as it was able to help us to formulate a quantitative risk assessment on things like, what would the R rate be on our project potentially." *"I see this as being potentially something which this model might be able to give us in terms of a quantitative reproduction number based on the project behaviour. As you talked about, everything through from behaviours through two particular risk areas of and hot spots and transmission within that model, might enable us to create a more quantitative risk assessment where we can be more certain in terms of the required controls that we need to identify to manage that situation."*	
C2 Structure and layout	*"In terms of the structure and layout, I don't have any major issues with that. I think you know that's something that can be evolved over time, as you make it less busy, as you make it more user friendly."* *"I think it looked great. The usability and structure of it. It seems you can put anything in. I guess it would be just more on our end of how we use it and how good the data is that we put in."*	*"That's something I think we'll just need to keep working with you on and put that in front of some of our NHS professionals to see how they would work with that particularly."*
C3 Ease of integration with other platforms	*"As with all of these things, we want to pull the information into a central source such as power BI because we use power apps for an awful lot of the data that we put together. So, our construction data is visible on power BI and that will be something very simply."* *"All into one system, the power BI, we definitely follow that sort of trend here and it would be more for me because the data going into it. It looks like you are capable of putting anything in the model obviously how we would monitor it on site and then pull that data back in."*	*"We would need to be able to have an API that we can plug into power BI from the system to tell us vital information about our numbers by project. So if you have this running on each individual project, our health and safety managers, occupational health managers would be utilising this model on a project by project basis and we would want to be able to see a project specific data alongside business wide overview as well, and that would be something where an API would be vitally important in enabling us to reproduce the information onto dashboards and other visual representation of that, so that our*

		leadership team could be pulling on the rope of that information and monitoring that effectively."
C4 Representativeness and relevance of captured information	*"I would just probably say, any system is only as good as what you put into it, and it's for you then falls to us to, as you say, get and put that work scheduling in, get those accurate representations of what the entire project looks like, what the floor plates would look like, what the welfare and office space would look like, to enable us to have that relevance to the project. So, the detail would be absolutely vital here in having something which actually provides us with that quantitative rather than the qualitative nature of the information."* *"The control measures might vary in different areas. Rather than just saying social distance in its two meters everywhere where we've got rid of that in some places, we've left open some places. We've got sort of the canteens might still be 2 meters, but have you walking down certain corridors, it might go back to whatever. Obviously if it's for modelling future ways, if we do go back into a pandemic, then we will be set at 2 meters everywhere. But in terms of modelling, how it is now and how it is on different sites."*	*"I think the control measures might vary in different rooms or areas which could be a good thing to see if you could change the variables."*

Limitations

It should be emphasised that the established COVID-19 transmission model in this study does not aim to provide an exact prediction about the development of COVID-19 on a construction site, but rather, the foundation to evaluate the feasibility of the proposed integrated ABM and SEIR in simulating COVID-19 transmission. The limitation of the integrated model exists in the following aspects. First, it should be noted that the COVID-19 simulation in this model is based on an extreme scenario for demonstration purpose. For instance, the basic transmission probability of each contact is 50% which was derived from the COVID-19 human challenge experiment [31] (i.e., volunteers were directly exposed to the COVID-19 virus and the result indicated that half of the volunteers were infected), However, a 50% chance of infection from a single exposure to the COVID-19 is considered unlikely. Also, the

simulation assumed that 10 messages were randomly sent to agents at the beginning of the simulation to create an outbreak of COVID-19 so as to evaluate the effectiveness of different safety control measures, which may not be a true representation of reality. The very high levels of transmission in the unmitigated baseline scenario are likely to have affected the predicted effectiveness of the control measures. In particular, if unmitigated rates of transmission are very high, measures that reduce the transmission risk per contact may only delay infection rather than prevent it. With lower baseline levels of transmission, the same control measures may become more effective at preventing infections. In addition, the purpose of safety control measures is to investigate the relative potential of each measure in mitigating COVID-19 transmission, but not the feasibility of implementing those measures in practice. For instance, it may not be possible to isolate a new infectious agent immediately (e.g., FSCM in the report) unless a regular daily testing of COVID-19 is conducted on site.

Conclusion

The aim of this work is to build the capacity and knowledge of the industry with regard to the effective use of simulation and modelling techniques to manage the transmission risks of infectious diseases on construction sites. To achieve this aim, the work developed and tested a proof-of-concept like model that integrated ABM and SEIR modelling approaches in an interactive and user-friendly manner, to simulate the dynamics of COVID-19 transmission and the epidemiological effects of various protective control measures, including social distancing, face covering, vaccinations rate, ventilation, and isolation. The work also considered population heterogeneity (e.g., age, vaccination status and household size), duration of contacts and site layout.

The work detailed how the model was built on an interactive and user-friendly platform using AnyLogic. In addition, it also showcased how to use the model and platform for estimating the transmission risk and identifying high-risk work areas on a construction site. In particular, the work enables users to select the level of compliance on different protective control measures so as to create different scenarios and visualise how different scenarios can affect the COVID transmission dynamic and identification of high-risk areas. As a result, users can identify the scenario (i.e., combination of compliance on different protective control measures) that is optimal with the consideration of operation cost and controlling the spread of the diseases.

The results of COVID-19 development on a construction based on various safety control measures scenarios revealed a strong positive correlation between preventing COVID-19 transmission risk and vaccination status as well as isolation. Wearing face covering and keeping good ventilation can to certain extent alleviate

the spread of COVID-19. As labour-intensive space where agents have to physically close collaborate, maintaining social distance is difficult to comply with.

Based on the industry engagement workshop, the industry partners have positive comments on all the evaluation criteria (i.e., usability of the platform, structure and layout, ease of integration with other platforms, and representativeness and relevance of captured information). Indeed, they are interested in utilising the model and integrating it with the existing systems.

Since the first confirmed case of COVID-19 in December 2019, the COVID-19 has been evolving from wild variant to Alpha, Beta, Delta, until current Omicron variant. The characteristics in terms of transmission capability and severity vary dramatically. Omicron variant was emerging when this study began, therefore, parameters of COVID-19 applied in this study focus on Delta variant. Also, with better understanding of COVID-19, the value of parameters of Delta variant of COVID-19 may have a certain possibility that is different from what is quoted in this study. The main vectors of COVID-19 virus revealed by existing research are droplet and airborne. It should be emphasized in this study that the 'message' or the virus the infectious agent send to surrounding is droplets as there is a lack of comprehensive understanding about the impact of airborne on COVID-19 transmission. Which is also the potential future direction that incorporates airborne in the COVID-19 transmission model.

SEIR model was employed in this study for describing the pathogenesis of COVID-19 where COVID-19 was divided into 'Susceptible', 'Exposed', 'Infectious' and 'Recovery' states and the values of parameters regarding COVID-19 for instance, transmission probability per contact and incubation duration were collect from multi resources based on experimental or public data analysis which inevitably are less representative for all countries or areas worldwide. Also, the deeper understanding reveals that COVID-19 is more than 'SEIR' state, for instance, 'Infectious' is further divided into pre-symptom, asymptomatic and symptomatic. Besides, some parameters are far more complex (e.g., function of time) instead of a fixed value that are not captured in this study.

Construction project delivery and contractual performance

Introduction

In '*Keeping the UK Building Safely'* we described the crucial role of the construction sector in terms of its contribution to our economy, prosperity, and quality of life. However, the potential of the sector has been constrained by historically low levels of productivity – an average of 21% lower than that of the wider economy since 1997. The 2016 '*Farmer Review*' identified several contributory factors including the cyclical and volatile nature of the sector, the unpredictability of future work and a lack of collaboration across the sector. It concluded that transforming the sector would require shared leadership by the industry, its clients, and the government.

The *Construction Sector Deal* formed part of the *Industrial Strategy* and attempts to drive improvements across the sector. In relation to skills, the deal was expected to deliver reforms to the Construction Industry Training Board (CITB) and a coordinated approach to promoting construction careers. The statement also re-affirmed the targets in Construction 2025 (published in July 2013) to achieve a 1/3 reduction in the cost of construction and whole life cost of assets.

This was instilled into the '*Transforming Construction*' Industrial Strategy Challenge Fund (ISCF) investment and focused on the digitalisation agenda including Building Information Modelling (BIM), automation sensors, data analytics and industry 4.0 technologies. Consequently, several research platforms emerged in response to the challenge including

The Construction Innovation Hub – a £72m investment by UK Research and Innovation (UKRI); it is a collaboration of the Manufacturing Technology Centre (MTC), BRE Ltd. and the Centre for Digital Built Britain at the University of Cambridge.

The Active Building Centre – a £36m UKRI ISCF investment. It is described as 'a research and technology organisation that convenes industry, academia and government to deploy active buildings at scale' led by the University of Swansea. An 'active building' is defined as one that 'generates and stores its own electricity.'

The Centre for Digital Built Britain (CDBB) - a partnership between the Department for Business, Energy & Industrial Strategy (BEIS) and the University of Cambridge. It is badged as 'the home of the UK BIM and Digital Built Britain Programmes.'

Transforming Construction Network Plus (UCL, Imperial, Warwick) – an Economic and Social Research Council (ESRC) investment. It has a stated vision 'to deliver

transformational impact by adopting an integrated approach, situating construction as a production system for built assets that adds value to cities and their infrastructures.'

Project X – Improving Project Delivery in Government. An ESRC funded research collaboration between government, academia and industry representatives. Its stated aim is to 'generate unique insights into the performance of major projects and programmes in Government, insights that can be used to drive continuous improvement in performance and delivery confidence.'

The Productivity Institute - funded by the Economic and Social Research Council (ESRC) and based in Alliance Manchester Business School, University of Manchester, is an inter-disciplinary programme that is working directly with policymakers and businesses to better understand, measure, and enable improvements in productivity across the whole of the UK, with the aim to improve living standard and well-being.

The March 2021 Budget signalled "*a departure from the industrial strategy brand"* and was replaced by a new strategy, '*Build Back Better: Our Plan for Growth*' which is linked to outcomes of '*The Barber Review*' and the initiation of '*Project Speed*.' However, the challenge facing government in realising its strategy is significant; the sector has suffered from decades of poor productivity relative to other sectors (see Fig. 26). Building work has recorded the lowest level of productivity across all sectors since 2009 and worryingly, appears to exhibit a downward trend. The data on civil engineering appears better, this is largely attributable to the nature of the industry, higher levels of directly employer labour, longer project durations and thus greater certainty of work. ONS data shows that productivity in the construction industry was volatile during the coronavirus (COVID-19) pandemic, primarily due to restrictions in working. Output per hour increased by 2% from 2019 to 2022, primarily because output was lower than hours worked. This was particularly notable in the specialised construction activities sector, where dropped by 16% and hours worked by 20%.

The COVID-19 pandemic has transformed the landscape that pre-dated the *Industrial Strategy*; pre-2020 assumptions may no longer be valid, particularly in the context of the capacity and availability of the construction sector. The COVID-19 pandemic has served to further emphasise the need for cross-sectoral reform and a re-doubling of efforts to tackle relatively poor productivity; it is against this landscape that we aim to understand the opportunities and challenges facing the sector as new ways of working evolve within the context of health, safety, and welfare.

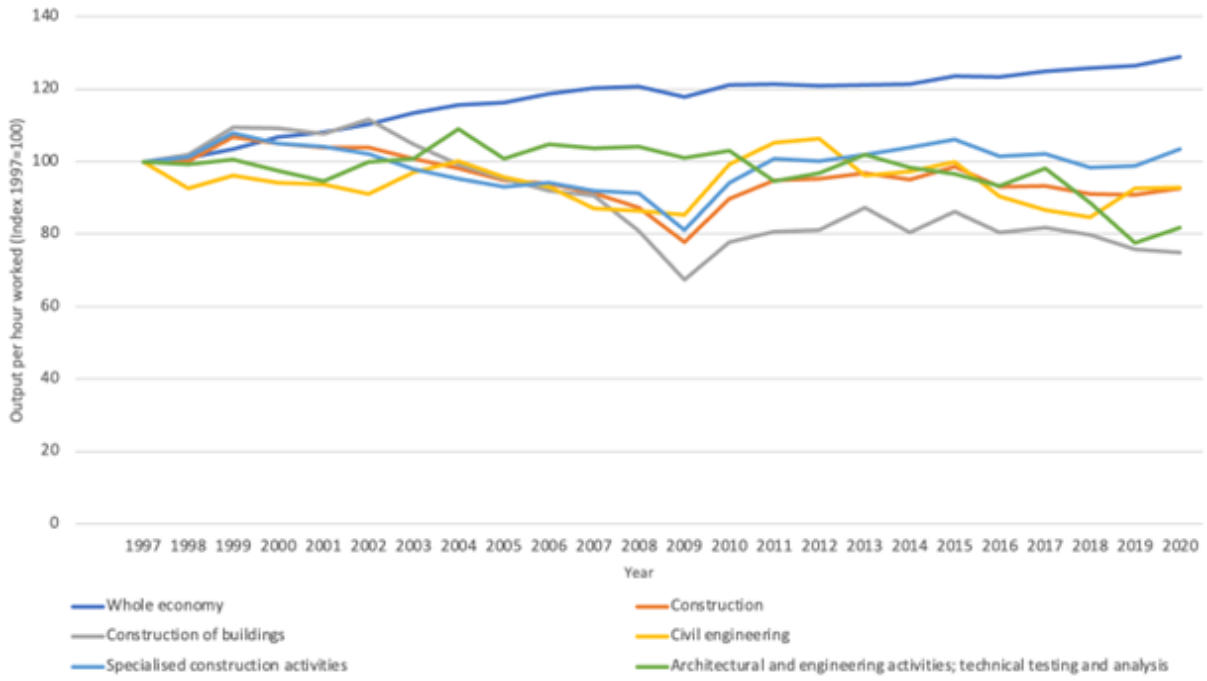


Fig. 26 Productivity growth in the construction industries compared with the whole economy (Source, ONS 2021)

The COVID-19 pandemic has served to re-emphasise the significance of safe working environments and learning from the pandemic may provide useful in future revisions of the Construction Design and Management Regulations; some questions for duty-holders include:

- Clients – what new models of sponsorship/promotion have emerged during the COVID-19 pandemic to support safe recovery of the sector at all levels?
- Principal designers/designers – what 'constructability' lessons have emerged from projects delivered during the pandemic and what is the role of digitalisation as an enabler?
- Principal contractors/contractors - what opportunities and threats remain in delivering safe working conditions?
- Workers – what are the experiences of the site workforce, including directly employed, Construction Industry Scheme (CIS) and self-employed workers on site through the pandemic?

It follows that re-orienting construction project delivery to focus on the societal value of good health, safety and welfare is crucial. Questions to consider include:

- Procurement – are clients 'setting the scene for safety' through leadership at the project front-end?
- Contractual environment – is the future pipeline of work clear, evenly distributed (levelling up) and incentivising the sector to invest in people, skills and training?

- Contracts – how can contractual instruments promote greater focus on health, safety, and welfare? What are the impacts of the COVID-19 pandemic on construction contract performance?
- Health, safety and welfare as a 'public good'- what is the role of central and local government in promoting new procurement routines aligned with the Public Services (Social Value) Act 2012?

It is not within the scope of this report to seek answers to all these questions, nevertheless – this report will add to our current understanding of the pressures facing small-to-medium sized participants and to identify the opportunities that learning from the pandemic may offer.

Aims and objectives

The overall aim of this part of the study is to contribute evidence to support the COVID-19 recovery of the construction sector, building upon existing industry thought-leadership, policy and project delivery guidance through the lens of health, safety and welfare in a post-pandemic world.

The objectives of the study are

- To provide evidence of the impact of the COVID-19 pandemic in the context of small-to-medium sized construction industry participants

- Establish the priorities for a sustainable transformation of the sector in the context of the Government's '*Build Back Better*' strategy.

- Identifying the factors influencing the performance of small-to-medium sized industry participants through a causal map that is co-produced using data obtained from industry participants.

- Contribute to the wider evidence being generated on health, safety and wellbeing through the PROTECT programme activities including dissemination events and workshops.

The UK Government's 'Construction Playbook' identifies several cross-cutting themes including health, safety and wellbeing – the expectations are that contracting authorities will deliver this priority (and others such as building safety) through construction project delivery.

Research Methodology

The objectives are achieved through a multi-methods approach, as illustrated in Fig. 27. This methodology allows us to improve our existing knowledge and understanding of the current landscape of academic and 'grey' literature relevant to the UK construction sector.

Step 1: Bibliometric analysis and evidence review (secondary research) – this provides insights into the relevant literature and identifies concentrations of literature in addition to existing gaps and overlaps relevant to this study

Step 2: Systems modelling (primary research) – this provides insights into the actuality of construction project delivery. This stage includes survey, rich picturing, and causal modelling to graphically illustrate the complexities facing the construction sector, and small to medium sized organisations

Step 3: Findings – A synthesis of the evidence from secondary and primary research in the form of this report

Fig 27: Summary of research methodology

Stage 1: Bibliometric analysis and evidence review (secondary research).

To identify the issues relevant to post COVID-19 recovery of the construction sector by means of a thorough review of the existing literature. Stage 1 aims to create an understanding of the key issues that are likely to influence the ability of the construction sector to respond to the threats and opportunities presented by the COVID-19 pandemic. The secondary review process can be broken down into three key phases:

Firstly, we constructed a list of search terms and classified potential sources of evidence in the form of peer-reviewed empirical research, industry association surveys, policy insight and analysis etc. from a range of sources including research

commissioned and published by UK and non-UK government departments, arms-length and public bodies, professional bodies, consultancies and research centre's. In addition, any relevant evidence made available by contacts made through our initial work described in '*Keeping the UK Building Safely.'* We also considered additional references in the form of citations in articles sourced through the Web of Science. We started with a set of pre-defined keyword search terms; these were identified from a content analysis of the 'Keeping the UK Building Safely' report and were determined in a qualitative way based on consensus within the research team. Various trials of combinations of search terms were performed using the search function on Web of Science. Following a series of trials, we determined that the 'technology AND construction' combination used in the search field 'TITLE' achieved an optimal set of results; 3,247 documents were retrieved with most of the scholarship published in the technical journals including civil engineering, construction building technology and materials sciences (multi-disciplinary).

Secondly, we then determined an appropriate set of exclusion criteria to ensure that the literature was relevant to the study. This is a particularly challenging task given the various usages and connotations of the word 'construction' in the academic literature. The purpose of the exclusion criteria is to ensure the sources of evidence reflected the nature of this study (see Table 16).

Finally, a detailed review of the academic and grey literature in relation to the aims and objectives.

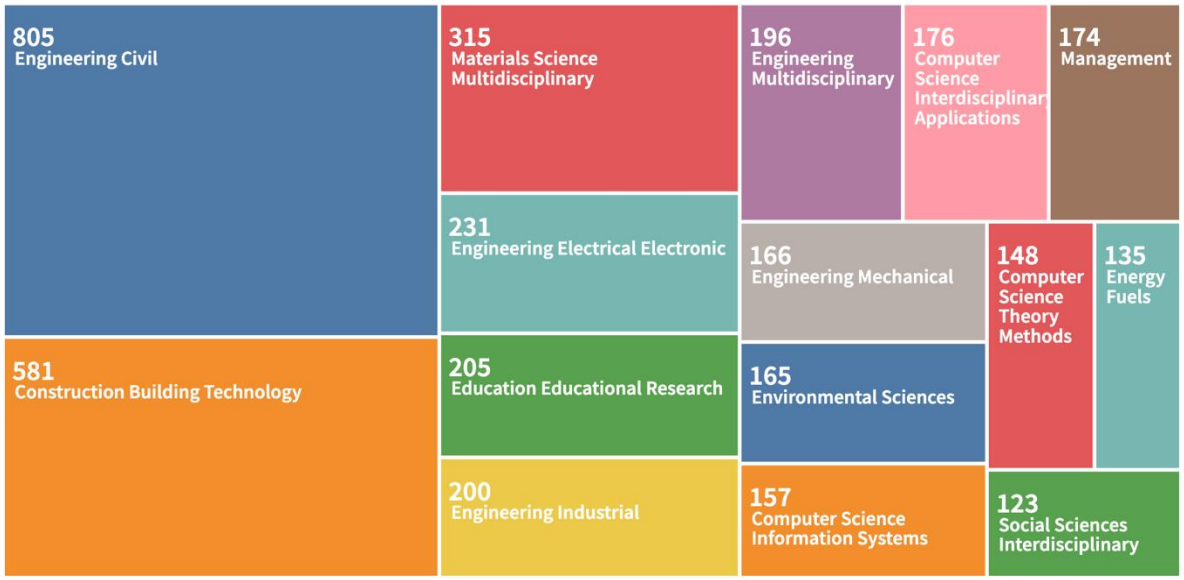


Fig 28. Analysis of the keyword search on Web of Science (3,247 publications selected from Web of Science Core Collection [search term combination 'construction AND technology (Title)']

The search results were imported into the bibliometric analysis tool, VOSviewer. This is widely used by researchers to construct and visualise 'bibliometric networks' – these can take the form of peer-reviewed journals, researchers, or individual publications, and can be created using citation data, bibliographic coupling, co-citation, or co-authorship relations.

The resulting network visualization (Fig 29) and heat-map (Fig 30) show graphically how different areas of scholarship relate to the aims and objectives of the study. Fig. 6 shows three distinct areas of scholarship - characterised by clusters of keywords; the green cluster relates to the literature concerned primarily with construction technologies and construction specific themes; the blue cluster is primarily concerned with broader technology and innovation issues beyond the construction sector, the red cluster is primarily comprised of scholarship that is located in the management sciences, whereas the yellow cluster, which is less well defined, appears to characterise the intersections of technology, work and management. The yellow cluster is particularly interesting to us and is explored in the context of sociomateriality in later sections of the report.

Title	Authors	Source Title	Publication Date	Publication Year	Volume	Issue	Total Citations	Average per Year
ARTIFACTS - OR HOW THE SOCIOLOGY OF SCIENCE AND THE SOCIOLOGY OF TECHNOLOGY MIGHT BENEFIT EACH OTHER	PINCH, TJ; BIJKER, WE	SOCIAL STUDIES OF SCIENCE	1984	1984	14	3	1085	27.82
SOCIAL CONSTRUCTION OF COMMUNICATION TECHNOLOGY	FULK, J	ACADEMY OF MANAGEMENT JOURNAL	OCT 1993	1993	36	5	450	15
Automated construction by contour crafting - related robotics and information technologies	Khoshnevis, B	AUTOMATION IN CONSTRUCTION	JAN 2004	2004	13	1	393	20.68
What's Under Construction Here? Social Action, Materiality, and Power in Constructivist Studies of Technology and Organizing	Leonardi, Paul M.; Barley, Stephen R.	ACADEMY OF MANAGEMENT ANNALS	2010	2010	4		318	24.46
A review on the viable technology for construction waste recycling	Tam, VW; Tam, CM	RESOURCES CONSERVATION AND RECYCLING	JUN 2006	2006	47	3	227	13.35
The social construction of technology: Structural considerations	Klein, HK; Kleinman, DL	SCIENCE TECHNOLOGY & HUMAN VALUES	WIN 2002	2002	27	1	217	10.33
Development of a Three-Dimensional Bioprinter: Construction of Cell Supporting Structures Using Hydrogel and State-Of-The-Art Inkjet Technology	Nishiyama, Yuichi; Nakamura, Makoto; Henmi, Chizuka; Yamaguchi, Kumiko; Mochizuki, Shuichi; Nakagawa, Hidemoto; Takiura, Koki	JOURNAL OF BIOMECHANICAL ENGINEERING-TRANSACTIONS OF THE ASME	MAR 2009	2009	131	3	206	14.71
Real-time resource location data collection and visualization technology for construction safety and activity monitoring applications	Cheng, Tao; Teizer, Jochen	AUTOMATION IN CONSTRUCTION	SEP 2013	2013	34		187	18.7
SYNTHETIC TECHNOLOGY FOR THE CONSTRUCTION OF OXOCENES AND RELATED MEDIUM-RING SYSTEMS	NICOLAOU, KC; PRASAD, CVC; HWANG, CK; DUGGAN, ME; VEALE, CA	AMERICAN CHEMICAL SOCIETY	JUL 5 1989	1989	111	14	163	4.79
Boundary objects and the social construction of GIS technology	Harvey, F; Chrisman, N	ENVIRONMENT AND PLANNING A	SEP 1998	1998	30	9	161	6.44

Table 16: Citation report for the keyword search on Web of Science (3,247 publications selected from Web of Science Core Collection [search term combination 'construction AND technology (Title)']; ten highest ranked papers by citation count.

Stage 2: Systems modelling (primary research)

One of the main objectives of the research study is to identify specific issues relevant to small-to-medium sized construction industry participants and illustrate the complexity of the challenge they face. To achieve a more nuanced understanding of the issues specific to this sector, and to enhance the findings from Stage 1, we carried out a simply online survey of Chartered Building Companies in the UK using public access information available from The Chartered Institute of Building (CIOB) wesbite[1]. In seeking to develop a more nuanced understanding of the impact of COVID-19 on the construction sector, we have identified asked a series of questions that are relevant to our understanding of the productivity challenge facing the sector, including:

- What is the impact of COVID-19 on small-to-medium sized industry participants?
- What innovative working practices and capabilities have emerged from the impact of NPI's on small-to-medium sized industry participants?

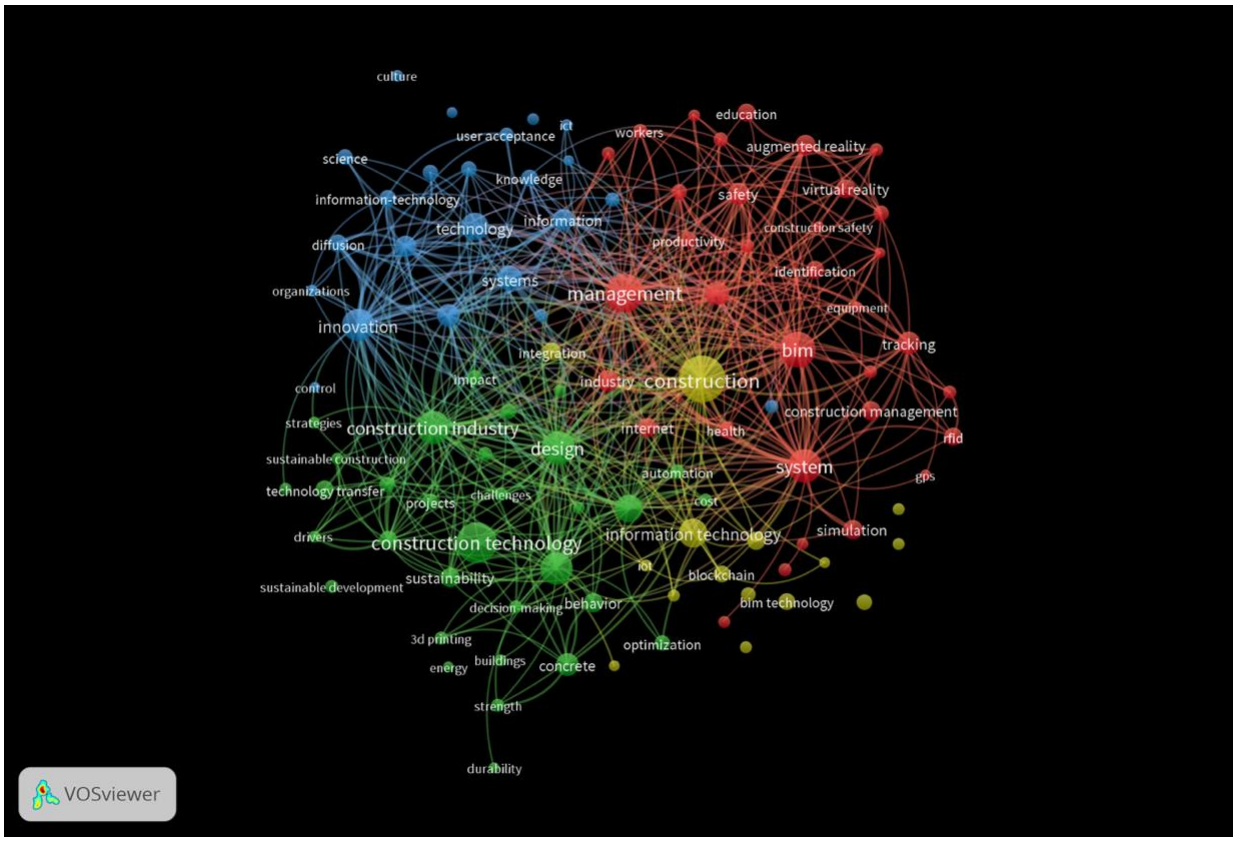


Fig 29. Network Analysis of the keyword search on Web of Science (3,247 publications selected from Web of Science Core Collection [search term combination 'construction AND technology (Title)']

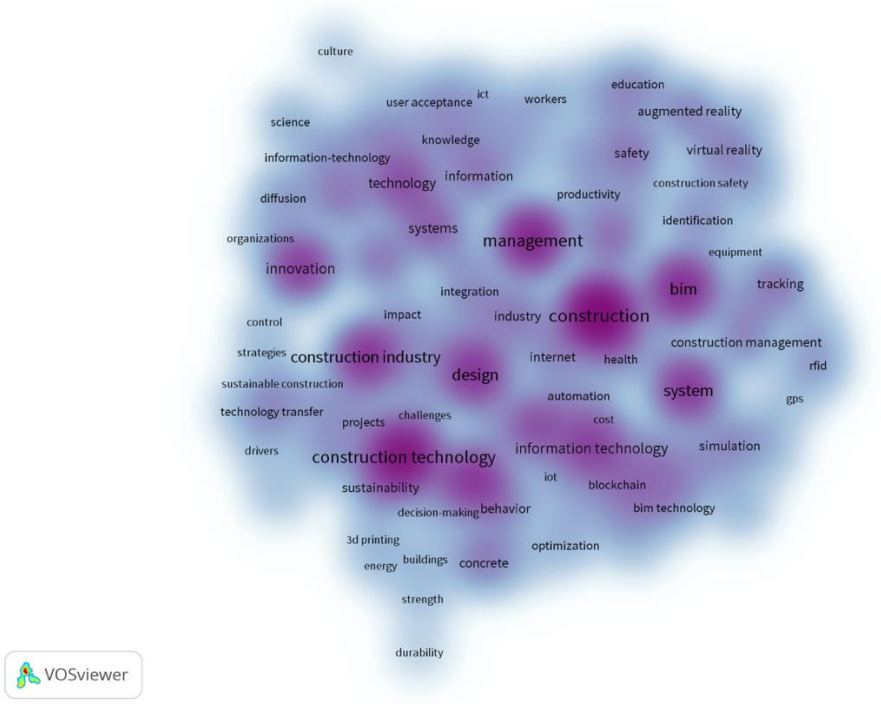


Fig 30. Heat map of the keyword search on Web of Science (3,247 publications selected from Web of Science Core Collection [search term combination 'construction AND technology (Title)']

- How risk perceptions and risk appetite amongst small-to-medium sized industry participants has changed during the pandemic – what factors frame risk perception?

The survey was issued by email and potential participants (Fig. 31) were provided with information about the aims of the wider project and the purpose of the research. Potential participants were informed that the processing of responses to the survey is based on the legal principal of consent. The data collection instrument was designed to ensure that participants were able to: -

- elect not to respond to the survey participation request
- select the questions that they wished to answer
- withdraw responses following completion (provided that the participant can specify the precise date and time of survey completion).

Region	% of all companies (rounded)
England	
East Midlands	2
East	17
London	9
North East	2
North West	7
South East	25
South West	8
West Midlands	5
Yorkshire and the Humber	5
Northern Ireland	5
Scotland	2
Wales	3
Channel Islands	2
Ireland	2
Other countries	5
Total (n=446)	

Figure. 31 Chartered building company registrants by region (allocated by postcode)

We then combined this data with evidence from Stage 1 to develop a conceptual understanding of challenges facing the construction sector, primarily through the lens of small-to-medium sized construction firms. We deployed a ‘rich pictures’ approach to capture the complexity of the challenges to enable the construction of a causal model to illustrate systemic challenges. Both techniques are components of ‘soft systems methodology’ (SSM) – an approach widely used in social sciences research to help shape interventions in situations of complexity, typically those encountered in the management sciences, organisational design, and policy contexts.

Stage 3: Report writing

A synthesis of the evidence from Stages 1 and 2 in report form and shared through the PROTECT programme series of dissemination events and activities organized by the wider research community.

Literature review

Introduction

The construction industry is regularly challenged to embrace technological advances; sector wide skills shortages, foundational materials supply and price instability, the increasing complexity of buildings and civil engineering coupled with government aspirations to meet ambitious targets such as improving productivity are amongst the many causes.

The challenges to adoption of new technologies in the construction sector are multi-faceted; risk appetite, procurement and contracts, the 'tiered' structure of the industry and contractor capabilities are widely recognized factors. Scholars and industry commentators have been known to suggest that the construction sector has much to learn from other sectors such as petrochemical and high-value manufacturing including automotive and aerospace; yet these arguments are often ignorant of the 'materiality' of construction as a skill and a craft.

In the report '*Keeping the UK Building Safely; a scoping study'* - we highlighted the Construction Sector Deal, which allocated c. £420m of government investment to support industry transformation. The policy focused on three key areas; digitalisation, manufacturing (with a focus on productivity improvements, safety and quality) and performance across the five 'industrial strategy' themes:

- Ideas – the harnessing of digital technologies and platform/manufacturing-based methods of construction.
- People – reforming industry recruitment and training to attract, retain and develop the skills that the industry needs.
- Infrastructure – delivering the 'National Infrastructure Assessment' (the long-term infrastructure needs of the UK) alongside the Infrastructure and Projects Authority's 'Construction Pipeline.'
- Business environment – tackling the negative impacts of a highly fragmented industry sector.
- Places – bolstering the supply chain and technical skills base to ensure that construction activity is distributed across the UK.

Subsequently, the publication of the 'Construction Playbook' has served to emphasise the government's view that technological innovation and the wider adoption of Modern Methods of Construction (MMC) are essential to solving the 'productivity puzzle.' The presumption for MMC appeared in the 2020 spending review, which explicitly stated that '*The government's increased investment in*

infrastructure through SR20 must be matched by faster, smarter delivery. Project Speed, a new taskforce, takes steps to cut down the time it takes to develop, design and deliver vital projects. Projects funded through SR20 will also make increased use of Modern Methods of Construction.'

In the following sections of this report, we explore the relevant academic and grey literature in the context of COVID-19 and its' impact on the UK construction sector. This includes consideration of small-to-medium sized organisations and some international perspectives.

COVID-19 and its' impact on the construction sector

On March 11, 2020, the World Health Organization (WHO) publicly classified Covid-19 as a pandemic. This brought all sectors to a halt, including the construction industry, resulting in the shutdown of construction sites and related manufacturing enterprises worldwide. To control the spread of the virus, the UK government introduced several non-pharmaceutical interventions (NPIs) including stay at home orders ("lockdown"), recommending alternate 'week in – week off' rostering of staff on their return to work, restrictions on the use of public transport to enable safer travel for key workers, local travel restrictions (for example 5-mile limit for non-essential travel) and 6-foot physical distancing for two or more workers on-site. We know from our earlier work that NPIs had an impact on the construction industry, in terms of delivery against cost and schedule but we are not yet clear what the longer-term impacts will be on the wider sector – this is important in the context of an industry that is primarily comprised of large numbers of small to medium sized organisations and self-employed workers who may not benefit from the protections that exist in larger business. Recent data published by the House of Commons library indicates that business operating within the construction sector accounted for 16% of all businesses in the UK, but perhaps more interestingly, contribute to only 8% of employment and turnover; the report suggest that the large number of construction workers who are self-employed (and therefore defined as enterprises), rather than being classed as employed in the sector.

In March 2020, Constructionline (a pre-qualification and assessment service for the construction industry) surveyed its members to assess the impact of the COVID-19 pandemic on the construction industry and its supply-chain (n=4,300). Their survey findings include several significant issues:

- 87% of respondents said that their business has been affected by COVID-19
- 38% of respondents stated that they expected to face significant financial difficulties due to COVID-19

- 60% stated that they had awareness of the Construction Leadership Council (CLC) site operating procedures and a similar number stated that they believed that their staff were following the CLC's recommendations
- 53% stated that their company had experienced staff absences due to COVID-19
- 1/3 of all respondents stated that they would use the Coronavirus Business Interruption Loan Scheme and nearly half said that they would use the UK government's offer to support 80% of staff salary during the qualifying period.

In Northern Ireland, a smaller survey by the Construction Industry Training Board NI (n=48) in 2020 revealed that: -

- 90% of those surveyed either furloughed or made staff redundant during the COVID-19 Pandemic.
- 35% of those surveyed employed apprentices with most of these companies furloughing over 80% of apprentices.
- 71 % of respondents had between 1 and 5 sites operating prior to lockdown with over 80% of these being closed during the pandemic and those that were open focused primarily on emergency work or operating in a reduced format

More recently, the Insolvency Service has recorded several significant company administrations across the UK, one notable example was PDR Construction Ltd, based in Hessle, East Riding of Yorkshire – a builder with c115 staff and turnover of c£83m. It went into administration, leaving a chain of unpaid subcontractors and materials suppliers. In a statement by the administrator, reported to BBC News, the impact of the COVID-19 pandemic was clear.

> *"[PDR Construction Ltd.] has experienced challenging market conditions including the timely delivery of a number of recent projects, resource issues within the sector - principally as a result of the Covid-19 pandemic - and contractual disputes with private clients including a recent significant lost adjudication"*

An article in the *Financial Times* (17th January 2022) reported on the PDR Construction administration and wider impacts associated with price rises in the construction logistics and supply-chain. In one example, the cost-pressure facing small-to-medium sized organisations is evidenced; the cost of a 40ft shipping container to supply construction materials from China to northern Europe was reported to be $1,500 in summer 2020 but increased to $14,200 by January 2022.

The peer-reviewed literature on the impact of COVID-19 on small to medium sized industry participants is scarce; publication and citation (by time) of COVID-19 research on the impact of the construction from 2020 to 2022 is shown in Fig. 32.

This is noteworthy in the sense that the construction sector is characterised by many businesses that are often referred to as ‘unregistered’ - such as the self-employed. The Federation of Master Builders estimates that SME’s account for 99% of all businesses operating in the UK’s construction sector.

A bibliometric analysis of the available literature is shown in Fig. 33. The chronological network (for the period 2021-22) shows that the initial literature tended to focus on generic issues such as economics and sustainable development and subsequently developed into more specific issues on project management, health and safety and supply-chain. The co-occurrence network shows that most of the literature is organised into three distinct clusters; the green cluster is primarily associated with management literature, the blue cluster is concerned with health and safety and supply-chain literature, and the red cluster identifies literature relevant to the workplace.

Fig 32: The volume and document citation by time of COVID-19 impact on construction sector participants research from 2020 to 2022

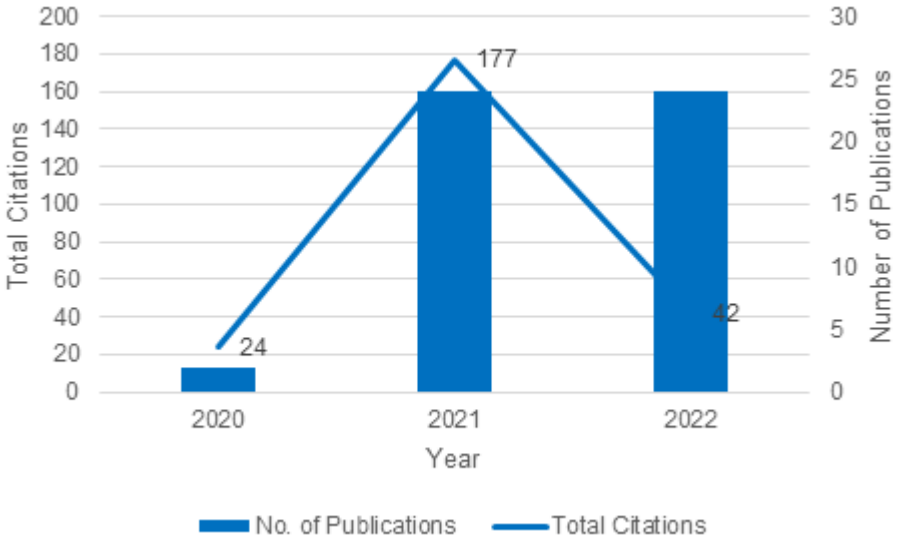
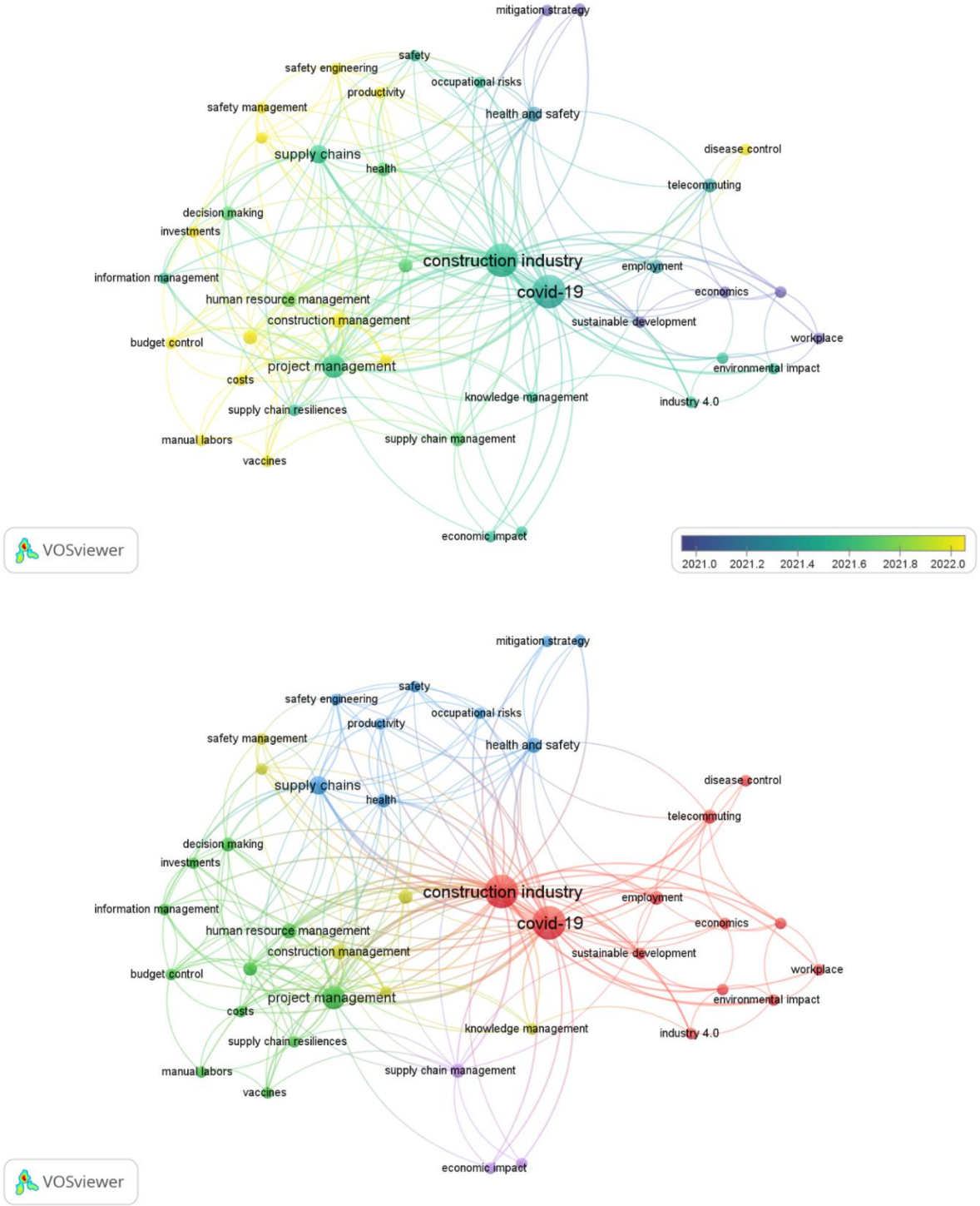


Table 17: Journals that have published the most cited articles on pandemic impact on construction sector participants and what are their characteristics

Journal name	Total Publications	Total Citations
Journal Of Engineering, Design and Technology	11	42
Journal Of Management in Engineering	6	33
Sustainability (Switzerland)	4	3
Engineering, Construction and Architectural Management	3	3
Buildings	2	21
Construction Management and Economics	2	7

Figure 33: Themes that have been explored on the topic of COVID-19 impact on construction sector participants and how are they related.



Worldwide, Covid-19 has negatively impacted construction industry participants. Several studies have investigated the impact of the pandemic on industry participants and construction projects in their local contexts.

For example, in Europe, specifically in the UK, Stride et al., (2021) and Salami et al., (2021) studied the impact of the pandemic on industry participants, and the strategies that were followed to cope with the pandemic. They found that projects were delayed, employees lost their jobs, companies moved to a more digitalised working environment where possible and embraced communication technology, enabling collaboration during the pandemic.

Other research revealed that the construction industry faces significant challenges and suggests that a more diverse workforce could have enormous benefits in terms of developing modern technology and addressing the skills shortage. However, it was suggested that the industry should improve working conditions for current employees while also attracting new employees through remote and flexible work arrangements. They suggest that Industry 4.0 may benefit mental health and well-being by facilitating colleague interaction. In total, 69% of interviewees stated that they had adequate technology for remote working and another 21% stated that their technology could be improved. This demonstrates the importance of changing policies to ensure employee safety by advising employees on proper seating, the use of appropriate chairs, and the proper placement and height of a "desk."

In Africa, specifically in Ghana, Agyekum et al., (2021) discovered that the pandemic had led to decreases in productivity and increases in project delays and associated payments from financiers. In South Africa, Aigbavboa et al., (2022), categorised the impact of pandemic to short-, medium- and long-term impacts. On the short and medium terms, they found that job losses, loss of revenue, increase of material costs, potential bankruptcy of SMEs, delay in project delivery and inability to finance projects are among the most influential effects on industry participants. The long-term effects included, bankruptcy of large construction firms, business interruption and massive job losses. The study identified a total of 18 COVID-19 impacts on the construction sector. A study on the impact of COVID-19 on the construction industries in developing countries by Ahmed et. Al. (2022) cites schedule delays, project suspension, cost overrun and effects on mental health as particularly significant factors.

In Asia, studies on the adverse impact of COVID-19 on construction industry participants reveal similar findings. In Malaysia, Esa et al., (2020) and Jagun et al., (2022), found that Covid-19 caused projects delays, cost overrun, unavailability of human resources and materials. In Singapore, Ling et al., (2022) study revealed that projects suffered severe delays (by 45%) and cost overruns (more than 5%) and lower quality compared with those before the pandemic. Other studies in the UAE (Sami Ur Rehman et al., 2022), Jordan (Bsisu, 2020) and Iraq (Al-Mhdawi et al., 2022) found the factors impacted the most by the pandemic are, safety management measures, interpretation of the contract language, building material prices, risk management practices, availability of construction labour (including subcontractors).

As the UK emerges from the pandemic and aligning to the “Building Back Better” UK government agenda, a more holistic, systems-led approach to construction is needed. Application of principles of sociomateriality and examining construction as a sociotechnical system can provide clarity to initiatives such as MMC and OSM, potentially leading to better overall effectiveness and construction industry performance.

Survey results and system modelling

The online survey resulted in a response rate of 23%. The main findings of the survey were:

- 85% of respondents said that their company had been directly impacted by COVID-19
- 40% of respondents stated that they expected to face short-to-medium term difficulties due to COVID-19
- 60% stated that they felt unsupported as a sector
- 65% stated that their company had experienced staff absences due to COVID-19
- 95% stated that they felt that the outlook for the construction sector post-pandemic was uncertain, reasons given include
    - Materials prices
    - Labour and skills availability
    - Inflation
    - Availability of affordable finance

Using the survey data, literature review findings and the results from *'Keeping the UK Building Safely Report,'* we have produced a graph (Fig 34) which illustrates the complexity associated with the challenge facing the UK construction industry in a post-pandemic economy. It has five key regions (denoted by a colour code) and illustrates points of interconnectedness (variables defined by a larger number of cause-and-effect relationships), which could be described as intervention points. Whilst the graph cannot be exhaustive of all issues that a relevant to understanding complexity, it is helpful in highlighting some important points

It focusses our attention on five themes that we believe are characteristic of the challenge facing the UK construction sector, and small to medium sized enterprises. The graph illustrates the connectedness of these themes with other themes in the wider construction system. The graph also provides indications of the incidence of multi-level associations – these are helpful in shaping our understanding of the relationship between central government policy making and the actuality of challenges facing the sector at a local level.

Moreover, the graph shows the relationships between different variables across the construction system, and the presence of highly interconnected variables which are likely to be influential in the long-run behaviour of the system.

Finally, the points of high interconnectedness provide a strong focus for further investigation and are potentially areas policy professionals to focus their attention on.

The five key regions we have identified in our research are: -

Orange	**Productivity:** The government's ambition to 'Build Back Better' by promoting greater investment in infrastructure programmes and projects may not necessarily deliver long-term productivity improvements; a decade of increasing underperformance in the sector is a consequence of systemic and entrenched problems. It is widely believed that a major cause of the UK's poor productivity performance, relative to the period 1990-2007, is a significant rise in self-employment and a "long tail" of unproductive small businesses. This has been known for some considerable time and was emphasised in the 2018 House of Commons Business, Energy and Industrial Strategy Select Committee report into small businesses and productivity. The enquiry included evidence from the ONS, which showed that 90% of the firms in the lowest decile of the labour productivity distribution (referred to as "the laggards" in the report) were businesses employing less than 10 people. By contrast, the top quartile of businesses are in the region of two-to-five times more productive than the bottom quartile.
Red	**Resilience:** The sector is extremely vulnerable to shocks. Of the three industries that experienced the highest number of insolvencies in the 12 months ending Q1 2022, Construction accounted for the greatest proportion (3,213 insolvencies, 19% of cases) followed by repair of vehicles (2,100 insolvencies, (13% of cases) and accommodation and food services (1,977 insolvencies, 12% of cases with industry captured). Unsurprisingly, the construction sector usually has the highest quarterly number of insolvencies of any industrial grouping (ONS 2022). The construction sectors' recovery from the pandemic is critical to economic recovery, but this is an unrealistic prospect unless sustained effort to transform procurement routines is maintained. The tragedy of the Grenfell Tower fire and the subsequent findings from the inquiry have highlighted many practices within construction projects that are simply unacceptable. The Independent Review into building safely (The Hackett Review), revealed how commercial practices led to unrelenting focus on price at the expense of health and safety. It is well known that the sector operates on narrow profit margins characterised by aggressive price competition and a culture of undercutting. This environment is neither

	resilient nor sustainable.
Blue	**Materials**: Construction supply-chains are exposed to significant uncertainty. Our own research uncovers evidence of construction materials price quotes expiring after 24 hours because of inflationary concerns - arising from COVID-19 and the war in Ukraine, we suspect. The increased cost of energy, reported to be in the region of 55% in April 2022, is likely to impact upon energy intensive foundation materials suppliers such as steel, concrete, and cementitious products. The concerns are so great that it is likely that the volatility of energy prices may lead to surcharges to ameliorate the additional costs, which are ultimately absorbed by clients. An absence of materials price continuity will have a profound effect on smaller business who will invariably find it harder to quote for projects on fixed price contracts., which are often sought by clients, particularly in the domestic segment.
Green	**Digitalisation and technological innovation** are key to improving productivity, but entrenched structures, fragmentation and 'ways of working' in and across the construction industry present significant transformation challenges. The digital transformation challenge is not one that is unique to the UK; a recent report by the European Commission highlights concerns that the digitalisation of the construction sector appears to be purely focused on BIM (Building Information Modelling) despite the availability of other technologies such as automated fabrication through robots and autonomous devices, 3D printing and scanning, sensors and the Internet of things (IoT). The need to consider implementation of digitalisation in the construction sector is incorporated into an EU procurement directive published in 2014 – the subsequent departure of the UK from the EU necessitates some work to ensure that UK's construction sector remains competitive in the wider European and international context.
Purple	**Materiality of construction**: Recognition of the importance of the materiality of construction is crucial; efforts to accelerate modern methods of construction across the sector should be tempered with an appreciation of the value that is attached to the skill of 'building.' People and technology are equally important considerations in the presumption towards Modern Methods of Construction (MMC)

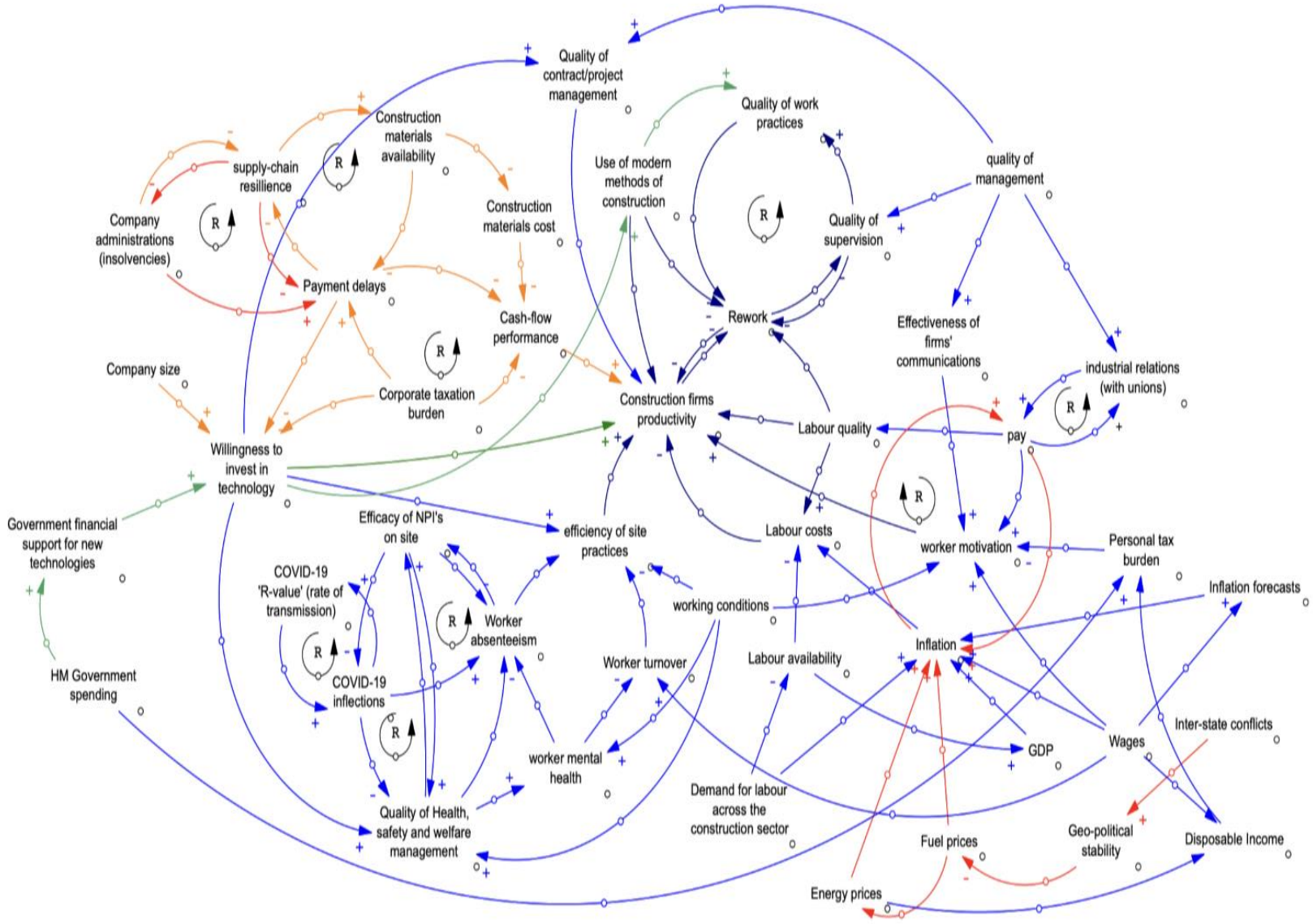


Fig 34: Systems map of challenges facing small-to-medium sized construction businesses in the post-pandemic UK economy.

Contractual performance

Introduction

In the 2021 report ‘Keeping the UK Building Safely: a scoping study’, evidence of the impact of systemic and deep-rooted challenges in the construction industry in the context of the pandemic is presented. Six key themes, pertinent to industry’s response to reducing COVID-19 transmission, are identified: contractual partnerships; organisational culture; communication; multi-level challenges; context of the sector; and best safety practice and technology use. We know that contracts are a key factor in shaping the behaviour of construction project participants and this is elegantly reflected in the comments of one participant to the study who told researchers that ‘COVID has changed the world, except for the contract on this job!’

In May 2020, the Cabinet Office issued new guidance to encourage responsible contractual behaviour during the pandemic; it states that ‘parties to contracts impacted by the COVID-19 emergency should act responsibly and fairly, support the response to COVID-19 and protect jobs and the economy.’ This guidance was designed to mitigate against the negative impacts of COVID-19 and complement new HMT Treasury supported mechanisms including Coronavirus Business Interruption Loans (CBILs) and ‘bounce-back’ loans. Nevertheless, ONS data reveals the extent to which COVID-19 has ravaged the construction industry; company insolvencies in the 12 months leading up to Q1 2022 were 3,213, accounting for 19% of all insolvencies. In February 2022, 307 insolvencies were recorded, the highest on record since the beginning of the pandemic. Our analysis also reveals evidence that contractors are paying circa 20% more for construction materials when compared to the same time in 2021.

Aim and objectives

Aim

In this rapid-evidence study, we seek to develop a more detailed understanding of the impact of the COVID19 pandemic on the performance of construction contracts in the context of building and civil engineering projects across the UK.

Objectives

- Produce a rapid evidence review and bibliometric analysis on the peer-reviewed literature associated with the performance of construction contracts during the COVID19 pandemic

- Gather and analyse data on the performance of construction contracts in the UK including dispute prevalence

- Identify and characterise two case studies of dispute resolution during the COVID19 pandemic in the UK

- Make recommendations aligned with the UK governments' ambition for improving productivity in the construction sector

Research methodology

This report adopts a qualitative methodology, based on a combination of structured systematic literature review supplemented by primary data gathered from the Royal Institution of Chartered Surveyors (RICS). The literature search draws upon a corpus of peer-reviewed articles identified through the Web of Science database. The searches were conducted using the 'Topic' search or the 'All Fields' options, both of which include looking for keywords within the title, abstract and keywords fields of each article.

An initial series of searches were undertaken during mid-February 2022 using a sequence of key-word combinations focused on the terms "construction" and "COVID", with adaptations to take account of synonyms. Because of the polysemous character of the some of the keywords used, especially the words "construction" and "contract," it was necessary to manually filter the articles identified in each search by inspecting their title and abstract to exclude items that appeared to have no direct relevance to the aims and objectives of this report. In many cases such exclusions involved articles in which the word "construction" was being used to mean something distinctly different, for example, the construction of an argument, or a theory or hypothesis; or in the sociological sense (i.e. 'constructivist'). Likewise, many of the excluded articles used the word "contract" as a verb, for example to contract a disease.

These searches were undertaken in a hierarchical way, extending the search terms and noting the additional articles of relevance identified at each step. The

combinations of keywords and numbers of further relevant articles identified at each step are shown in Table 18 below.

Step	Keyword combination	Total number of articles found in this step	Number of further relevant articles identified
1	Construction *AND* COVID *AND* UK	85	5
2	Construction *AND* COVID *AND* [UK *OR* Britain *OR* England]	142	6
3	Civil Engineering *AND* COVID	28	2
4	Construction Sector *AND* COVID	38	6
5	Construction *AND* COVID *AND* Contract* (i.e. Contract + something e.g. Contract Law)	51	22
6	Construction Sector *AND* [COVID-19 *OR* COVID *OR* Coronavirus *OR* Sars-CoV-2 *OR* Pandemic]	44	6
7	Construction *AND* [COVID *OR* Pandemic] *AND* Contract	39	3
8	Construction *AND* [COVID *OR* Pandemic] *AND* Delays	17	6

Table 18. Keyword combinations and outcomes from initial searches

This initial series of searches generated a total of 56 articles. This number might be compared with an overall total of 1794 articles produced by an unfiltered search with the keywords “Construction” *AND* COVID when searching with the ‘All Fields’ option, or 1269 with the ‘Topic’ option; and an overall total of 6398 articles in an unfiltered search with the keywords “Building” *AND* COVID when searching with the ‘Topic’ option. By contrast, an unfiltered search with the keywords “Civil Engineering” *AND* COVID using the ‘Topic’ option produced only 4 articles, of which only one was of relevance, but gave 28 articles when using the ‘All Fields’ option, of which two were relevant.

A preliminary consideration of the 56 articles identified in this first series of searches showed that only 14 devoted more than a minor consideration to contractual or legal issues, with most concentrating on health and safety or practical construction matters. A more detailed analysis and review of these 56 articles in given later in this report.

However, it became clear from this preliminary examination that the contractual issues raised in those 14 articles concerned matters of contract law and legal interpretation that were of wider applicability that just the construction industry. Furthermore, some of the impacts on the construction industry identified in those

articles arose from disruptions elsewhere, for example within the supply-chain, to which wider contract law was likely to apply. Because of these observations and the influence in Common Law jurisdictions of legal precedents set in one area of contract law on decisions in another area, it was decided to complement this first series of literature searches by a second series of structured searches using the 'Topic' option and the terms "COVID" *OR* "Pandemic" in combination with terms related to contract law, sometimes filtered with the term "contract" or the term "construction". In this series of searches, only articles with a publication date of 2019 onwards were identified, to exclude articles of a largely historical relevance.

Again, it was necessary to filter the articles identified in each search by manually inspecting their title and abstract to exclude items that appeared to have no direct relevance to this investigation. The various combinations of keywords and numbers of relevant articles identified are shown in Appendix 1. This second series of searches generated an additional 46 relevant articles not found in the first series of searches, as well as finding again 25 of the 56 articles identified in the first series of searches.

As a final part of the search process, at the beginning of March 2022, a further search using the 'Topic' option was undertaken on the Web of Science database using the search terms "COVID19" *OR* "COVID" *OR* "coronavirus" *OR* "Sars-CoV-2" *OR* "Pandemic" in combination with the term "contract", whilst restricting the search to articles with a publication date of 2019 onwards and to those categorised within the database under the following categories: 'Construction Building Technology' or 'Engineering Civil'; 'Business' or 'Business Finance'; 'Law'; 'Management'. Again, the articles identified in each search were filtered manually by inspecting their title and abstract so as to exclude items that appeared to have no direct relevance to this investigation. The results of this search are summarised in Table 19, below.

Web of Science Categories	**Total number of articles found in this Category**	**Number of relevant articles found**	**Number of relevant articles not found previously**
'Construction Building Technology' or 'Engineering Civil'	16	2	0
'Business' or 'Business Finance'	35	6	0
'Law'	76	21	2
'Management'	25	2	0

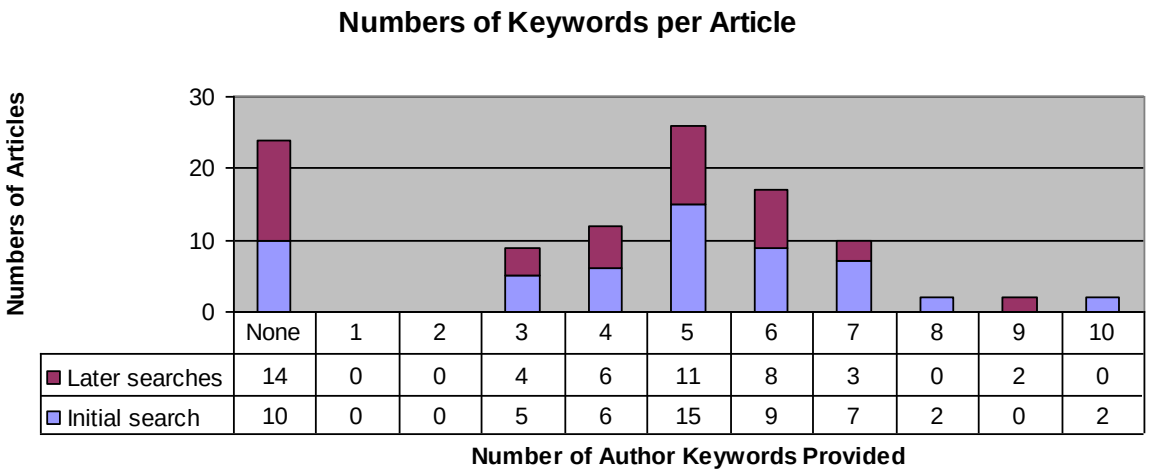
Table 19. Web of Science Categories and numbers of articles found in final searches

The fact that only two relevant articles were found within these Categories that had not been identified in earlier searches gives confidence that the 102 articles found previously plus the two additional articles identified in this final search represent a comprehensive collation of relevant peer-reviewed literature as published up to the end of February 2022.

These 104 articles were then subjected to the process of review and analysis described in the subsequent sections of this report.

The 104 peer-reviewed articles identified via the structured literature search described earlier were analysed in a structured manner using a variety of approaches, starting with examination of the keyword phrases provided by the author or authors of each article.

A preliminary inspection of data from the Web of Science database showed that of the 56 articles identified in the initial searches, 10 did not have any author keywords; whilst of the 48 articles identified in the later searches, 14 had no author keywords. For those articles with author keywords, the number of keywords provided varied between 3 and 10 per article. Figure 35 below shows the frequency distribution of the number of keywords provided.



	None	1	2	3	4	5	6	7	8	9	10
Later searches	14	0	0	4	6	11	8	3	0	2	0
Initial search	10	0	0	5	6	15	9	7	2	0	2

Figure 35. Numbers of author provided keywords per article

The 46 articles with keywords identified in the initial searches had a total of 253 keyword phrases, whilst the 34 articles with keywords identified in the later searches had a total of 178 keyword phrases. An analysis of these author provided keyword phrases was undertaken to establish the number of unique keyword phrases used and the frequency of their use. After being amended to eliminate minor differences, such as spelling and capitalisation, this analysis showed that of the 253 keyword phrases in the 46 articles from the initial searches, 88 keyword phrases were used in more than one article, and 165 keyword phrases were used in only one article. In the

equivalent analysis of the 178 keyword phrases in the 34 articles from the later searches, 46 keyword phrases were used in more than one article, and 132 keyword phrases were used in only one article.

When the overall total of 104 articles were analysed, 24 had no author provided keywords and of the 431 keyword phrases that were provided, 147 phrases were used in more than one article, with the remaining 284 keyword phrases used in only in one of the 80 articles with author provided keywords.

Not surprisingly, “COVID-19” was the most commonly shared keyword phrase, appearing in 54 of those 80 articles; 33 of the 54 articles being from the initial searches and 21 from the later searches. “Force majeure” was the next most commonly shared keyword phrase, used in 14 of those 80 articles; only 3 of these articles being from the initial searches and 21 from the later searches.

The next most shared keyword phrases were “Construction industry” and “Construction”, each of which being used in 10 of the 80 articles. In these cases, more of the uses were from articles identified in the initial searches; where “Construction industry” was used in 10 of the 46 articles with keywords identified in the initial searches and the keyword “Construction” was used as a single keyword in a further 9 of the 46 articles. By contrast, the keyword phrase “Construction industry” was not used at all in the 34 articles with keywords identified in the later searches and the single keyword “Construction” was used only once in those 34 articles.

However, the word construction was also used as an adjective in keyword phrases such as “Construction site”, “Construction management”, “Construction project”, “Construction safety” and “Construction workers”; with each such phrase only being used in five or fewer articles. In total, the word construction was used, alone or in combination with other words, within 54 keyword phrases shared amongst 44 of the 80 articles with author provided keywords.

Other relatively frequently used words, not so far discussed, which appeared alone or in combination with other words within the keyword phrases that were shared by 10 or more articles are: safety (used within a total of 21 keyword phrases in 16 articles); pandemic (within 16 keyword phrases in 16 articles); and law (within 12 keyword phrases in 10 articles). The frequency with which each unique keyword phrase is used is shown in Fig 36 for those keyword phrases that are provided in more than one article.

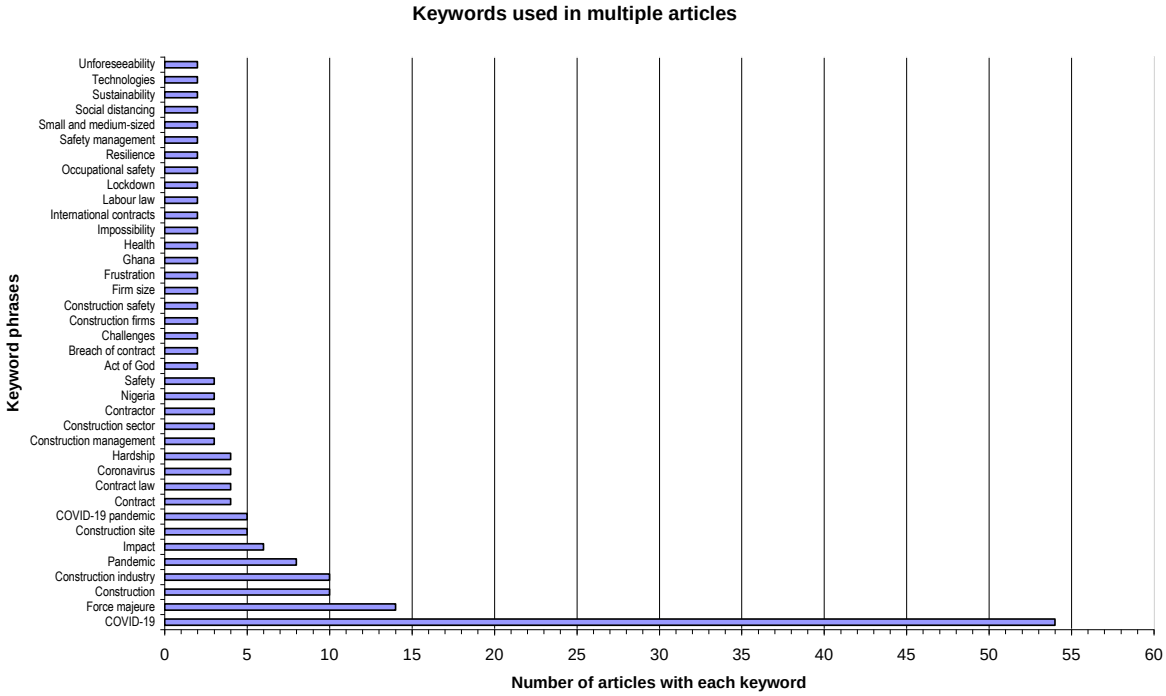


Figure 36. Frequency of use for keyword phrases used in more than one article

The preliminary analysis of the 104 peer-reviewed articles identified via the structured literature search also examined their abstracts, as curetted in the World of Science database. Of the 56 articles identified in the initial searches, 2 did not have an abstract; whilst of the 48 articles identified in the later searches, 1 had no abstract in the database.

For the remaining 101 articles, this preliminary examination was used to identify the main topics addressed by the article, the general methodology or research methods on which it was based, its technical focus and the geographical or contextual scope of its contents. An assessment was also made regarding the nature of the main findings or conclusions reached in each article. For the three articles without an abstract, a similar assessment of their character was obtained from their titles and from a speed-reading of their full text.

The results of this preliminary analysis were used to identify the more significant articles that should be analysed in detail and those for which a less detailed review would be more appropriate to the purposes of this report.

An indication of the range and character of the articles is shown in the following summary of this preliminary analysis. The geographical coverage of the articles ranged from a specific focus on individual countries and their legal systems to wider comparative examinations of pairs of countries or more and to the general international situation. The distribution of the geographical and legal focus of the articles is shown in Fig. 37 and Fig. 38. For simplicity, the specific countries and

legal systems involved have been grouped into a manageable number of broadly homogenous categories. In interpreting the contents of each article allowance was made for the different context and circumstances applying in the countries concerned when assessing the relevance of that article's findings to the UK.

In the case of legal systems, particular attention was paid to articles dealing with Common Law systems, especially English Law, and to the Common Law aspects of those articles which addressed multiple legal systems or were comparative in nature.

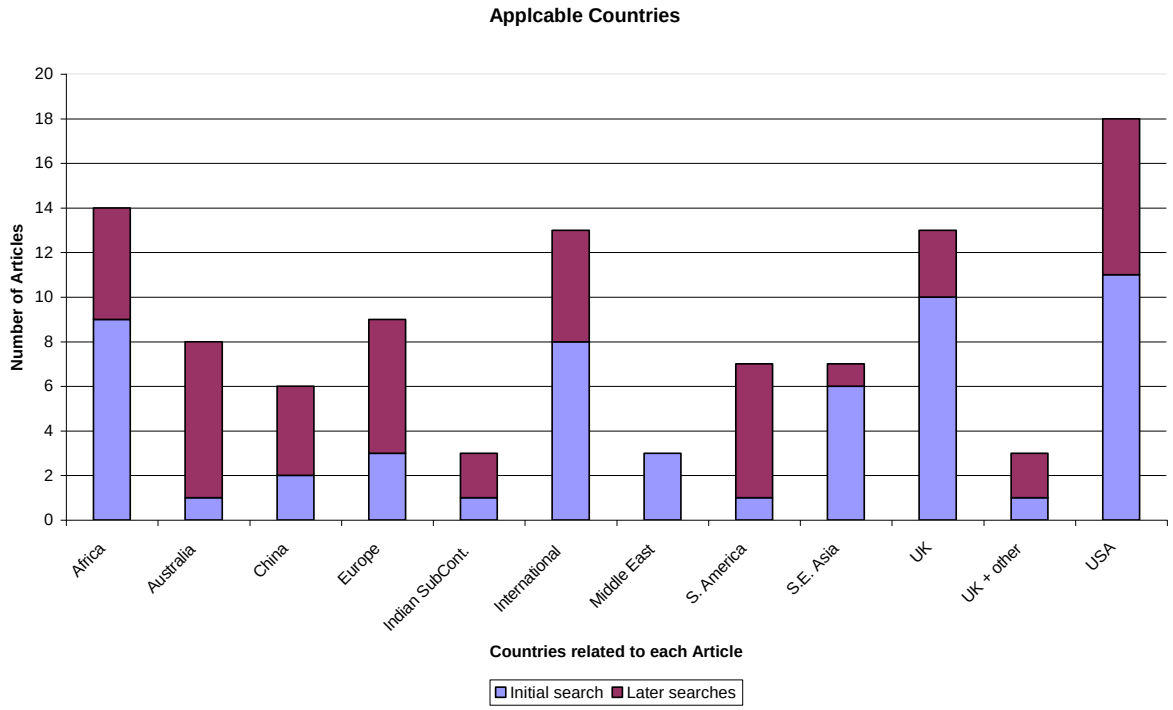


Fig. 37 Numbers of articles applicable to various countries or regions

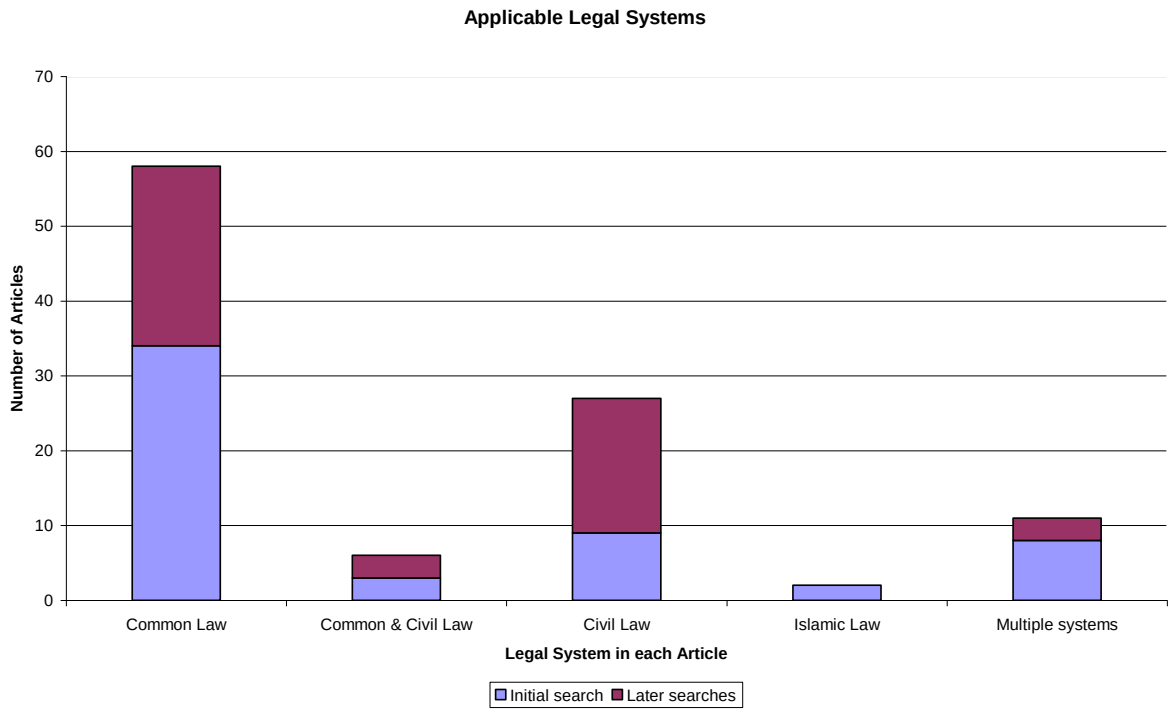


Fig 38. Numbers of articles applicable to various legal systems or jurisdictions

The 104 articles covered a wide range of academic approaches, data sources and research methods. Whilst almost all of the articles contained some introductory review of relevant literature, 54 had substantial reviews of either published literature or other contemporary data sources. Those articles focused on contractual and legal issues, mainly articles identified in the later literature searches, often had substantial reviews of legal theory and case-law, typically comparative in nature. A total of 27 articles employed this type of approach.

Empirical data collection was widely used amongst the articles identified in the initial literature searches, with different methods sometimes used in combination within the research reported in the same article. Across all 104 articles, questionnaires were the most widely reported method of data collection, employed in 20 of the articles; interview surveys were used in 17 of the articles. By contrast, only 8 of the articles reported using case studies and only two specifically referred to using focus groups. However, reference was made to using ‘expert opinion’ in 15 of the articles, especially those focused on legal matters.

The methods used to analyse data also varied greatly, with a minority of articles based on advanced statistical analysis techniques, for example applied to epidemiological data on COVID-19 transmission or to financial data on construction company stock prices or to measures of construction activity and employment. In some cases, relatively advanced statistical techniques, such as structural equation modelling, were employed to analyse empirical data from questionnaire surveys. In total, 26 of the 104 articles used this more advanced quantitative method. The other

articles that used empirical data largely employed qualitative methods of data analysis, or so-called mixed methods, including less advanced techniques, such as factor analysis. Most of the articles concerned with legal issues used methods of comparative analysis and reference to legal theory and case-law.

To conclude the preliminary analysis of the 104 peer-reviewed articles identified via the structured literature search, a qualitative rating was attributed to each article, derived by subjective judgement, using a Likert-type scale on each of two dimensions: its contextual relevance for this investigation; and its legal content and relevance to the contractual circumstances applying to UK construction projects. The resulting distributions of these two ratings across all 104 articles is shown in Fig 39 and Fig 40.

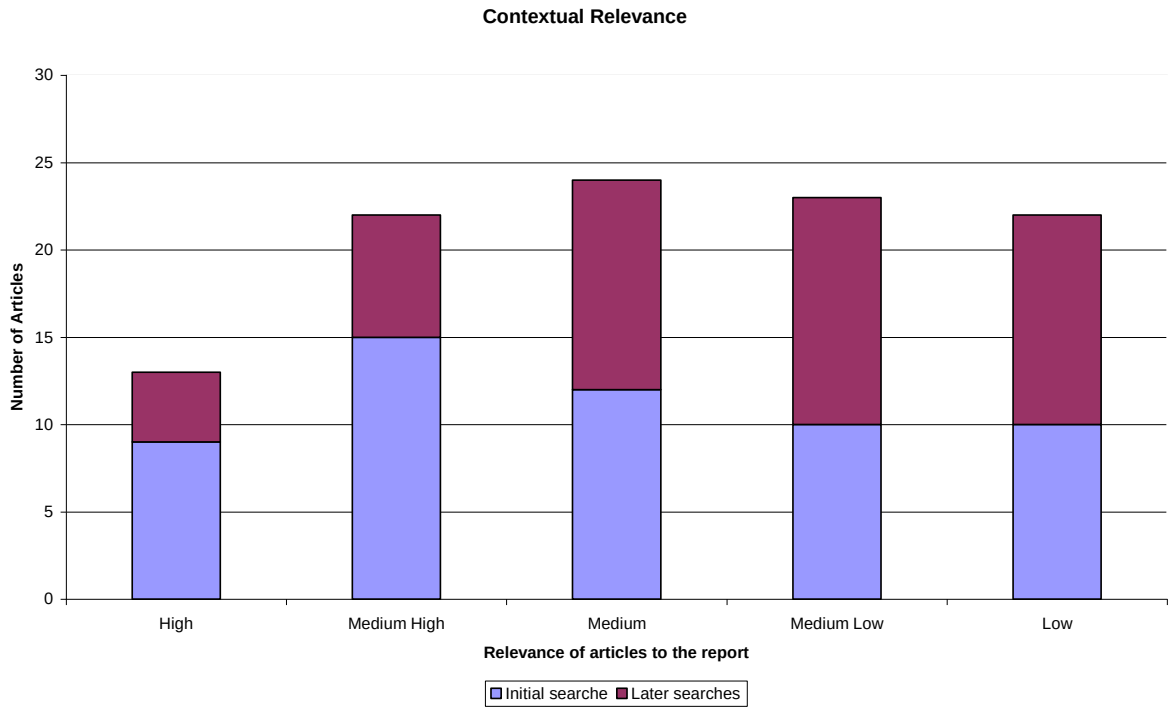


Fig 39. Numbers of articles with different levels of contextual relevance

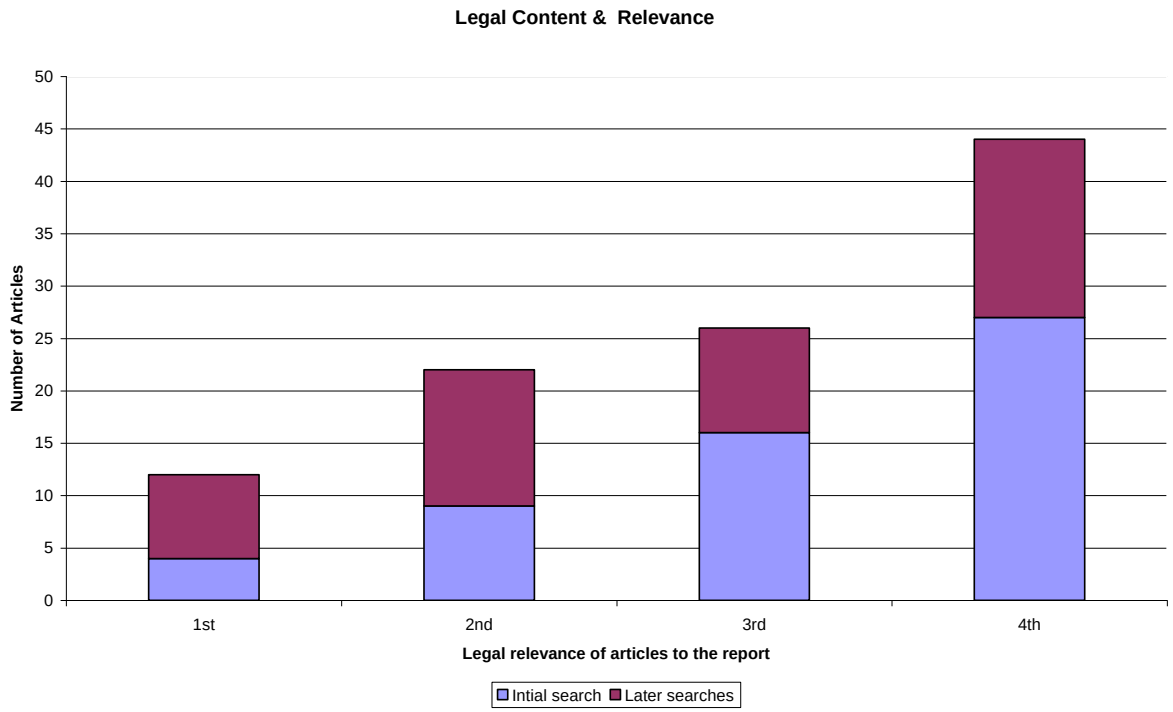


Fig 40. Numbers of articles with different levels of legal content and relevance

Using a combination of these two ratings, the top 26 apparently most relevant articles were selected for detailed thematic analysis from the total of 104 articles identified via the structured literature search. The remaining articles were reviewed in less detail.

The basis of that thematic analysis and the resulting findings from the review are explained later in this report.

Literature review

Introduction

The preliminary analysis of the 104 peer-reviewed articles, identified via the structured literature search, revealed eleven underlying themes in their findings that were likely to be influential to understanding the impacts of the COVID-19 pandemic on construction contracts in the UK and thus draw meaningful conclusions regarding their performance and fitness for purpose. These eleven themes are listed below in the order in which they appear most likely to have had an impact of the performance of construction contracts.

It is important to note that these impacts are inherently inter-dependent and are reflective of the complex interactions associated with the organisational structure of

the UK construction industry and the ways in which construction projects are designed, procured and implemented. Since the impacts of the COVID-19 pandemic on the UK construction industry are both multifaceted and are likely to be long-lasting, with various levels and time effects in the interaction between these themes, the order in which they are listed here is to some extent arbitrary and should not be interpreted as any indication of relative importance or of causation between the different themes.

The eleven themes identified within the literature are:

- Health and safety issues
- Epidemiological issues
- Workforce issues
- Construction issues
- Regional issues
- Supply-chain issues
- Project issues
- Contractual issues
- Viability issues
- Procurement issues
- Legal implications

Whilst the reporting of the literature review is grouped under these eleven thematic headings, it should be noted that the impacts of the eleven themes overlap and thus the allocation of parts of the findings from individual articles to any particular theme is to some extent arbitrary.

The review of the literature and reporting of the findings from individual articles has been undertaken through the lens of impacts on the performance of UK construction contracts.

The selection of findings and emphasis placed upon them should not, therefore, be regarded as wholly representative of the individual articles from which they are drawn.

Although the predominant sources used in this thematic review are the top 26 apparently most relevant articles selected from the 104 peer-reviewed articles identified via the structured literature search; it also reflects relevant information from the rest of those 104 articles and from some of the sources cited within them. In particular, some information has been taken from a paper by Ogunnusi et al (2020) that is cited in Ogunnusi et al (2021) and reports a more quantitative analysis of empirical data from the same survey work but was published in the International

Journal of Real Estate Studies, which is not amongst the journals curetted in the Web of Science database.

Note on dates and context

In interpreting the findings and commentaries within the 104 peer-reviewed articles identified via the structured literature search, it is important to have regard to the context in which the research reported in those articles was undertaken. In particular, the prevalence of COVID-19 infection, the existence of restrictions on movement and other activities, the nature of the infection control and other advice to the construction industry, the existence and apparent transmissibility of the prevailing coronavirus variants, and the existence, take-up and effectiveness of Covid vaccines have all changed over time during the course of the COVID-19 pandemic.

Additionally, these factors, and especially the prevalence of infection and the take-up of vaccines, have varied from place to place as well as over time. Whilst these variations and differences may have been particularly obvious between one country and another, they have also been significant within countries. Even within the UK, the prevalence of infection and associated impacts on workforce availability, together with local differences in government restrictions have at times differed markedly both between the four devolved constituent countries and between different parts of England.

Consequently, it is important to consider, when contemplating the findings and conclusions in the articles, the dates when any data were collected and especially surveys or reviews of contemporary information were conducted that have been used in the articles. This is particularly important because most of the empirical research reported in those 104 articles was undertaken between April and September 2020, despite many of the articles not being published until mid-2021 or early 2022. Even where articles were submitted for publication in mid-2021 or later and were citing sources from 2021, those sources were often based on data or contemporary information collected no later than autumn 2020.

Thus, much of the commentary, discussion and conclusions in the articles is based on a situation before the widespread availability of Covid vaccines and relates to the situation in the UK associated with the first wave of COVID-19 infections and the initial lockdowns and other restrictions during the period from late March 2020 through to autumn 2020.

Health and safety issues

Concern over the health implications of the COVID-19 pandemic, both for individual workers and for the risks of disease transmission within the workforce and wider society dominated the early responses to the pandemic in the UK and elsewhere worldwide. The resultant direct consequences for construction activities arose partly through the various non-pharmaceutical interventions (NPIs) introduced by governments in the UK and elsewhere and their impacts both on the workforce, which are considered under other themes, and more specifically from the necessary changes made to working practices. These changes were adopted to meet various government restrictions or associated guidance, such as the Site Operating Procedures issued by the UK Construction Leadership Council, and also to address the health concerns of the workforce and meet the general duty on employers to reduce workplace risks by taking preventative measures to protect the health and safety of workers and others (Sierra 2022, Jones et al 2022, Stiles et al 2021).

The changes to working practices, typically involving more working from home where possible and substantial adaptation to working methods in offices and on-site, have had both impacts on costs and productivity that are considered under other themes, and on non-Covid aspects of health and safety. These secondary health and safety impacts have included some evidence of distraction or reduced focus on other non-Covid health and safety issues, a reduction in levels of supervision resulting from some ‘management staff’ moving off-site to work from head-office or home, and the use of some Covid protection measures such as face coverings, adversely affecting or interfering with the effectiveness of other safety related PPE or safe working practices (Stride et al 2022, Jones et al 2022, Stiles et al 2021). On the other hand, there is also some indication that the additional attention to the scheduling and planning of construction activities needed to address social distancing and other Covid-related requirements has resulted in the potential for improvements in health and safety matters more generally (Stride et al 2022, Jones et al 2022, Stiles et al 2021). However, the studies on which these observations are based were all undertaken at a relatively early stage in the COVID-19 pandemic and all of the studies comment on the lack of sufficient time and data for any clear conclusions on whether these secondary impacts will on balance have a positive or negative overall effect on construction health and safety.

What is clear, however, is that the additional management effort required to respond to the health risks associated with the COVID-19 pandemic and the necessary changes in working practices have had substantial impacts on the execution of construction projects which inevitably have contractual implications. These issues are addressed under later themes and in subsequent parts of this report.

Epidemiological issues

Whilst the COVID-19 pandemic has clearly had impacts on the construction sector through the various health and safety measures and changed working practices adopted to directly address the risks of disease transmission within the working environment, it has also been affected by wider epidemiological issues. The literature related to both the UK and the USA shows that workers in the construction industry are amongst those experiencing a higher-than-average rate of COVID-19 infections (Stiles et al 2021, Pasco et al 2020). Furthermore, the peripatetic character of construction work, with some workers living in hostels during he working week whilst travelling often substantial distances home at weekends and other workers travelling from site to site during their work, creates both greater risks of wider disease transmission within the community and greater likelihood both of exposure to infection outside of the workplace and of workers being constrained by geographical variations in Covid-related controls, such as movement restrictions (Assaad & El-adaway 2021, Amoah & Simpeh 2021, Gan & Kohl 2021).

Whilst the imposition of movement controls has been limited within the UK, there is some evidence that travel restrictions, especially those applying to international travel, may have exacerbated shortages of skilled on-site workers. Short-term shortages in the workforce have also been caused not only by direct COVID-19 sickness effects, but also by workers self-isolating due to infection of others in the same household and due to child-care issues arising from school closures (Sierra 2022, Rakha et al 2021).

The various trade-offs between epidemiological concerns regarding infection control and limiting the adverse economic impacts of restrictions imposed to limit COVID-19 transmission have been the subject of both empirical studies and mathematic modelling (Assaad & El-adaway 2021, Rakha et al 2021, Pasco et al 2020). Although the conclusions of these studies generally suggest that the overall health and economic impacts from restrictions outweigh the direct economic harm they may cause, the direct economic impacts often fall disproportionately on individuals and individual companies and on their ability to fulfil their contractual obligations. The detailed implications of this situation for the performance of such contracts are considered under later themes, but it is clear that the global nature of the COVID-19 pandemic coupled with its highly contagious nature pose particular problems for the drafting and administration of contracts for projects that may extend over several years and involved supply-chains that extend across continents (Casady & Baker 2020, Olatoye 2021, Kiraz & Ustun 2020).

Workforce issues

The impacts of the COVID-19 pandemic on the construction workforce have ranged from direct adverse effects on the health of individual workers, through indirect health impacts through stress and other effects induced by changes in working practices or by the economic and psychological effects related to potential illness or loss of income, to loss of employment or insolvency (Sierra 2022, Stride et al 2022, Jones et al 2022, Ogunnusi et al 2022, Ogunnusi et al 2021). Of course, such issues are not unique to the construction sector, nor to the UK (Assaad & El-adaway 2021, Ayat et al 2022), but the long-term impacts on the UK construction workforce may be difficult to predict given its traditional reliance on casual or self-employment and the predominance of small and medium-sized enterprises in the UK construction industry.

At a wider industry level, workforce shortages, especially amongst skill site-workers, have been exacerbated by some of the effects of the COVID-19 pandemic and the NPIs and other measures adopted in response (Sierra 2022, Stride et al 2022). So, whilst some in the workforce have faced redundancy and substantial losses of income, elsewhere delays to construction have apparently been caused by a lack of suitable workers, or at least by their temporary absence from work. It is unclear whether in the longer term the COVID-19 pandemic will result in greater construction workforce shortages, or whether a general reduction in construction activity will lead to an increase in unemployment in this sector.

Meanwhile, for those projects where Covid-related workforce shortages have led to delays, the resulting contractual implications may be problematic. This is an issue considered under later themes and in subsequent parts of this report.

Construction issues

There are many types of construction work, from new-build to renovation and maintenance; all usually involve a variety of activities: some undertaken by people working alone, most by people working in groups, often in close proximity; some involving large and complex construction plant, others with people using hand tools or supervising and checking the work of others. Some construction work takes place in the open air, on large construction sites, in the street, or on the outside of buildings; but some of necessity takes place inside buildings, or in confined spaces often with poor ventilation. The impact on construction work of Covid-related NPIs such as social distancing has inevitably has therefore been both substantial and multifaceted (Sierra 2022, Stride et al 2022, Jones et al 2022, Stiles et al 2021).

Many of the articles from the literature search reported substantial reductions in on-site productivity as a direct consequence of the changes to working practices introduced as a consequence of the COVID-19 pandemic. The following quotations exemplify this point:

> "The implication is that social distancing, the protocol with the greatest impact, is reducing on-site productivity by an average of 20%." (Sierra 2022)

> "Reports display that this involves other challenges such as increasing construction costs and a greater need for pre-fabrication as social distancing is proving to be difficult due to manual handling procedures and sites are progressing with a minimal effect due to having a skeleton workforce." (Stride et al 2022)

> "While normally trades work around each other in what can be rather confined spaces, social distancing makes these arrangements much more complex. Where construction involves buildings, these final project stages are more likely to occur indoors, with a higher risk of COVID-19 transmission. The difficulty of these arrangements is exacerbated by these trades often being self-employed or working for small companies within the supply chain. It is not simply that people within the same organization are having to coordinate, but that people from different organizations need to consult and coordinate in a way that has not previously been required." (Stiles et al 2021)

> "Coping with the presence of a coronavirus pandemic on a construction site is difficult, especially when there are suggestions of new and uncomfortable ways of doing the job as a measure to combat the spread of the disease. The construction industry faced an unprecedented disruption in all its activities as the Covid-19 pandemic continues to alter the operational balance of the world. The industry is caught between service assessment of essential and non-essential projects and stakeholders' constant adjustment to implications of site opening and closure around governmental conditions and guidance, while at the same time working to keep the site operational, workers protected and businesses afloat." (Salami et al 2022a)

> "A survey conducted by Suiko (part of Turner & Townsend) on 45 projects completed during the pandemic, revealed the productivity losses of about 7% as a result of labour shortage and impact from social distancing …." (Ogunnusi et al 2021)

The impacts on individual construction projects will have varied according to the nature of the work and of the site, with some projects finding it easier than others to accommodate new ways of working. In some cases, these changed ways of working may have brought advantages, as exemplified by the following quotation:

> "A range of mitigating measures were put in place in attempts to keep projects to programme. One site introduced a second shift to boost construction whilst maintaining fewer workers on site at any one time. This had the added advantages of offering flexibility to the workforce to fit in with family commitments and was generally well received." (Jones et al 2022)

And there is some evidence that the increased time spent planning work to ensure social distancing produced more efficient ways of working for individual workers, albeit at the expense of a slower overall rate of progress on the project overall and

an increase in the managerial effort involved, as exemplified by the following quotations:

> "On all project sites there was an increase in time spent planning work and tasks, to ensure there were not too many workers in each area." (Jones et al 2022)

> "Although some sites had reduced productivity overall and fell behind schedule, there was a strong feeling amongst almost all interviewees that the productivity or effectiveness of individual workers and individual gangs had improved. In other words, there was higher output per worker, even if total site output was reduced by having fewer workers." (Jones et al 2022)

> "Despite these positive views, there was also a recognition that the additional planning was very time consuming for those in management roles. Many interviewees considered it unrealistic in the longer term as it would lead to construction projects taking longer to complete due to the reduced workers on site, and it was considered unlikely that clients would tolerate a longer programme." (Jones et al 2022)

In addition to these direct impacts on the construction work undertaken on-site, there were also impacts related to changes in the working arrangements for some supervisory and management staff where relocation away from on-site offices and a change to greater remote working, whether from 'satellite' offices or from home, brought a mix of benefits and disadvantages, as exemplified by the following quotations:

> "The possibility of working from home using flexible working policies, has typically been used by companies to attract talent, as it appeals to prospective employees. Some companies are more adept than others by continuing to work effectively but are still hampered by other organisations that delay their free-flowing motivation, removing efficiency, productivity and value for money whilst inevitably increasing the skills shortage." (Stride et al 2022)

> "Since government guidelines required workers to stay home if it was not deemed 'essential' to travel to site, the resulting low visibility caused by senior leaders working from home led to some interviewees feeling unsupported and commenting that the challenges faced on site were not recognised by the senior staff." (Jones et al 2022)

> "The reduced ability of the consultants to adequately supervise and inspect works on sites is a big factor that has weighed heavily on them as a result of the heightened level of required site safety for all site personnel." (Salami et al 2022a)

The net overall impact on construction activity has generally been negative, with substantial increases in costs and delays. These effects have been exacerbated by other impacts of the COVID-19 pandemic, explored in more detail under other themes. The following quotations summarise this situation:

> "Organisational crisis has proven to be a major factor for businesses within the construction industry …. there are six main issues that have impacted the industry …. delay and suspension, cancellation, supply chains, additional risk, labour and capital which all relate to the general issues within the sector …." (Stride et al 2022)

> "Many projects are still working to the same timelines and delivery dates expected of their clients, despite a drop in productivity during the peak of lockdown, and an ongoing reduction of site staff." (Stiles et al 2021)

All of these impacts have direct consequences for the delivery of construction projects and hence have substantial contractual implications.

Regional issues

As already noted, some of the impacts of the COVID-19 pandemic have differed between regions, partly because of differences in the NPIs adopted to control infection, but also due to geographical differences in social and economic factors affecting the construction industry, and to differences in behavioural responses to COVID-19.

Firstly, there have been differences in policies regarding NPIs between England, Scotland, Wales and Northern Ireland, with associated differences in guidance relating both to working and social activity in general, and to the construction industry in particular. These differences have ranged from technical details, for example regarding social distancing and face coverings, to more substantial differences regarding the dates and requirements of lockdown restrictions and of their relaxation. (Stride et al 2022, Jones et al 2022).

The specific impact of these differences is unclear, but differences have been noted in the views expressed by the construction industry in different parts of the UK, as shown in the following quotation:

> "The different health and safety measures applied in each territory could be the reason behind the results of the survey conducted by Build UK (*in 2020*) …. This survey revealed that 29% of contractors in England and 32% in Wales think that they would have significant financial difficulties this year due to COVID, while the percentage increases to 42% in Scotland and 45% in Northern Ireland." (Sierra 2022)

The differences in NPIs between in different parts of the UK were not limited to differences between England, Scotland, Wales and Northern Ireland, but included at various times differences in the restrictions imposed in different parts of England, sometimes at a local level. Such differences were usually associated with differences in levels of COVID-19 infection, which would in turn lead to differences in the availability of workers due to individual sickness or to social isolation etcetera.

There is also some suggestion that attitudes towards the perceived risks associated with COVID-19 and thus behaviour with regard to being willing to continue working, either in the face of such risks or despite being required to self-isolate, may have varied with local circumstances. The following quotations illustrate these issues:

> “Interviewees were asked about their own and others’ perceptions of COVID-19 risk. Some were very anxious and had been reluctant to return to work. Others observed that some people took risk less seriously than they did … For self-employed workers who would lose income if they were not at work, there was often a strong drive to return to work for financial reasons, regardless of perceived risk.” Jones et al 2022
>
> “Despite the substantial communications about COVID-19 risk, there was evidence that compliance and motivation were starting to fade several months into the pandemic, particularly as social rules were relaxed outside of work” (Jones et al 2022)
>
> “Thus, the large contractors who work in locations with more relaxed health and safety regulations, as it happens in England, and for the public sector, may not have been affected as much by the crisis as those SMEs located in Northern Ireland and Scotland and working for the private retailing, hotel, or leisure sectors, since the regulations in these locations are stricter, and those sectors have been heavily affected by the crisis.” (Sierra 2022)

Such local and regional differences in the incidence of COVID-19 and in the various responses to the pandemic, both by authorities and by individuals, will have increased the difficulties faced by the construction industry in adopting a consistent approach to its contractual obligations and in managing its contractual relationships.

Supply-chain issues

Because UK construction activity is heavily reliant on imported materials, components and equipment, the impact of the COVID-19 pandemic on UK construction has not been limited to its effects within the UK. The global nature of the pandemic has disrupted the supply chain both through its impact on construction materials manufacturers and through wider disruption to the logistics industry worldwide. This has resulted in shortages of some key construction materials, delays and uncertainties around materials delivery, and substantial increases in prices for both the materials and for their transport (Sierra 2022, Salami et al 2022b).

In March and April 2020, these supply difficulties applied not only to construction materials but also to some of the materials, such as hand sanitiser and disinfectants, needed to meet hygiene and safety requirements. In some cases this caused further delay before even limited construction work could recommence, as well as resulting in much greater costs for such safety measures than would normally apply (Sierra 2022).

The global and inter-dependant character of the supply chains involved and the ongoing fluctuations in the intensity of the pandemic and its attendant restrictions affecting different countries at different dates since the beginning of 2020 have led to recurrent disruptions that have continued to impact on the UK construction industry even when UK COVID-19 infection levels and attendant restrictions have abated.

The following quotations illustrate some of these impacts and their widespread character:

> "China represents about a third of global manufacturing, and the lockdown of China during the first months of 2020 started to have an impact on the availability of products for construction in early March …. Since March, several other countries have suffered severe lockdowns and not all parties involved in the supply chain, such as raw material suppliers, intermediate assemblers, manufacturers or carriers, have returned to work at the same speed … " (Sierra 2022).

> "The items with a significant impact on projects that presently pose a challenge to contractors are mainly mechanical-electrical products … such as HVAC systems, LED lighting, lighting fixtures, fire safety devices, elevators and some other products such as cast iron fixtures, millwork and imported special timber, tiles and stones …"(Sierra 2022).

> "The construction industry was uncertain about supplies from suppliers as the pandemic spreads due to complications in accessing supplies leading to possible shutdown by suppliers. … This led to delivery failures or failure in keeping to material delivery schedules, which impacted heavily on the local supplies and projects" (Salami et al 2022b).

> "As a result of stoppage of production lines in Mainland China due to workers' quarantine program, shipping containers with materials are held up in China's port and there was no transport for finished products from manufacturing factories. The halt in the supply chain potentially caused enormous delays in construction work and cost overruns on projects …" (Salami et al 2022b)

> "The coronavirus outbreak has challenged and continues to challenge every aspect of the supply chain within the AEC industry, forcing stakeholders to cope with increasing uncertainties and continuous change." (Nassereddine et al 2021)

> "The coronavirus pandemic has reflected how vulnerable the globally integrated supply chains can be, especially for businesses that rely on a single supplier or a handful of vendors that are concentrated in one country or geographical region …" (Assaad & El-adaway 2021)

> "The results align with most of the interviewees, who highlighted the significant escalation of construction raw materials and equipment prices due to supply chain disruptions …" (Al-Mhdawi et al 2022)

> "Construction supply chains can be complicated, especially in large projects, owing to the variety of materials used and involvement of many parties (suppliers and subcontractors) required in the construction phase …" (Al-Mhdawi et al 2022)

The significance of these impacts will have varied from project to project, but they will all have been likely to result in delays and in additional costs, with uncertainty regarding the extent to which these might be covered by insurance of how they might be treated within the various contractual relationships involved, as the following quotation shows:

> "The novel coronavirus (Covid-19) pandemic has resulted in the disruption of activities in major centres of global production, with adverse portents for contractual obligations

across global supply chains. The global pervasiveness and dynamic propagation of the risks arising from contractual failures provides an opportunity to reconsider the nature and impact of mechanisms for excusing failure to perform contractual obligations under adverse circumstances …" (Olatoye 2021)

Project issues

Although some construction work, such as routine maintenance, is done on an operational basis, most of the construction activity is undertaken in the form of construction projects. A project is usually defined as a 'temporary endeavour to achieve one or more defined objectives' (BSI ISO:21502 2020), and construction projects, which may have a duration ranging from a few weeks to 10 or more years, are usually implemented by multiple organisations working together. Although these may sometimes be referred to collectively as 'a project delivery organisation' (Stiles et al 2021), the constituent organisations usually remain legally separate bodies whose collaboration takes place within an often-complex framework of commercially driven contracts and contractual relationships.

The various impacts of the COVID-19 pandemic summarised under the previous themes have effects on construction projects both directly, via their practical implications for progress with construction activities, and indirectly through their consequences for the financial and business relationships between the different organisations involved. These latter influences are considered in more detail under later themes in this report, but it is important to note that the method of procurement and the contractual relationships and detailed contract terms used in the project are likely to have significant financial and other implications that will inevitably impinge upon the practical aspects of project execution.

As noted under earlier themes, the COVID-19 pandemic along with the restrictions and the mandated responses to it, has impacted adversely on almost every aspect of construction projects. This has reduced on-site productivity, disrupted the supply of essential materials, increased the need for planning and supervision, and led to substantial cost increases (Sierra 2022, Jones et al 2022, Salami et al 2022a, Salami et al 2022b). As a consequence, over 90% of construction projects in the UK were affected during the 'first wave' of the pandemic in 2020 (Ogunnusi et al 2021), with ongoing impacts both delaying the completion of projects currently under construction and resulting in the deferral or cancellation of planned projects (Salami et al 2022a, Assaad & El-adaway 2021).

Although similar impacts on construction projects have been experienced world-wide (Assaad & El-adaway 2021, Ayat et al 2022), these impacts, whilst widespread, have affected individual projects in different ways and to varying degrees, as indicated by

the following quotation, which draws in part on a survey by Elliott Davis, a North American based business consultants which has construction industry specialists:

> "There is no consensus about the duration and the intensity of the impact, the cost of the impact or if certain projects or markets will shut down or recover soon. A clear example is that, so far, the construction industry has not been uniformly affected. According to the survey carried out by Elliot Davis in May (2020), 13% of the companies have already reduced their workforce, 15% reported significant impacts, but 20% reported that they had no impact or were still ahead of the plan for 2020. The reality is that each contractor is a unique case depending on its size, in which specific sectors of the industry it works …., its location, the local government regulations and aids, and its proximity to sustainable sources of labour and materials." (Sierra 2022).

Although reporting North American data, this quotation echoes experience across the UK construction industry.

The responses to the COVID-19 pandemic have had financial as well as practical consequences, as shown by this quotation:

> "In responding to unexpected events such as that of the Covid-19 pandemic, project schedules are adversely affected especially the critical path activities leading to financial loss through associated project delays." (Salami et al 2022a)

It is also apparent that the wider consequences of these impacts are likely to extend beyond the realm of practical issues and will inevitably affect contractual relationships and the ways in which a project contracts are administered (Salami et al 2022a, Salami et al 2022b).

Contractual issues

The relationships and especially the financial relationships between the participants in construction projects are framed by the contracts between them; and because contractual risks are central to the ways in which many of those participants decide their responses to the COVID-19 pandemic, understanding the contractual issues involved is key to assessing how well construction contracts have performed during the pandemic.

Identifying and managing likely risks are a regular part of any construction activity and financial risks, alongside safety, environmental and operational risks, would have formed a part of the normal commercial considerations and decision making involved in negotiating the terms under which construction projects were procured and their contracts agreed. That said, it appears extremely unlikely that the outbreak of a global pandemic would have been regarded as a likely risk that would impact upon any construction project procured before 2020, at least in the UK (Salami et al 2022a, Casady & Baxter 2020, Osman & Ataei 2022, Hennings et al 2022).

The treatment of unexpected and unforeseen events beyond the control of parties to a contract are often dealt with through what are commonly referred to as ‘Force Majeure’ clauses within the contract, although the term force majeure may not necessarily be used within the terms of the contract (Salami et al 2022b). Issues relating to the legal interpretation of such clauses and to the applicability of the legal concepts involved are considered under a later theme in this report. This theme concentrates on what has been found within the literature about how the impacts of the COVID-19 pandemic relate to construction contracts commonly used within the UK.

Most UK construction work is undertaken under the terms of a contract based on one of the suites of ‘standard construction contracts’: usually either one from The Joints Contract Tribunal (JCT) contract families, intended primarily for building construction; or from the Institution of Civil Engineers’ NEC family of contracts, intended primarily for civil engineering works and infrastructure projects. Now, neither of these families of contracts use the term force majeure and neither expressly provide clear provisions for the advent of epidemics such as COVID-19 (Salami et al 2022b, Ogunnusi et al 2021, Ogunnusi et al 2022, Assaad & El-adaway 2021). Never-the-less, both the JCT and NEC families of contracts do have clauses which, to varying degrees, make provisions for the occurrence of unforeseen events or circumstances beyond the control of the parties to the contract, which have broadly the same effect and may be regarded as ‘Force Majeure’ clauses in all but name (Salami et al 2022b).

However, the concept of force majeure is not formally recognised within the legal doctrine of English Common Law, as applicable to Contract Law, unlike its formal status within the doctrine embodied within many of the codified Civil Law systems (Salami et al 2022b, Hennings et al 2022, Vorotyntseva et al 2021). Consequently, the effect and interpretation of force majeure type clauses within UK construction contracts will depend greatly on their precise wording and on the circumstances giving rise to any attempt at their application (Sierra 2022, Salami et al 2022b).

It is notable that, under both the JCT and NEC families of contracts, not only does a party to a contract who is attempting to use these force majeure type clauses to seek relief from the contractual obligations have to show that the relevant exceptional circumstances that are required to give effect to the clause apply; they have also to show that the contractual obligations concerned have been rendered unachievable as a direct result of the exceptional circumstances as allowed under the relevant clause. Usually, they also must show that these circumstances were beyond their control and that they did everything reasonable within their powers to mitigate the impact of the exceptional circumstance. (Salami et al 2022b, Zin et ak 2021, Hennings et al 2022).

Furthermore, in most circumstances, even a successful application for relief from contractual obligations under the force majeure type provisions of both the JCT and NEC families of contracts will provide a construction contractor only with an extension of time to complete the contract without incurring any contractual penalties for late completion. It will not provide recompense for any additional costs incurred due to this extension of time nor to other impacts of the pandemic, unless the contract terms specifically provide for this, which they normally do not or do so only to a very limited extent. Although there are some provisions under which such a contract could be terminated so relieving a construction contractor of their obligations, only in extreme circumstances would such settlement be on terms that did not leave the contractor financially disadvantaged (Salami et al 2022b, Assaad & El-adaway 2021).

It is therefore anticipated that, as most construction contractors face delays and financial losses on their contracts because of the impacts of the COVID-19 pandemic, contractual disputes are likely to increase substantially. This is despite the UK government urging all parties involved in the construction industry to act in a fair and responsible way and to seek where possible to ensure payments due between the parties involved are made on an equitable basis (Sierra 2022). It must be remembered that these issues of contractual obligations and payments apply not only between a project owner or client and the 'main contractor' undertaking the construction work, but usually also between a 'main contractor' and an often-complex web of sub-contractors and suppliers. In such circumstances, the scope for disputes about delays and their cause, or about non-payment or late payment for work are likely to rise. This is of particular concern given that the construction industry is one of the most adversarial and dispute prone sectors of the economy (Ayat et al 2022).

Viability issues

As already shown under earlier themes, the COVID-19 pandemic has caused substantial disruption to construction work for most projects. This in turn has created financial problems for contractors who have faced not only greater financial outlays, from unexpected expenditure and increased costs; but also lower financial receipts, as anticipated payments for work done have reduced, either because of delays in the completion of parts of the work or due to delays in its inspection and certification, or even deliberate delays in payment, perhaps caused by the financial difficulties experienced by other parties to their contracts (Sierra 2022, Ogunnusi et al 2022, Ayat et al 2022).

The following quotations illustrate some of these issues:

> "The main challenges for contractors tend to be the maintenance of the cash flow, completing projects on time and the availability of skilled workers. The pandemic is disrupting all three. Therefore, contractors are under substantial pressure. … Project cost and maintenance of the cash flow, or in other words, the money is always one of the main challenges for contractors. (Sierra 2022).

> "All interviewees claimed that site works had slowed down and subsequently were making a loss as it was costing more to run the sites than progress was earning." (Stride et al 2022).

> "Construction businesses just like every other business around the world had to absorb the financial shock of delays in delivering construction materials; downtimes on construction sites; and suspension in cash flow from the client. On construction projects, the contractor depends on the financial flow from the client and lending organisations." (Ogunnusi et al 2022).

These impacts, which are likely to have both short term and longer-term implications, have tended to affect contractors differently depending on their size and on the type and location of their construction activities, as the following quotations indicate:

> "Contractors have been affected differently not only depending on the territory in which they work. The economic resilience also depends on the size of the company. Small- and medium-sized enterprises (SMEs) are the backbone of the construction industry, but these types of companies do not usually have large reserves of money …. contractors dedicated only to the private sector will be at greater economic risk, especially if they are engaged in sectors such as retail, hotels and leisure …. in the coming months, there will be an increase in competition for available work, more pressure on operating margins, and aggressive cost control by construction companies. … Insolvency has increased, and cash flow has decreased. Therefore, money has become the biggest challenge for many contractors." (Sierra 2022).

> "There are a multitude of construction organisations including Faithful and Gould (2020), Turner and Townsend (2020), and Arcadis (2020), claiming that there will be significant price rises in the construction industry due to the coronavirus pandemic. … Arcadis claimed that construction costs are constantly increasing in the UK …. they further claimed that the increasing costs could be inflated further, due to COVID-19. … Faithful and Gould further revealed that some estimates display that companies have seen a £2500 per week rise on their construction costs to comply with COVID-19 guidelines. These inflated costs will have a huge impact on the sector and could see businesses fall into liquidation leaving many employees without a job." (Stride et al 2022).

Whilst the longer-term implications of these financial pressures are less clear, several sources indicated that both the duration of the impacts of the COVID-19 pandemic and their potential recurrence were likely to have effects well beyond the duration of the then current COVID-19 outbreak, as the following quotations explain:

> “The obvious reality is that the Covid-19 outbreak will be here longer than anticipated and while it continues to change the world outlook, the construction industry needs to ensure that their workers, sites, projects and businesses are secured for the duration of the Covid-19 pandemic.” (Salami et al 2022a).

> “As construction sites resume operations and workers return to jobsites, the impacts of coronavirus are expected to weigh heavily on the business going forward. … The Covid-19 climate has pushed many construction firms to the edge, making re-evaluation of contractual terms and conditions imperative in a bid to adjust to the prevailing economic realities.” (Salami et al 2022b).

> “In addition, halting other businesses has ripple effects on current and future construction work …. . One predictable result of these ripple effects is an increase in construction bankruptcy filings, which already are more numerous than those of non-construction businesses or industries … . Although force majeure clauses allow contractors to get an extension of time for a project, they typically do not provide additional cost reimbursement; which also might contribute to the failure or bankruptcy of construction firms. All aforementioned measures can bankrupt many construction organizations that have contractual obligations to stay on schedule, and can increase the risk of incurring significant financial penalties.” (Assaad & El-adaway 2021).

How these longer term threats to the viability of firms in the construction sector develop will depend on many factors, some of these will be associated with the general state of both the UK and the wider economy, others will be associated with the ways in which construction projects are delivered and the methods of procurement employed. Central to these influences are likely to be issues of the allocation of risks and of the form and administration of contracts throughout the construction supply-chain, as the following quotation exemplifies:

> “By the very nature of the current crisis, its resolutions will be fundamentally different from that of the last major, global economic crisis. …. However, crises precipitated by the current pandemic will be different. The eye of the storm will be the failure of contracts at firm level. Under the circumstance, the bargain of economic actors will be hashed out at bilateral levels. …. However, for the cases in concern, the relevant problems emerge in the circumstance of incomplete information about the “state of the world” in which the contract would be performed or enforced.” (Olatoye 2021).

Procurement issues

Construction projects can take a wide variety of forms, from building a single bespoke house, or even just a house extension, to a multi-billion-pound multi-year project such as a nuclear power station or a new railway. Just as the type and scale of projects can differ, so can the methods of procurement and the form of construction contracts have employed. Furthermore, there is not necessarily a simple relationship between the scale and type of project and the most appropriate

method of procurement, nor between procurement method and form of contract or contracts.

However, different methods of procurement and forms of contract do have a substantial influence on the relationships between project participants and on how the risks involved in construction work are distributed. This is important because, as several of the references have stressed, the COVID-19 pandemic has highlighted longstanding problems within the construction sector which, if they are to be addressed effectively, are likely to require changes in those relationships and procurement methods (Jones et al 2022, Ogunnusi et al 2022, Nassereddine et al 2021).

The following quotations show both some of the origins of these problems and part of what addressing them will require:

> "Various articles have been written about the inefficiencies and chronic problems plaguing the AEC industry where design challenges, fragmentation, low productivity, low margins, cost and schedule overruns, labour shortages, wastage, unsafe working conditions, and miscommunication are commonplace. … Although a crisis, the COVID-19 pandemic has also served as a wake-up call for the industry as it has brought to the surface longstanding problems and highlighted areas in urgent need of reform and improvement." (Nassereddine et al 2021).

> "The negative impacts of COVID-19 on the construction industry largely stem from the UK Governments 'Construction 2025 report', two-thirds of construction contracting firms are not innovative and consequently freezing technological progress within the sector. …. All the respondents in this study agreed that there should be more focus on construction planning and management. …. The idea of proactive planning was suggested by the respondents. Proactive planning involves building more flexible construction teams who will be resilient to change and crisis." (Ogunnusi et al 2022).

> "The unique position of the project client to drive the project agendas has been highlighted by key construction reports in the UK over the last three decades (Latham, 1994; Egan, 1998; Wolstenholme, 2009; HM Government, 2013). ….. Accordingly, if there are to be changes to how construction operates which build on the learning from COVID-19, clients will need to drive this. Particularly, they need to avoid the 'race to the bottom' which remains prevalent in a competitive fixed-price, lowest first cost, tender-led culture (Egan, 1998). For example, this research has illustrated the potential benefits of 'building slower but better' where clients may need to accept later project starts and longer build times to achieve higher quality, improved OSH and lower costs in the long-term." (Jones et al 2022).

> "The traditional project delivery system of design-bid-build is known to inhibit coordination, limit cooperation and innovation, and promote the reward of one stakeholder at the expense of others. By contrast, Integrated Project Delivery (IPD) emerged as an innovative delivery system that challenges the legacy of the AEC [Architecture, Engineering and Construction] industry." (Nassereddine et al 2021).

If a greater degree of collaborative working is to be achieved within project delivery, then this will require changes both to construction project management and also to methods of procurement, as indicated by the following quotations:

> "The launch and implementation of IPD have revolutionized the way construction projects are being delivered by promoting communication, collaboration, trust, and transparency among the construction owner, designer, contractor, and subcontractors. The benefits of IPD were exemplified during the pandemic where stakeholders were required to work collectively and collaboratively to address associated challenges and ensure proper delivery of projects …" (Nassereddine et al 2021).

> "Experts expect that cost-plus contracts will increase in the future due to the pandemic, because these contracts are flexible approaches for both owners and contractors … It is expected that the integrated delivery method (IPD) will increase, because all project participants (owners, architects, contractors, and subcontractors) are working together as a team, and early collaboration between them can avoid unnecessary delays, change orders, and budget overruns …" (Assaad & El-adaway 2021).

These changes will in turn have implications not only for the choice of form of construction contract, but most likely also for the ways in which those contracts are drafted and administered.

Legal implications

In reviewing the researched literature regarding the legal implications for construction contracts of the COVID-19 pandemic it is essential to have regard to both the applicable legal system or systems with which the research or discourse in the literature relates, and to the legal jurisdiction or jurisdictions involved. It is also necessary to consider which forms of contract are relevant and which legal doctrines or legal principles might be evoked in their interpretation.

As can be seen in the Methodology section of this report, most of the reviewed literature, 58 of the 104 articles, related to situations in which a Common Law system was applicable, as is the case within the UK. In addition, a further 6 articles involved a mix of Common Law and Civil Law contexts, usually involving some comparative material; whilst of the remaining 40 articles, 27 involved a predominantly a Civil Law context only. This is important because the legal doctrines applicable to the disruptions to the contracts arising from the COVID-19 pandemic are substantially different under Common Law from those typically adopted by Civil Law jurisdictions.

The analysis provided under this theme will primarily consider legal implications applicable under Common Law and will focus on an English Law context. However, some of the commentary will draw on articles dealing with other Common Law jurisdictions, such as the USA, India, and Australia, as well as those explicitly dealing with comparative law or relevant aspects of international legal protocols.

It is also notable that within Common Law jurisdictions there can be substantial differences in the ways in which Contract Law is interpreted and applied. These differences derive in part from differences in the drafting of the terms within typical or standard construction contracts used in different countries or by various international organisations, for example the International Federation of Consulting Engineers (FIDIC). More significantly, however, some important differences between Common Law jurisdictions arise from specific local legislation and from differences in case-law and past legal precedent. Such differences exist not only between countries but also, for example between individual States within the USA. Even within the UK, there are some potentially important differences in Contract Law between the English and Scottish legal systems, with respect to the remedies available in cases of breach of contract.

This report focuses on the English legal system and on English Law, as applicable to construction contracts undertaken within England and Wales. However, only 10 of the articles from the initial search were exclusively or predominantly related to the UK situation and of these only one had content with the 1st (top) level of legal content and one with 2nd level legal content. Even within the later searches, which were focused on legally related search terms, only a further two articles were exclusively or predominantly related to the UK situation and had 1st or 2nd level legal content. Since rather more of the articles with a 1st or 2nd level legal content that included substantial Common Law coverage related to other jurisdictions, such as the USA and Australia, this review also includes material from those sources with appropriate allowance for the legal jurisdictions involved.

Some comparisons are also made with legal implications applicable under Civil Law doctrines, mainly drawing on those articles specifically with a comparative legal focus. This is relevant because some contracts affecting construction projects in the UK may be governed by non-UK legal jurisdictions, for example contracts within the supply-chain related to the supply or delivery of components or materials essential to the project.

Two legal concepts are frequently mentioned within the reviewed literature: ‘Force Majeure’ and ‘Frustration of Contract’, although the term ‘Force Majeure’ is not formally recognised within the doctrine of English Common Law, whereas ‘Frustration of Contract’ is a long-standing doctrine in common law, with its application in English Law governed by the provisions of specific legislation (Law Reform (Frustrated Contracts) Act 1943). The relevance of these concepts in the context of the COVID-19 pandemic is discussed in some detail in at least 10 of the articles, with most of the discussion related to force majeure (Sierra 2022, Salami et al 2022b, Assaad & El-adaway 2021, Vorotyntseva et al 2021, Olatoye 2021, Kiraz & Ustun 2020, Allchurch 2021).

However, many contracts do include specific clauses, often referred to as force majeure clauses, that endeavour to apply the concept of force majeure to the terms of the agreement contracted between the parties. Such arrangements exist within almost all construction contracts, although they may not employ the term ‘force majeure’. But, the applicability and interpretation of such clauses will depend on their precise wording and its relationship to the circumstances and events of that particular case. The courts, especially in England, have usually interpreted force majeure clauses narrowly when determining their application (Sierra 2022, Salami et al 2022b), as indicated by the following quotation:

> “Extensions of time or additional costs as a result of COVID will depend upon the terms and conditions of the contract. There is no simple legal definition of what constitutes force majeure, as this always depends on the wording of the contract …. Stakeholders should be wary of assuming that simply pleading force majeure will exempt them from their contractual obligations. …” (Sierra 2022).

Various legal issues that are likely to arise with regard to the interpretation and applicability of force majeure clauses are widely discussed in the literature, but with limited consensus shown between different articles. Some of these apparent inconsistencies may be related to differences of jurisdiction, but it is clear that considerable uncertainty exists regarding how force majeure clauses in typical construction contracts might be applied in individual cases. The following quotations illustrate this point:

> “Force majeure events are exceptional events outside the parties’ control, which impedes the execution of construction contracts either physically or legally. This is in opposition to mere difficulties, time consumption or incurred expenses experienced in the execution of construction contracts. … Since the outbreak of coronavirus pandemic, a lot of discussions have been generated on whether force majeure clause offers justification for Covid-19 as being an unforeseeable event outside the purview of the contractor or not.” (Salami et al 2022b).

> “Consequently, in the context of Covid-19 pandemic, the declaration of force majeure is to a large extent an uncharted territory. … During the pandemic, the burden of proofs will be on the party seeking to rely on the force majeure provision to prove Covid-19 pandemic hindered their contractual performance.” (Salami et al 2022b).

> “… two major contractual and legal issues which the parties will encounter are the applicability of the force majeure clause and whether the delays are excusable events which may allow a project participant to avoid liability (such as liquidated damages) caused by the inability to perform …” (Assaad & El-adaway 2021).

> “…it is expected that many disputes will arise about whether the impacts of the pandemic on a project party were direct or incidental. This distinction is important to establish, because in the case of a direct impact, a project participant can assert the coronavirus as a genuine reason for non-performance, whereas if the impact is incidental, the party cannot reasonably expect to succeed in any subsequent dispute.” (Assaad & El-adaway 2021).

> "When determining whether a party can invoke the force majeure clause, the mere occurrence of a force majeure event is not the only qualifying factor to excuse performance. Rather, the event must be the proximate cause of the damage suffered, and the affected party must show that it lacked the ability to mitigate the adverse impacts of the event; meaning, that although the occurrence of force majeure event is required to trigger the clause, the focus is on a party's ability to control and mitigate impacts relative to its contract obligations, not the event itself." (Hennings et al 2022).
>
> "The issue of recognizing the pandemic, as a force majeure, can be approached from different points of view. Opponents of this approach may argue that, for example, an event constitutes force majeure only if it meets the legal criteria, making it impossible to fulfil the obligation. From this point of view, Covid-19 and the government's response to the epidemic can be a force majeure in certain sectors of the economy …. According to this position, the recognition of Covid-19 as a force majeure will require the establishment of a causal link that made it impossible to fulfil the obligation in each case." (Vorotyntseva et al 2021).
>
> "In terms of understanding the meaning of the concept of force majeure, all countries which accept this doctrine come to a consensus that such circumstances should be unpredictable, irreversible, and independent of the will of the parties." (Vorotyntseva et al 2021).
>
> "Under simple Force Majeure clauses, the legal consequences that typically follow an effective declaration of Force Majeure event are, in the case of a temporary event, suspension of performance, and termination of the contract where the event or its effect does not cease or sufficiently abate within the period of suspension." (Olatoye 2021).
>
> "The combination of the near total absence of case law on contracts in past pandemics, the fact that relevant permanent legislation is not targeted specifically at pandemics, and the temporary nature of legislative and regulatory interference with contractual obligations during COVID-19 leads to the conclusion that there is no body of pandemic doctrine." (Allchurch 2021).

In summary, the main areas of legal uncertainty surrounding the application of so-called force majeure clauses would appear likely to centre around the following issues:

- Does the drafting of the force majeure clause include the words "pandemic" or "epidemic" or phrases that can be argued extend in their interpretation to include the COVID-19 pandemic?
- Does the force majeure clause require the circumstances in which it becomes applicable to have been unforeseen, or unforeseeable?
- To what extent and at what point in time did the existence of the COVID-19 pandemic become a foreseeable event?
- Were the consequences regarding which relief for the non-performance of the contract is sought due solely to the COVID-19 pandemic?

- Are the event or its effects which are claimed to constitute a force majeure beyond the control of the party to the contract claiming relief from its obligations?
- Did the party claiming such relief do everything practicable to minimise or mitigate the consequences of the force majeure event?
- Are these force majeure circumstances or effects permanent or only of temporary duration, and if temporary, is their duration foreseeable?

With respect to the issue of the applicability of a force majeure clause in the face of particular events or circumstances, much will depend not only on its precise wording, but also on whether it is drafted so as to provide a so-called 'exhaustive' definition or listing of its applicability, or is 'non-exhaustive', by for example containing phrases such as "… or similar impediments …", or "…. circumstances beyond the control of …". (Allchurch 2021).

The other main legal concept often mentioned within the reviewed literature, albeit rather less frequently than 'Force Majeure', is 'Frustration of Contract'. This concept relates to circumstances in which it becomes impossible, or at least impracticable, to fulfil the obligations of the contract. In some Common Law jurisdictions this legal concept has, by case-law precedent, become extended, so that the concept has evolved into one of frustration of purpose, as illustrated by the following quotations:

> "The doctrine of impossibility includes physical impossibility as just described as well as extreme impracticability of performance. Impossibility and impracticability doctrines are closely related and often indistinguishable in application by courts. The application of impracticability allows for a broader scope of circumstances that may permit release from a contract and absolute physical impossibility is not a prerequisite for an excuse." (Hennings et al 2022).

> "The doctrine of frustration may apply if an event occurs that causes the performance of an obligation to substantially frustrate the principal purpose for which one of the parties entered into the contract." (Hennings et al 2022).

In some jurisdictions, for example in some of the States of the USA, this concept of frustration of purpose has been extended even further to embrace the concept of 'commercial impracticability' and thus to relieve a party to a contract of their obligations when its circumstances have altered such that its financial implications have changed substantially from those envisaged when the contract was made. This somewhat extreme extension of the legal concept of frustration renders it comparable to the legal concept of 'Hardship' which can be applicable in many, but not all, Civil Law jurisdictions (Olatoye 2021).

In a few articles it is suggested that, in some circumstances, the legal concept of frustration could perhaps be used to obtain relief from the obligations of a contract where either the contract did not contain a force measure clause, or the prevailing

potential force measure circumstances did not fully meet the threshold required by such a clause (Zin et al 2021, Hennings et al 2022, Vorotyntseva et al 2021). It must be stressed that both this possibility and the extension of the concept of frustration to include unforeseen financial distress are not consistent with the doctrine of frustration of contract as applied in English Law (Herbots 2021, Kiraz & Ustun 2020).

The possible applicability of the legal concept of 'Frustration of Contract' to the impact of the COVID-19 pandemic on construction contracts under English Law is considered further in a legal analysis given in the Findings section of this report. This confirms that the high threshold normally required under English Law to establish grounds for frustration of contract as a consequence of the COVID-1p pandemic are unlikely to apply to construction contracts being undertaken in the circumstances typically applying in England during the period March 2020 to April 2022.

One further legal principle under English Common Law that has possible relevance to the impact of the COVID-19 pandemic on UK construction contracts is the principle that obligations in a contract which would require actions that would be contrary to law are not enforceable (Khalef et al 2022, Zin et al 2021, Khanderia 2020, Vorotyntseva et al 2021). The implications of this principle would be even stronger where a contract contained a clause explicitly covering such a situation, as may often be so within a force majeure clause. Indeed, the JCT family of construction contracts do contain such a clause which relates to how the UK Government's actions as a statutory power directly impact on the execution of the works (this is in clauses 2.26.12) - this is very interesting in the context of a dispute around the event entitling the affected party to relief.

The following quotations show the potential relevance of this principle:

> "An example would be where an outbreak of the pandemic elsewhere has triggered government containment actions or S.C.D. that directly affected the relevant party. In addition to the possibility of relying on the item of the Force Majeure clause enumerating governmental action, affected parties, it has been argued, also stand a good chance of being covered by the item "Act of God", one of the most common items in the enumeration approach to Force Majeure clauses." (Olatoye 2021).

> "The mere existence of the COVID-19 pandemic alone does not constitute a force majeure event, but the effects of COVID-19 can also give rise to force majeure claims. The measures imposed by governments to combat COVID-19 can be alleged as a force majeure event. (Kiraz & Ustun 2020).

> "Whether governments' requirements on the reduction of working hours and their curfew announcement due to COVID-19 cause delays in production can fall into the parties' sphere of risk is a question to be answered. In our opinion, these situations are beyond the parties' sphere of risk and cannot intervene in the situation. Thus, if the obliged party fails to perform his obligations, or there has been no production or less production as a

> result of the curfew or reduction of working hours, this non-performance should be regarded as an impediment beyond his capacity." (Kiraz & Ustun 2020).

Finally, it should be noted that the legal remedies applicable in most Common Law jurisdictions in the case of frustration of contract are different to the remedies applying under the provisions of typical force majeure clauses. The legal response to a judgement of frustration of contract is essentially to nullify the obligations under the contract and to effect its termination; whereas the remedies specified under typical force measure clauses provide for an extension of time, with relief from consequent penalties such as liquidated damages, but with no recompense provided for additional expenditure. Only in exceptional circumstances do force measure clauses normally provide for termination of the contract, as shown by the following quotation:

> "A key difference between a force majeure clause and common law principles is that a force majeure clause typically allows for temporary suspension of contractual obligations, while the common law principles allow for permanent termination. Additionally, while a force majeure clause is contract specific, the application of common law principles varies from state to state." (Hennings et al 2022).

In English Law, the remedies in the case of frustration of contract are proscribed by the Law Reform (Frustrated Contracts) Act 1943.

Conclusions

Overall, there are various key conclusions that may be drawn from the literature regarding the impacts of the COVID-19 pandemic on UK construction contracts and their likely implications for the UK construction sector.

Firstly, the pandemic and society's responses to it, have had multifaceted impacts on the construction sector:

- Initial responses included site shut-downs and disruption, with considerable uncertainty over health and safety concerns and some confusion over the appropriate responses to COVID-19 infection risks.
- Although the construction industry was able to develop guidance on how to adapt to the pandemic and to restart activities fairly quickly, that guidance was inevitably subject to frequent variations in response to changing government requirements and advice as the course of the pandemic evolved.
- As a consequence to the required changes in working methods, construction sites became less productive and progress on construction projects slowed markedly.
- This situation was exacerbated by shortages of available construction workers as a result of illness, the requirements for self-isolation and problems associated with other covid-related restrictions.

- Construction activities were also adversely affected by disruptions to the availability and supply of essential materials, equipment and components arising from covid-related impacts in manufacturing and logistics world-wide.

Secondly, these disruptive impacts on construction activity have had substantial consequences for construction projects:

- Ongoing projects have been delayed and substantial additional costs have been incurred in their construction work.
- Some anticipated projects yet to start construction have been deferred or even cancelled.
- Payments for work on existing projects have been delayed, with consequential cash-flow impacts throughout the supply-chain affecting both sub-contractors and materials suppliers.
- There is evidence of increased of increased contractual disputes and claims for additional payments and for extensions to contractual completion dates.

Thirdly, whilst there is little evidence yet of how the provisions made within construction contracts for unforeseen events, such as a pandemic, are being applied in practice in response to COVID-19, the literature suggests a degree of uncertainty regarding the applicability and interpretation of those provisions, and about how effective they may be in protecting the legitimate interests of all the parties to those contracts, as revealed by the contrast implicit in following two quotations:

> "The purpose of including a force majeure clause in a contractual agreement is to eliminate potential disputes by negotiating the risk allocation provisions up front so that when such events occur the parties may look to the contract to determine whether a party is excused from performing its contract obligations, temporarily or permanently" (Hennings et al 2022).

> "The number one cause of construction disputes as reported is, poorly drafted or incomplete and unsubstantiated claim with the Covid-19 pandemic impact playing significant role. The volatility and uncertainty will most likely lead to uptick in the number and type of conflict as construction businesses become unable or unwilling to meet present contractual commitments and/or have readjust to new constraints on their budgets and operations" (Salami et al 2022b).

This situation appears to indicate that either construction contracts as currently drafted may not be well suited to coping with the effects of events like the COVID-19 pandemic, or that although adequately drafted, the terms of these contracts are not fully understood by those administering them, at least as regards their force majeure clauses or similar provisions.

The lack of substantial evidence in the literature regarding the outcome of contractual disputes or of legal judgements or other determinations regarding the use of force majeure clauses is unsurprising given the inevitable time-lag between the occurrence of any disruption and the resolution of any claims or disputes arising from it. The implications

regarding the timeliness of information found from published peer-reviewed literature inherent in the publication process has been mentioned at the start of this literature review. Similar, or even greater time differences exist between the occurrence of events or disputes and the publication information regarding any subsequent outcomes or judgements.

Other reasons for the lack of published information are the practical difficulties of undertaking empirical research on these issues during the pandemic; their commercially sensitive and confidential nature; and the indications that, at least in the initial stages of the pandemic, almost everyone affected in the construction sector adopted a pragmatic approach to address the disruption it was causing, rather than rushing to assert their contractual rights.

This latter point is illustrated in the following quotations from the literature:

> "Parties should be more willing to split the difference in COVID-19 contract cases than they would ordinarily be, regardless of the presence of contract clauses that purport to assign unilateral consequences for pandemic risks, … That is, we think this is one of the few areas where uncertainty about outcomes should spur more settlement, since it makes it advisable to compromise, at least on the margin" (Hoffman & Hwang 2021).
>
> "In view of the foregoing, it is safe to essay that, in light of the potentially global ramifications of the Covid-19 pandemic, regardless of relative rights under the doctrinal grounds or in contract, parties are likely to adopt a bilateral approach aimed at contract-saving, with the possibility of renegotiation and, if relevant, adjustment of terms." (Olatoye 2021).
>
> "The outbreak of the Covid-19, which affected all stakeholders in the construction industry has motivated the desire to establish good relationships based on the awareness and understanding of the ongoing struggle with the Covid-19 pandemic, as well as to reduce claims and litigations. ….. In construction contracts, the room for parties to maintain good relationships is planned into provisions for conflict resolution through agreed alternative dispute resolution procedures, which include mediation, adjudication and arbitration." (Salami et al 2022b).

These types of alternative dispute resolution procedures are commonly specified within construction contracts and widely used amongst these are several provided by the RICS Dispute Resolution Service. Data on adjudication applications were obtained from the RICS covering the period from the start of 2020 up to March 2022, so as to ascertain a more contemporary insight on the trends in construction industry disputes. These are presented and analysed in the next section of this report.

As a final comment from the literature reviewed for this report, it is important to appreciate that all commercial contracts of necessity are concerned in part with the management of risk and those risks include both unforeseen adverse events and the implications of contractual default and potentially the insolvency of parties to the contract. Thus, as the following quotations indicate, a well drafted contract may be important, but so is avoiding prolonged and expensive disputes:

> “When it comes to contract negotiation in general, proper allocation of risk in all facets of the agreement is key. As previously noted, “a force majeure clause is not intended to buffer a party against the normal risks of a contract” …” (Hennings et al 2022).
>
> “Against the backdrop of costly and uncertain court proceedings parties may be better off settling their dispute quickly and amicably themselves.” (Pedamon 2021).

In this regard, contracts and especially force majeure clauses and similar contractual provisions need to be both drafted and administered in the light of prevailing circumstances. Those circumstances now and for the foreseeable future include the risk of recurrent pandemics.

Data analysis and main findings

We gathered data from the RICS Dispute Resolution Service to gain an understanding of the impact of the COVID-19 pandemic on prevalence of formal disputes in construction contracts. RICS provide a range of dispute resolution mechanisms including arbitration and adjudication.

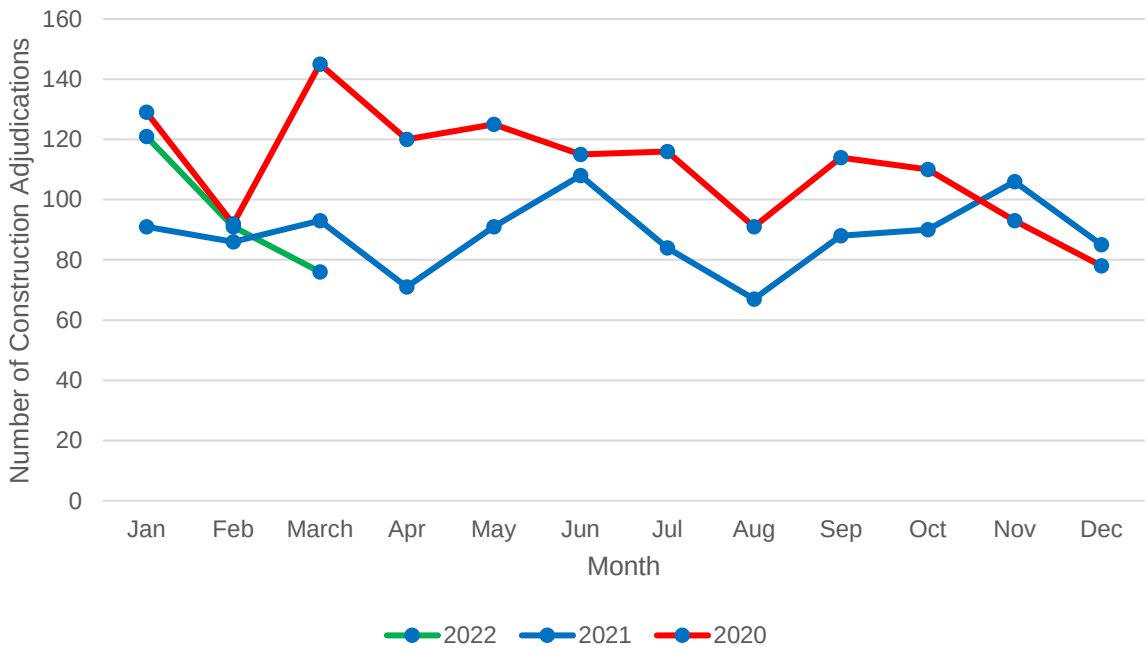


Figure 41: Monthly volumes for construction adjudication applications to the RICS Dispute Resolution Service (DRS) for the period Jan 2020 to March 2022.

DRS received a small surge of applications in December 2020 prior to the lockdown in Jan 2021. December will traditionally experience lower volumes, however November 2020 experienced lower volumes. This could be due to the government’s circuit breaker, which was initiated before Christmas 2020. RICS report that November is ordinarily a busy month, with an average of 120 applications. But due to

the circuit breaker, some of those urgent matters were submitted in December 2020. The increase in applications to DRS in March and April 2020, are attributed to the lock down with firms keen to improve business cash-flow, with most of these disputes were relating to non-payment issues.

Between Jan- Apr 2021 there was a downturn in applications. It is possible that the lockdown during this period significantly impacted on the sector, more so on this occasion than in previous lock-down. A rise in volumes can then be observed as the lockdown ended. There was a fall in applications during August, attributable to the summer holidays; this is followed by a slow build throughout the remainder of 2021. In December 2021, there is a fall in applications, but applications received were higher than December 2020

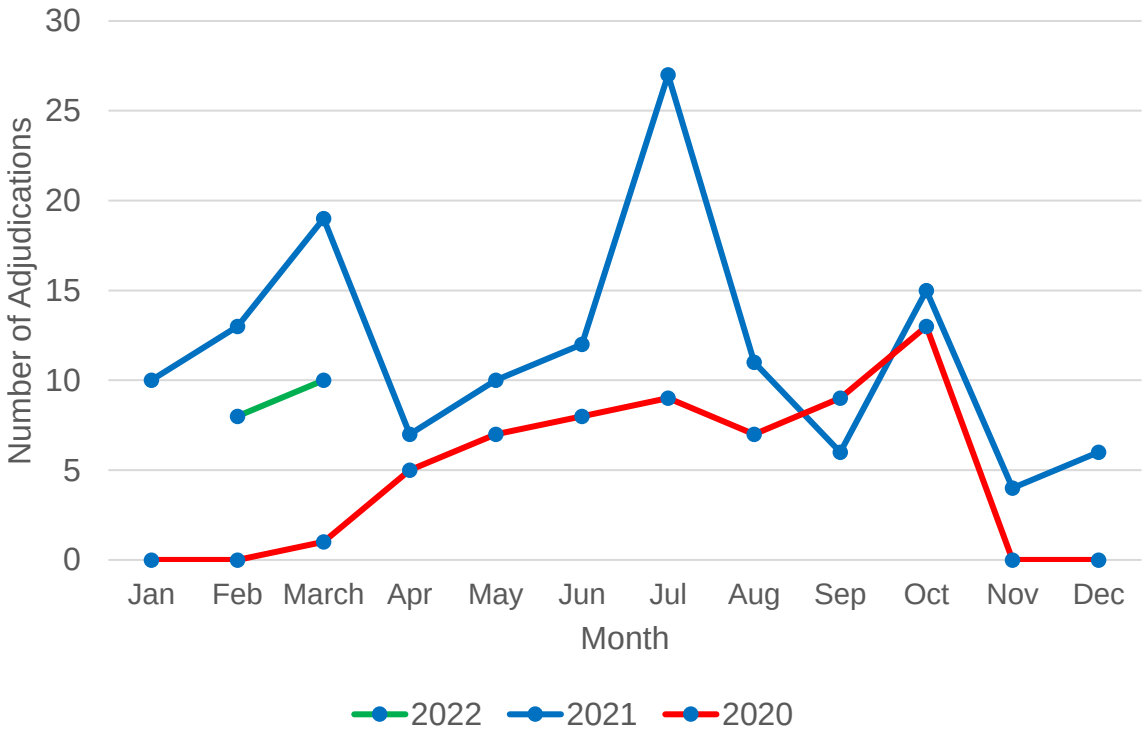


Figure 42: Monthly volumes for low value and summary adjudication applications to the RICS Dispute Resolution Service (DRS) for the period Jan 2020 to March 2022

RICS received over 200 applications through the **low value adjudications services** since the launch of the scheme in March/April 2020.

The service started to gain traction in 2021, with application trends peaking in March, July, and October 2021. The March increase may be attributable to the conclusion of the third lockdown and the pre-Easter break. The RICS believe that the July upward trend is quite natural prior due to the commencement of the summer holiday period.

There is then normally a trend in November, ahead of Christmas but upturn came in October rather than November in 2021. We are not able to explain this trend.

Conclusions

Productivity improvement across the construction industry is crucial to the UK's post-pandemic economic recovery, but growth must be within the constraints of the UK Government's commitment to reduce carbon emissions by 78% by 2035. The full extent of the economic consequences of the pandemic are yet to be known, but early data suggest that the path to recovery will be slow - particularly in the context of global uncertainty arising from the conflict in Ukraine. For people in the UK, inflationary pressures, and the associated increases in the cost of living is likely to lead to greater demand for social housing and by implication, on the house building/refurbishment sector more generally.

Industry structure and the productivity challenge

The impact of the COVID-19 pandemic on the construction sector is well documented in this report and elsewhere. The rate of insolvency in building and construction sectors is particularly troubling. The consequences of this may manifest in low confidence amongst domestic and commercial clients, which in turn creates reticence to commence new building projects. The spill-over effect can be equally damaging, less apprenticeships, education, training opportunities and ultimately, much needed skills. The construction sector is facing a perfect storm of unstable material prices, supply-chain fragmentation, labour shortages and the enduring practices of irresponsible contractual behaviours that are a symptom of aggressive attempts to drive down cost.

Valuing the 'materiality of construction'

The temptation to focus on technology solutions should be tempered by a recognition and acceptancy of the importance of the 'materiality' of construction. The benefits of a presumption towards 'modern methods of construction' are obvious in the context of entrenched social issues such as affordable housing; speedier project delivery and greater cost certainty offer great potential in the social housing sector where the need is greatest.

Delivering social value through construction projects

Legislation to promote social value through construction projects in the public sector has been in force since 2013; The Public Services (Social Value) Act (2012) requires public buyers to consider social, economic and environmental benefits through procurement. On the 1st January 2021, new rules came into force that require all major procurements to explicitly evaluate social value (where appropriate to do so) rather than just to consider it. The Government Commercial Function has developed a model to aid departments and public bodies in achieving compliance – this a thematic model, which covers a broad range of policy outcomes including recovery from the impact of COVID-19. The model provides prompts towards the type of activities that, in the delivery of the contract, many lead to desirable social outcomes – of relevance to the construction sector are: -

- Create employment, re-training, and other return to work opportunities for those left unemployed by COVID-19, particularly new opportunities in high growth sectors.

- Support organisations and businesses to manage and recover from the impacts of COVID-19, including where new ways of working are needed to deliver services.

- Support the physical and mental health of people affected by COVID-19, including reducing the demand on health and care services.

- Improve workplace conditions that support the COVID-19 recovery effort including effective social distancing, remote working, and sustainable travel solutions.

The potential benefits that may arise from a construction industry that is re-oriented on delivering greater social value cannot be overstated, particularly in a post-pandemic economy. Some examples of where this is happening already can be found in Appendix 6.

Construction contract implications arising from COVID-19

Epidemic and pandemic situations are not ‘unknowns’ and in future climate scenarios, may become more prevalent; there is some evidence of increasing likelihood of zoonotic transmission and emergence of ‘novel’ diseases; increasing ‘globalisation’, international travel and movement of goods, animals & plants; plus increasing complexity of supply chains all combine to raise future risk levels of the occurrence and/or impacts of such events. War and civil unrest impacts also give rise to similar issues.

Standard JCT and NEC contracts do not explicitly address ‘epidemics’ and ‘pandemics’ in an adequately encompassing fashion. In any event, it may be difficult to draft clauses, either in ‘standard’ contracts or in bespoke ones to adequately cover the range of situations that may evolve.

Government responses to any future epidemics and pandemics are inherently unpredictable. The JCT ‘family’ of construction contracts contain a standard clause to cover the UK Government’s actions as a statutory power and how this directly impacts on the execution of the works (clause 2.26.12) - this is noteworthy in the context of a dispute around the event entitling the affected party to relief.

The legal basis for claims outside of ‘strict’ contract provisions are uncertain and risks of ‘secondary’ claims or successful ‘protection’ of contractual defaults remain unclear.

Inadequate provision for statutory sick pay etc.; this impacts on workforce compliance with infection prevention measures and potentially conflicts with the employers’ duty of care.

Conventional approach of risk allocation difficult to apply when so many of the risk impacts arise from issues outside the control of the contracting parties. Much more a matter of acceptable / appropriate risk sharing and risk management across all parties in the construction / project implementation process than an issue of contract terms and law.

In a highly competitive market for construction work, with generally low margins, under-capitalised contractors and adversarial contractual relationships that are dependent on the uncertainties of relatively short-term projects largely procured on fixed-price or lowest bid terms, widespread adverse events are likely to leave clients facing the dilemma of contractor default and unfinished projects versus re-negotiated contracts with little certainty regarding their ultimate outcome. Some considerations include

- Contracts should focus on an equitable / mutually acceptable allocation / distribution of risk
- Clients face the potential consequences of ‘risk aversion’: either much greater ‘risk premiums’ in their pricing or greater risks of default, contractor insolvency and an unfinished project
- Need for a more collaborative approach to project delivery and a less adversarial basis for procurement

Main conclusions

Transmission risk and perception

In the main report we use the evidence to make broad recommendations on transmission risk and perception and safety leadership, based on the experiences of those working in construction through the pandemic. For example, we suggest emphasising the existing culture of safe working in construction and linking COVID-19 risk controls to existing safe working guidelines, as this has been perceived as effective by many participants. We also suggest that organisations understand the need to lead by example and show visible leadership to influence compliance with safety rules.

From the research undertaken and responses given by participants about their experiences of working in construction during COVID-19 we can make some broad recommendations. While these may not be applicable across the whole industry, they provide useful insights and potential for experiential and vicarious learning. We can make the following recommendations in relation to transmission mitigation measures and risk perception:

- Emphasise the existing culture of safe working in construction and link COVID-19 risk controls to existing safe working guidelines.
- Recognise the potential for tension and differences in working practices between different tiers and provide clear guidance to employees of safe working in the context of COVID-19 risk.
- Acknowledge different risks between indoor/outdoor working and home/onsite and give guidance in relation to such risk and working practices as applicable
- Acknowledge and address areas where close working and social distancing is difficult to maintain / enforce.
- Allow and encourage employees to report concerns and promote best practice and potential solutions as applicable.
- Build on the safety and ‘looking after each other’ culture that exists on site and emphasise the need to do this in relation to COVID-19 rules as well as traditional safety rules.
- Draw on and share examples of best practice across organisations / tiers to build knowledge of what worked / didn’t work.
- Ventilation is perceived as important, ensure good messaging is provided about ventilation measures in different activities / sites as appropriate.

- As above for cleaning, testing, contact tracing.

- Acknowledge concerns of employees relating to risk outside of the workplace and provide good guidance (e.g., from external sources) on risks and risk mitigation measures being implemented, for example in public transport.

- Understand that compliance to rules will change over time and is linked to general perception of risk overall. Reinforce messaging as appropriate to maintain focus on risk in workplace and the need to ensure this risk is being managed.

- Appreciate that risk control measures can be associated with safety climate perceptions and wellbeing. This reinforces the need for explicit risk controls and good messaging, communication etc.

Safety leadership

We can make the following recommendations in relation to safety leadership:

- Continue to place emphasis on mental health support, and target it appropriately to different groups, e.g., working from home / on site.

- Continue with provision of mental health support shown to be engaged with, e.g., EAPs.

- Understand the need to lead by example and show visible leadership to influence compliance with safety rules.

- Be aware that regular and honest communication from leaders is important to get employee buy in.

- Consider creative messaging to engage with groups / subcultures where compliance may be lower, e.g., using motivational speakers / male influencers.

- Keep good levels of contact with employees to monitor compliance and wellbeing.

- Understand the likelihood of compliance fatigue over time and design messaging and support to emphasise the need to ‘protect each other’. Explicitly address and discuss compliance fatigue and the implications of this with employees.

- Integrate COVID-19 safety with existing construction safety practice to normalise the required ways of working at any given time.

- Recognise that good safety leadership is essential with regard wider compliance.

- Design and implement communication methods for targeting at different groups as appropriate.

- Seek to simplify and disseminate clear organisation rules based on government guidance, where possible make messages short and easy to understand.

- Ensure communication methods are two-way and allow for back-and-forth communication.

In conclusion the experiences of those working in the construction context during the COVID-19 pandemic offer useful and interesting insights and lessons to be learned for the future. A wide range of transmission mitigation measures were used to prevent outbreaks of COVID-19 at work, and these were broadly well received, and compliance was high. The perception of risk was very high at the start of the pandemic and reduced over time. Safety leadership employed a range of tactics to support the workforce, both on site and those working remotely. There were a wide range of examples of strong leadership and communication and in particular support for mental health and general wellbeing with a focus on putting the people first.

Transmission modelling

We developed and tested a proof-of-concept like model that integrated ABM and SEIR modelling approaches in an interactive and user-friendly manner, to simulate the dynamics of COVID-19 transmission and the epidemiological effects of various protective control measures, including social distancing, face covering, vaccinations rate, ventilation, and isolation with the consideration of population heterogeneity (e.g. age, vaccination status and household size), duration of contacts and site layout.

The work detailed how the model was built on an interactive and user-friendly platform using AnyLogic. In addition, it also showcased how to use the model and platform for estimating the transmission risk and identifying high-risk work areas on a construction site. In particular, the work enables users to select the level of compliance on different protective control measures so as to create different scenarios and visualise how different scenarios can affect the COVID transmission dynamic and identification of high-risk areas. As a result, users can identify the scenario (i.e., combination of compliance on different protective control measures) that is optimal with the consideration of operation cost and controlling the spread of the diseases.

Based on the industry engagement workshop, the industry partners have positive comments on all the evaluation criteria (i.e., usability of the platform, structure and layout, ease of integration with other platforms, and representativeness and relevance of captured information). Indeed, they are interested in utilising the model and integrating it with the existing systems.

Construction project delivery and contractual performance

Productivity improvement across the construction industry is crucial to the UK's post-pandemic economic recovery but this must be tempered by the government's commitment to reduce carbon emissions by 78% by 2035. The full extent of the economic damage caused by the pandemic is yet to be known, but early figures suggest that the path to recovery will be slow - particularly in the context of global uncertainty arising from the conflict in Ukraine. For people in the UK, inflationary pressures, and the associated increases in the cost of living is likely to lead to greater demand for social housing. Whilst it is a common for governments to use infrastructure investment as a means of economic stimulus, the evidence suggests that this must be achieved through the delivery of sustainable living places through improvements in productivity, valuing the materiality of construction, and increased social value through construction.

Appendices

Appendix 1 - Literature Review summary table

Article title	Methodology	Focus of research	Findings	Limitations and future research
1. Safety and health management response to COVID-19 in the construction industry: A perspective of fieldworkers (Location; USA)	Quantitative: Questionnaire survey (187 valid response) was conducted with the fieldworkers, 18 years and older, and currently active in the construction industry	Research questions of the research. 1. What are the frequent COVID-19 preventive safety measures used on construction projects? 2.Are fieldworkers satisfied with preventive measures provided by their employers? 3.Does information on the use and effect of COVID-19 preventive measures differ based on demographic characteristics?	1. strategies implemented to increase social distance and minimize group gathering to 10 persons in certain workstations were perceived to be substantially more effective than job-site screening strategies 2. Smaller companies and subcontractors reported significantly lower implementation proportions than the medium and large companies 3. Fieldworkers were favourably disposed toward using technologies, such as video-conferencing apps and wearable sensing devices, to slow the spread of COVID-19 on construction job sites.	The study extends current knowledge by highlighting the need for continued advocacy aimed at smaller construction companies that have limited resources for occupational health and safety management.
2. Compliance with COVID-19 regulations in micro-enterprises and SMEs in the Irish construction sector (location: Ireland)	Mixed: Questionnaire survey with mixed method (scored scaled and open-ended questions) 53-part questionnaire, were completed with 30 participants from 27 construction companies. Interview	1.The study exclusively focused on staff working in micro and small to medium enterprises (m/SMEs) from mid-November to mid-December 2020. 2.This study, while recognising the inevitable evolution of regulations as the pandemic	1.Toolbox talk can potentially play a huge role in terms of compliance with the regulations. However, in the small and medium companies the frequency of TbT is negligible due to the small number of workers at site. 2. The frequent of spot check is also negligible because of the limited resource and budget. It is not possible always to appoint a dedicated	There is need for further research in the area of developing regulations to facilitate the continuance of work in the face of a highly hazardous situation.

	questions were based on five core areas. These areas were: 1.) Tools to Assist, 2.) Thoughts on Guidelines, 3.) Compliance, 4.) Confined Space Works, 5.) Employee Attitude and Behaviour.	develops, is limited exclusively to the Irish construction industry context during a specific time frame of mid-November to mid-December 2020, will identify barriers to compliance and make suggestions for eliminating or reducing such barriers to improve compliance.	person to spot check. 3. This research indicates that there is a lack of knowledge about purpose-built platforms that allow quick and simple contact amongst staff on smaller sites, perhaps due to the fact smaller firms cannot afford to be paying yearly subscriptions for some of the bigger platforms. 4. 96.7% said they do not always comply with the regulation regarding wearing face masks. It is because of the old habit and older staff doing as they pleased. 5.It was found that the COVID-19 regulations greatly impacted those sites where workers had to perform tasks in confined spaces. Respondents reported that it was difficult to maintain 2m social distance while working in confined spaces as advised by the CIF.	
3. Evaluation of measures to prevent the spread of COVID-19 on the constructio n sites (Location: Malaysia)	Mixed: The research combined both exploratory and explanatory methods by asking both why and how questions. Questionnaire was sent to 400 respondents but only 120 responses were received by the cut-off date. Respondents are Project Managers,	This research identified, prioritised and categorized the COVID-19 preventive measures for construction sites. The questions that this research has sought answers to are: 1) What are the impacts of COVID-19 on the project? 2). What are the measures to reduce the spread of COVID-19 on sites? 3), How	Measures to reduce COVID-19 spread on construction sites. 1.Workers to cover their mouth and nose when they cough/sneeze 2. While using a scaffold, restrict access to one person at a time 3. Workers to work in teams but inter team's interaction is prohibited 4. Workers to work in teams but inter team's interaction is prohibited 5.Wash hand frequently No gathering or crowding Foods/drinks should be provided on sites-workers not allowed to	Whilst this research has provided insight into the approach to keeping sites COVID-19-safe, it has some limitations. In particular, though the respondents in this research provide a comparatively large sample, there is a need to increase the response rate.

	Quantity Surveyors, Health and Safety Officers, Site Supervisors	can the “COVID-19-safe” measures be structured for decision making on construction sites? and 4) How can sites be classified in terms of the “COVID-19 safe” measures?	eat outside during the working hours 6.Wear gloves Keep social distancing 7.Provide face masks to workers 8.Ensure regular supply of sanitizer 9.Disinfect surfaces and objects used by others 10.Restrict/stagger access to site welfare facilities 11.Fumigate sites at least once daily – especially at the close of day work 12.All workers must be examined for likely COVID-19 symptoms daily 13.No hugging/ handshaking on the site 14.Company provides separate accommodation for workers based on the projects they are working on 15.Display health advisory posters and infographics in a language understood by the workers 16.Provide health education to Workers regular 17.Abide by government policy 18.Suspend non-critical activities on sites until conditions improve 19.Self-isolation for workers who fall ill/sick 20.Provide incentive to a sick worker- with this, they will report their medical status 21.Ensure regular supply of clean/freshwater There are some additional measures listed by some of the	

			respondents	
4.Implementation challenges of COVID-19 safety measures at construction sites in South Africa (Location: South Africa)	Qualitative: Open ended questions. Respondents are construction professionals who are currently working in South African construction industry. About 30 interview questions were emailed to the respondents, of which 20 were received back, giving a response rate of 67%. One of them was not fully completed so that was deducted from analysis. Excel spread sheet was used to analyse the data.	This research focuses on. 1.The current COVID-19 safety measures in place at the construction site 2.Creating awareness and information sharing 3.Implementation challenges of the safety measures	The findings indicate that there are numerous challenges such as ignorance of COVID-19, the supply of poor personal protective equipment (PPEs) by contractors, lack of compliance, sanitising construction materials, difficulty in sharing tools and equipment, public transport usage by workers, superstition (COVID-19 is for a particular group of people), complying with social distancing rules, among others in the implementation of the COVID-19 safety measure at the construction site to curb the spread of the disease among the workers. These challenges have, therefore, hampered their effort to strictly adhere to the safety measures in accordance with the COVID-19 safety protocol at the project sites currently under construction.	The interviewees were construction professionals working in the South African construction industry during the COVID-19 period. As the interviews were self-administered open ended questionnaire, the flaws of this interview method as the possibility of not getting enough information from participants as they may give less information in their responses to the interview questions, and some of the respondents may not respond to the researcher.
5. Management of safe distancing on construction sites during COVID-19: A smart real-time monitoring system (Location: Singapore)	Quantitative: Case study analysis. A public housing construction site in Singapore was used as a case study to evaluate the feasibility and effectiveness of our proposed computer vision system. The	This study proposes a computer vision-based smart monitoring system to automatically detect worker breaching safe distancing rules. This proposed system consists of three main modules: (1) worker detection module using CenterNet; (2) proximity	The key contributions of our paper are twofold: (1) it is demonstrated that monitoring of safe distancing on construction sites can be automated using the proposed computer vision-based smart monitoring system; and (2) CenterNet, an anchorless detection model, outperforms current state-of-the-art approaches (e.g., Faster R-CNN, SSD) in the real-time detection	There are four limitations in our study. Firstly, the Homography approach used in this research to determine distance is sensitive to the point selections, and the estimation error is linearly proportional to the distance from the camera to the workers. Secondly, due to the lack of depth information from a regular CCTV

	construction contract requires CCTV cameras to be installed on the tower cranes for safety and security reasons. Hence, this study makes use of the existing system and video data.	determination module using Homography; and (3) warning alert and data collection module. A case of a public housing project in Singapore is used to validate the effectiveness and feasibility of our developed system.	of construction workers.	camera, the distance measurement using Homography are estimated. Thirdly, the calibration for distance measurement needs to be conducted every time the tower crane is jacked up. Fourthly, occlusion is still a major issue that affects most computer vision-based systems, and our developed system is not an exception. n future, the proposed computer vision-based system can also be integrated with Internet of Things (IOT), Cloud platform and wearables (e.g., wrist band), person-ReID detection method. By integrating these technologies, a more robust and responsive system can be developed and the worker who is breaching the safety distancing can be detected and tracked.
6. A construction project scheduling methodology considering COVID-19 pandemic measures (Location: Turkey)	Quantitative: A case study is used for analyzing the outcomes of the pandemic-based modelling, the original schedule of the case study ends in 46 days. In this study, a case study is borrowed from	This study addresses the project duration, pandemic risk, and project cost of a construction project case by using both multi-objective genetic algorithm and resource constrained project scheduling techniques, using modelling	Feasible schedules are obtained with durations occurring between 61 to 199 days, the pandemic risks range from 46% to 89%, and the total cost varies from 174,669.8 Turkish Lira (TL) to 186,126.7 TL. Consequently, the most optimal-final solution is obtained Alternative 5 (0.46% pandemic risk, 199 Day (10 workers) with 185,722 TL).	There are two limitations of this research. First, this study takes into account the project duration, pandemic risk, and project cost factors, and evaluates the related outputs data. There are other factors (e.g., quality, construction safety, environmental factor, productivity and satisfaction) that are

	Stumpf's (2000) delay analysis study for the construction of a house with a garage. Some minimal additions are made to the base case study such as approximated quantities are calculated assuming that the flat area of the structure is 150 square meters on a 225 square meter land.	of COVID-19 infection rate. Finally, the analytic hierarchy process (AHP), a multi-objective technique, is used to obtain an optimal solution using three criteria: project duration, total cost, and pandemic risk value. This study complies with current models on infection spreading and also optimization and decision-making techniques to find optimum resource allocation and scheduling alternatives. So that this study fills a gap that modelling the effects of the COVID-19 pandemic on construction projects. This study can be a reference regarding how construction workers can work in compliance with social distance in the event of a pandemic caused by infectious diseases such as COVID-19.	The possible rate of pandemic-related delays can be obtained by using both these techniques and the infection modelling method. Using the COVID-19 infection rate modelling, duration and cost changes are calculated by considering infection risk in construction workers.	not included in the scope of this study, no detailed evaluation is made about these factors. Secondly, this case study includes a residential project construction. However, in industrial applications, this study can easily adapt to different types of construction projects (like dams, hospitals, school constructions) to oversee the effects of pandemics and necessary take precautions.
7. Modelling the spread of COVID-19 on	Quantitative. This study proposes an agent-based modelling	Individual agents are the main components of the systems modelled with	The results of this study quantify what represents a big challenge for construction	The model formulation and implementation of agent-based modelling may

construction workers: An agent-based approach (Location: not mentioned)	(ABM) framework to simulate the spread of COVID-19 among construction workers. The simulation process begins with the arrival of construction worker agents to work at the construction project. Once worker agents are at work these are distributed among different types of activities classified as low, medium, and high risk regarding the spread of COVID-1919. Important to note, this model does not specify which construction activities are low/medium/high risk for workers. By doing this, the model can be flexible enough to be applied to different types of construction projects, as long as the project manager is able to identify and classify the activities that construction	ABM as these agents can interact under the same system environment. One type of agent is included in the model—i.e., construction workers. These agents basically transition between being out of work and being at work. The simulation process starts when construction workers agents arrive to work, these are classified according to the type of activities they will perform during the day in low/medium/high risk activities regarding the contagion of COVID-19.	engineering and management professionals in charge of projects during the pandemic. When looking at the percentages of workers that may get sick during a construction project—approximately between 30% and 90% depending on the level of risk of project's activities, managers in charge of planning the workforce may need to plan ahead, so the construction project can be completed as planned. From the results of this study, the main recommendation for construction and project managers should be to maximize the involvement of construction workers on low-risk construction activities regarding the spread of COVID-19.	oversimplify the real-life conditions under study. Specifically, the classification of activities—i.e., low/medium/high risk—to be performed by construction workers does not refer to specific construction activities. Future studies should investigate to classify the activities involved in construction projects as low, medium, and high risk regarding the spread of COVID-19.

	workers will perform as low/ medium/high risk regarding the spread of COVID-19.			
8. Modelling working shifts in construction projects using an agent - based approach to minimize the spread of COVID-19 -19 (Location: not mentioned)	Quantitative: Agent-based modelling (ABM) approach is used to assess multiple shifts to reduce the spread of COVID-19. Only one agent has been used for this AMB which is construction workers. The parameters and variables for this study are. 1.Percentage of workers assigned to each shift. 2. Time when the shift starts and ends. 3. Percentage of workers classified as healthy. 4. Contagion rate among construction workers on the same shift.	This study proposes using ABM to understand the influence of using multiple labour shifts to minimize the spread of COVID-19 among construction workers. To do so, the model accounts for the health status of workers regarding the spread of COVID-19 and the assignment of workers to either daily or night shifts.	This study found; Using night shifts increases average percentage of healthy workers in a project. Assigning roughly half of workers to a night shift increases average healthy workers by 20%. Using multiple shifts are a feasible alternative to reduce spread of COVID-19 among construction workers.	It is acknowledged as a limitation of this study that the agent-based modelling approach used may have oversimplified the real-life conditions faced by construction workers on construction projects. Another limitation of this study is the lack of data from a real project regarding the contagion rate of COVID-19 among construction workers to simulate workers' behaviour within the model.

Appendix 2 - Quantitative data extracts

Correlations

		Q17_1Transmission control measures (a) Social distancing	Q17_2Transmission control measures (b) Use of face coverings	Q17_3Transmission control measures (c) Enhanced cleaning regime	Q17_4Transmission control measures (d) Enhanced hand washing facilities	Q17_5Transmission control measures (e) Provision of hand sanitisers	Q17_6Transmission control measures (f) Enhanced ventilation	Q17_7Transmission control measures (g) Formation of work team bubbles	Q17_8Transmission control measures (h) Reduction of number of workers for specific tasks	Q17_9Transmission control measures (i) Remote working for office staff	Q17_10Transmission control measures (j) Staggered start and finish times	Q17_11Transmission control measures (j) Staggered start and finish times	Q17_12Transmission control measures (k) Testing on site	Q17_13Transmission control measures (l) Vaccination on site	Q17_14Transmission control measures (m) Access restrictions to canteen, site, changing facilities	Q17_15Transmission control measures (n) Changes to shared accommodations	Q17_16Transmission control measures (o) Any other measures (please state)	Q17_17Transmission control measures (p) None of the above	Management value Safety Climate Sub Scale	Immediate Supervisor Safety Climate Sub Scale	Communication on Safety Climate Sub Scale	Training Safety Climate Sub Scale	Safety System Safety Climate Sub Scale
Q17_1Transmission control measures (a) Social distancing	Pearson Correlation	1	.507**	.378**	.350**	.282**	.228**	.205**	.331**	.266**	.194**	.157**	.190**	.096*	.253**	.165**	.075	-.270**	.166**	.057	.162**	.164**	.142**
	Sig. (2-tailed)		<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.032	<.001	<.001	.096	<.001	<.001	.241	<.001	<.001	.003
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	427	426	432	432	437
Q17_2Transmission control measures (b) Use of face coverings	Pearson Correlation	.507**	1	.403**	.357**	.362**	.213**	.141**	.309**	.363**	.182**	.140**	.190**	.102*	.336**	.185**	.045	-.218**	.202**	.174**	.217**	.173**	.130**
	Sig. (2-tailed)	<.001		<.001	<.001	<.001	<.001	.002	<.001	<.001	<.001	.002	<.001	.023	<.001	<.001	.315	<.001	<.001	<.001	<.001	<.001	.007
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	427	426	432	432	437
Q17_3Transmission control measures (c) Enhanced cleaning regime	Pearson Correlation	.378**	.403**	1	.494**	.532**	.376**	.176**	.312**	.398**	.252**	.191**	.163**	.051	.329**	.193**	.118**	-.260**	.253**	.174**	.211**	.176**	.273**
	Sig. (2-tailed)	<.001	<.001		<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.253	<.001	<.001	.009	<.001	<.001	<.001	<.001	<.001	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	427	426	432	432	437
Q17_4Transmission control measures (d) Enhanced hand washing facilities	Pearson Correlation	.350**	.357**	.494**	1	.494**	.315**	.270**	.312**	.284**	.233**	.195**	.174**	.037	.327**	.182**	.084	-.234**	.229**	.161**	.184**	.130**	.184**
	Sig. (2-tailed)	<.001	<.001	<.001		<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.412	<.001	<.001	.063	<.001	<.001	<.001	<.001	.007	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	427	426	432	432	437
Q17_5Transmission control measures (e) Provision of hand sanitisers	Pearson Correlation	.282**	.362**	.532**	.494**	1	.298**	.116**	.295**	.353**	.219**	.177**	.203**	.016	.291**	.210**	.108*	-.349**	.216**	.164**	.194**	.131**	.185**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001		<.001	.010	<.001	<.001	<.001	<.001	<.001	.727	<.001	<.001	.016	<.001	<.001	<.001	<.001	.007	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	427	426	432	432	437
Q17_6Transmission control measures (f) Enhanced ventilation	Pearson Correlation	.228**	.213**	.376**	.315**	.298**	1	.301**	.346**	.257**	.244**	.237**	.211**	.110*	.282**	.243**	.126**	-.123**	.154**	.134**	.132**	.116*	.142**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001		<.001	<.001	<.001	<.001	<.001	<.001	.014	<.001	<.001	.005	.006	.001	.006	.006	.016	.003
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	427	426	432	432	437
Q17_7Transmission control measures (g) Formation of work team bubbles	Pearson Correlation	.205**	.141**	.176**	.270**	.116**	.301**	1	.369**	.123**	.144**	.089*	.169**	.122**	.228**	.193**	.139**	-.082	-.003	.040	.051	.032	.013
	Sig. (2-tailed)	<.001	.002	<.001	<.001	.010	<.001		<.001	.006	.001	.048	<.001	.007	<.001	<.001	.002	.068	.948	.413	.290	.506	.788
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	427	426	432	432	437
Q17_8Transmission control measures (h) Reduction of number of workers for specific tasks	Pearson Correlation	.331**	.309**	.312**	.312**	.295**	.346**	.369**	1	.348**	.355**	.257**	.237**	.138**	.409**	.334**	.195**	-.107*	.145**	.164**	.159**	.152**	.134**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	<.001		<.001	<.001	<.001	<.001	.002	<.001	<.001	<.001	.017	.003	<.001	<.001	.001	.005
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	427	426	432	432	437
Q17_9Transmission control measures (i) Remote working for office staff	Pearson Correlation	.266**	.363**	.398**	.284**	.353**	.257**	.123**	.348**	1	.234**	.155**	.186**	.047	.352**	.285**	.143**	-.180**	.236**	.179**	.232**	.202**	.207**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	.006	<.001		<.001	<.001	<.001	.291	<.001	<.001	.001	<.001	<.001	<.001	<.001	<.001	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	427	426	432	432	437
Q17_10Transmission control measures (j) Staggered start and finish times	Pearson Correlation	.194**	.182**	.252**	.233**	.219**	.244**	.144**	.355**	.234**	1	.527**	.187**	.063	.338**	.266**	.104*	-.093*	.163**	.048	.159**	.122*	.151**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	.001	<.001	<.001		<.001	<.001	.161	<.001	<.001	.020	.038	<.001	.323	<.001	.011	.002
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	427	426	432	432	437
Q17_11Transmission control measures (j) Staggered start and finish times	Pearson Correlation	.157**	.140**	.191**	.195**	.177**	.237**	.089*	.257**	.155**	.527**	1	.139**	.033	.311**	.266**	.027	-.067	.199**	.077	.183**	.159**	.158**
	Sig. (2-tailed)	<.001	.002	<.001	<.001	<.001	<.001	.048	<.001	<.001	<.001		.002	.464	<.001	<.001	.550	.135	<.001	.111	<.001	<.001	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	427	426	432	432	437
Q17_12Transmission control measures (k) Testing on site	Pearson Correlation	.190**	.190**	.163**	.174**	.203**	.211**	.169**	.237**	.186**	.187**	.139**	1	.081	.246**	.274**	.038	-.076	.090	.161**	.092	.109*	.121*
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.002		.073	<.001	<.001	.396	.089	.063	<.001	.056	.024	.011
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	427	426	432	432	437
Q17_13Transmission control measures (l) Vaccination on site	Pearson Correlation	.096*	.102*	.051	.037	.016	.110*	.122**	.138**	.047	.063	.033	.081	1	.042	.015	.024	-.028	.032	.012	.051	.083	.030
	Sig. (2-tailed)	.032	.023	.253	.412	.727	.014	.007	.002	.291	.161	.464	.073		.350	.741	.589	.529	.505	.800	.294	.083	.529
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	427	426	432	432	437
Q17_14Transmission control measures (m) Access restrictions to canteen, site, changing facilities	Pearson Correlation	.253**	.336**	.329**	.327**	.291**	.282**	.228**	.409**	.352**	.338**	.311**	.246**	.042	1	.381**	.081	-.107*	.097*	.115*	.118*	.139**	.120*
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.350		<.001	.072	.017	.045	.018	.014	.004	.012
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	427	426	432	432	437
Q17_15Transmission control measures (n) Changes to shared accommodations	Pearson Correlation	.165**	.185**	.193**	.182**	.210**	.243**	.193**	.334**	.285**	.266**	.266**	.274**	.015	.381**	1	.201**	-.078	.144**	.139**	.143**	.123*	.137**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.741	<.001		<.001	.082	.003	.004	.003	.011	.004
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	427	426	432	432	437
Q17_16Transmission control measures (o) Any other measures (please state)	Pearson Correlation	.075	.045	.118**	.084	.108*	.126**	.139**	.195**	.143**	.104*	.027	.038	.024	.081	.201**	1	.004	.111*	.072	.088	.093	.109*
	Sig. (2-tailed)	.096	.315	.009	.063	.016	.005	.002	<.001	.001	.020	.550	.396	.589	.072	<.001		.934	.022	.139	.069	.055	.022
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	427	426	432	432	437
Q17_17Transmission control measures (p) None of the above	Pearson Correlation	-.270**	-.218**	-.260**	-.234**	-.349**	-.123**	-.082	-.107*	-.180**	-.093*	-.067	-.076	-.028	-.107*	-.078	.004	1	-.282**	-.112*	-.244**	-.173**	-.168**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	.006	.068	.017	<.001	.038	.135	.089	.529	.017	.082	.934		<.001	.021	<.001	<.001	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	427	426	432	432	437
Management value Safety Climate Sub Scale	Pearson Correlation	.166**	.202**	.253**	.229**	.216**	.154**	-.003	.145**	.236**	.163**	.199**	.090	.032	.097*	.144**	.111*	-.282**	1	.420**	.855**	.767**	.772**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	.001	.948	.003	<.001	<.001	<.001	.063	.505	.045	.003	.022	<.001		<.001	<.001	<.001	<.001
	N	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	414	422	422	425
Immediate Supervisor Safety Climate Sub Scale	Pearson Correlation	.057	.174**	.174**	.161**	.164**	.134**	.040	.164**	.179**	.048	.077	.161**	.012	.115*	.139**	.072	-.112*	.420**	1	.409**	.376**	.415**
	Sig. (2-tailed)	.241	<.001	<.001	<.001	<.001	.006	.413	<.001	<.001	.323	.111	<.001	.800	.018	.004	.139	.021	<.001		<.001	<.001	<.001
	N	426	426	426	426	426	426	426	426	426	426	426	426	426	426	426	426	426	414	426	420	422	425
Communication Safety Climate Sub Scale	Pearson Correlation	.162**	.217**	.211**	.184**	.194**	.132**	.051	.159**	.232**	.159**	.183**	.092	.051	.118*	.143**	.088	-.244**	.855**	.409**	1	.856**	.817**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	.006	.290	<.001	<.001	<.001	<.001	.056	.294	.014	.003	.069	<.001	<.001	<.001		<.001	<.001
	N	432	432	432	432	432	432	432	432	432	432	432	432	432	432	432	432	432	422	420	432	428	431
Training Safety Climate Sub Scale	Pearson Correlation	.164**	.173**	.176**	.130**	.131**	.116*	.032	.152**	.202**	.122*	.159**	.109*	.083	.139**	.123*	.093	-.173**	.767**	.376**	.856**	1	.785**
	Sig. (2-tailed)	<.001	<.001	<.001	.007	.007	.016	.506	.001	<.001	.011	<.001	.024	.083	.004	.011	.055	<.001	<.001	<.001	<.001		<.001
	N	432	432	432	432	432	432	432	432	432	432	432	432	432	432	432	432	432	422	422	428	432	432
Safety System Safety Climate Sub Scale	Pearson Correlation	.142**	.130**	.273**	.184**	.185**	.142**	.013	.134**	.207**	.151**	.158**	.121*	.030	.120*	.137**	.109*	-.168**	.772**	.415**	.817**	.785**	1
	Sig. (2-tailed)	.003	.007	<.001	<.001	<.001	.003	.788	.005	<.001	.002	<.001	.011	.529	.012	.004	.022	<.001	<.001	<.001	<.001	<.001	
	N	437	437	437	437	437	437	437	437	437	437	437	437	437	437	437	437	437	425	425	431	432	437

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

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

The correlation between the risk transmission control measures and the subscales of safety climate

Correlations

		Q17_1Transmission control measures (a) Social distancing	Q17_2Transmission control measures (b) Use of face coverings	Q17_3Transmission control measures (c) Enhanced cleaning regime	Q17_4Transmission control measures (d) Enhanced hand washing facilities	Q17_5Transmission control measures (e) Provision of hand sanitisers	Q17_6Transmission control measures (f) Enhanced ventilation	Q17_7Transmission control measures (g) Formation of work team bubbles	Q17_8Transmission control measures (h) Reduction of number of workers for specific tasks	Q17_9Transmission control measures (i) Remote working for office staff	Q17_10Transmission control measures (j) Staggered start and finish times	Q17_11Transmission control measures (j) Staggered start and finish times	Q17_12Transmission control measures (k) Testing on site	Q17_13Transmission control measures (l) Vaccination on site	Q17_14Transmission control measures (m) Access restrictions to canteen, site, changing facilities	Q17_15Transmission control measures (n) Changes to shared accommodations	Q17_16Transmission control measures (o) Any other measures (please state)	Q17_17Transmission control measures (p) None of the above	Compliance Safety behaviour Sub Scale	Participation Safety behaviour Sub Scale
Q17_1Transmission control measures (a) Social distancing	Pearson Correlation	1	.507**	.378**	.350**	.282**	.228**	.205**	.331**	.266**	.194**	.157**	.190**	.096*	.253**	.165**	.075	-.270**	.109*	.115*
	Sig. (2-tailed)		<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.032	<.001	<.001	.096	<.001	.026	.018
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	419	422
Q17_2Transmission control measures (b) Use of face coverings	Pearson Correlation	.507**	1	.403**	.357**	.362**	.213**	.141**	.309**	.363**	.182**	.140**	.190**	.102*	.336**	.185**	.045	-.218**	.210**	.218**
	Sig. (2-tailed)	<.001		<.001	<.001	<.001	<.001	.002	<.001	<.001	<.001	.002	<.001	.023	<.001	<.001	.315	<.001	<.001	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	419	422
Q17_3Transmission control measures (c) Enhanced cleaning regime	Pearson Correlation	.378**	.403**	1	.494**	.532**	.376**	.176**	.312**	.398**	.252**	.191**	.163**	.051	.329**	.193**	.118**	-.260**	.206**	.231**
	Sig. (2-tailed)	<.001	<.001		<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.253	<.001	<.001	.009	<.001	<.001	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	419	422
Q17_4Transmission control measures (d) Enhanced hand washing facilities	Pearson Correlation	.350**	.357**	.494**	1	.494**	.315**	.270**	.312**	.284**	.233**	.195**	.174**	.037	.327**	.182**	.084	-.234**	.177**	.189**
	Sig. (2-tailed)	<.001	<.001	<.001		<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.412	<.001	<.001	.063	<.001	<.001	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	419	422
Q17_5Transmission control measures (e) Provision of hand sanitisers	Pearson Correlation	.282**	.362**	.532**	.494**	1	.298**	.116**	.295**	.353**	.219**	.177**	.203**	.016	.291**	.210**	.108*	-.349**	.292**	.264**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001		<.001	.010	<.001	<.001	<.001	<.001	<.001	.727	<.001	<.001	.016	<.001	<.001	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	419	422
Q17_6Transmission control measures (f) Enhanced ventilation	Pearson Correlation	.228**	.213**	.376**	.315**	.298**	1	.301**	.346**	.257**	.244**	.237**	.211**	.110*	.282**	.243**	.126**	-.123**	.160**	.184**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001		<.001	<.001	<.001	<.001	<.001	<.001	.014	<.001	<.001	.005	.006	.001	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	419	422
Q17_7Transmission control measures (g) Formation of work team bubbles	Pearson Correlation	.205**	.141**	.176**	.270**	.116**	.301**	1	.369**	.123**	.144**	.089*	.169**	.122**	.228**	.193**	.139**	-.082	.065	.098*
	Sig. (2-tailed)	<.001	.002	<.001	<.001	.010	<.001		<.001	.006	.001	.048	<.001	.007	<.001	<.001	.002	.068	.181	.045
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	419	422
Q17_8Transmission control measures (h) Reduction of number of workers for specific tasks	Pearson Correlation	.331**	.309**	.312**	.312**	.295**	.346**	.369**	1	.348**	.355**	.257**	.237**	.138**	.409**	.334**	.195**	-.107*	.156**	.196**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	<.001		<.001	<.001	<.001	<.001	.002	<.001	<.001	<.001	.017	.001	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	419	422
Q17_9Transmission control measures (i) Remote working for office staff	Pearson Correlation	.266**	.363**	.398**	.284**	.353**	.257**	.123**	.348**	1	.234**	.155**	.186**	.047	.352**	.285**	.143**	-.180**	.198**	.175**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	.006	<.001		<.001	<.001	<.001	.291	<.001	<.001	.001	<.001	<.001	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	419	422
Q17_10Transmission control measures (j) Staggered start and finish times	Pearson Correlation	.194**	.182**	.252**	.233**	.219**	.244**	.144**	.355**	.234**	1	.527**	.187**	.063	.338**	.266**	.104*	-.093*	.133**	.161**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	.001	<.001	<.001		<.001	<.001	.161	<.001	<.001	.020	.038	.006	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	419	422
Q17_11Transmission control measures (j) Staggered start and finish times	Pearson Correlation	.157**	.140**	.191**	.195**	.177**	.237**	.089*	.257**	.155**	.527**	1	.139**	.033	.311**	.266**	.027	-.067	.120*	.121*
	Sig. (2-tailed)	<.001	.002	<.001	<.001	<.001	<.001	.048	<.001	<.001	<.001		.002	.464	<.001	<.001	.550	.135	.014	.013
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	419	422
Q17_12Transmission control measures (k) Testing on site	Pearson Correlation	.190**	.190**	.163**	.174**	.203**	.211**	.169**	.237**	.186**	.187**	.139**	1	.081	.246**	.274**	.038	-.076	.096*	.116*
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.002		.073	<.001	<.001	.396	.089	.050	.017
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	419	422
Q17_13Transmission control measures (l) Vaccination on site	Pearson Correlation	.096*	.102*	.051	.037	.016	.110*	.122**	.138**	.047	.063	.033	.081	1	.042	.015	.024	-.028	-.066	-.046
	Sig. (2-tailed)	.032	.023	.253	.412	.727	.014	.007	.002	.291	.161	.464	.073		.350	.741	.589	.529	.177	.344
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	419	422
Q17_14Transmission control measures (m) Access restrictions to canteen, site, changing facilities	Pearson Correlation	.253**	.336**	.329**	.327**	.291**	.282**	.228**	.409**	.352**	.338**	.311**	.246**	.042	1	.381**	.081	-.107*	.162**	.244**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.350		<.001	.072	.017	<.001	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	419	422
Q17_15Transmission control measures (n) Changes to shared accommodations	Pearson Correlation	.165**	.185**	.193**	.182**	.210**	.243**	.193**	.334**	.285**	.266**	.266**	.274**	.015	.381**	1	.201**	-.078	.102*	.110*
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.741	<.001		<.001	.082	.037	.024
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	419	422
Q17_16Transmission control measures (o) Any other measures (please state)	Pearson Correlation	.075	.045	.118**	.084	.108*	.126**	.139**	.195**	.143**	.104*	.027	.038	.024	.081	.201**	1	.004	.048	.081
	Sig. (2-tailed)	.096	.315	.009	.063	.016	.005	.002	<.001	.001	.020	.550	.396	.589	.072	<.001		.934	.323	.098
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	419	422
Q17_17Transmission control measures (p) None of the above	Pearson Correlation	-.270**	-.218**	-.260**	-.234**	-.349**	-.123**	-.082	-.107*	-.180**	-.093*	-.067	-.076	-.028	-.107*	-.078	.004	1	-.258**	-.181**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	.006	.068	.017	<.001	.038	.135	.089	.529	.017	.082	.934		<.001	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	419	422
Compliance Safety behaviour Sub Scale	Pearson Correlation	.109*	.210**	.206**	.177**	.292**	.160**	.065	.156**	.198**	.133**	.120*	.096*	-.066	.162**	.102*	.048	-.258**	1	.759**
	Sig. (2-tailed)	.026	<.001	<.001	<.001	<.001	.001	.181	.001	<.001	.006	.014	.050	.177	<.001	.037	.323	<.001		<.001
	N	419	419	419	419	419	419	419	419	419	419	419	419	419	419	419	419	419	419	415
Participation Safety behaviour Sub Scale	Pearson Correlation	.115*	.218**	.231**	.189**	.264**	.184**	.098*	.196**	.175**	.161**	.121*	.116*	-.046	.244**	.110*	.081	-.181**	.759**	1
	Sig. (2-tailed)	.018	<.001	<.001	<.001	<.001	<.001	.045	<.001	<.001	<.001	.013	.017	.344	<.001	.024	.098	<.001	<.001	
	N	422	422	422	422	422	422	422	422	422	422	422	422	422	422	422	422	422	415	422

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

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

The correlation between the risk transmission control measures and the subscales of safety behaviour

Correlations

		Q17_1Transmission control measures (a) Social distancing	Q17_2Transmission control measures (b) Use of face coverings	Q17_3Transmission control measures (c) Enhanced cleaning regime	Q17_4Transmission control measures (d) Enhanced hand washing facilities	Q17_5Transmission control measures (e) Provision of hand sanitisers	Q17_6Transmission control measures (f) Enhanced ventilation	Q17_7Transmission control measures (g) Formation of work team bubbles	Q17_8Transmission control measures (h) Reduction of number of workers for specific tasks	Q17_9Transmission control measures (i) Remote working for office staff	Q17_10Transmission control measures (j) Staggered start and finish times	Q17_11Transmission control measures (j) Staggered start and finish times	Q17_12Transmission control measures (k) Testing on site	Q17_13Transmission control measures (l) Vaccination on site	Q17_14Transmission control measures (m) Access restrictions to canteen, site, changing facilities	Q17_15Transmission control measures (n) Changes to shared accommodations	Q17_16Transmission control measures (o) Any other measures (please state)	Q17_17Transmission control measures (p) None of the above	Safety Leadership
Q17_1Transmission control measures (a) Social distancing	Pearson Correlation	1	.507**	.378**	.350**	.282**	.228**	.205**	.331**	.266**	.194**	.157**	.190**	.096*	.253**	.165**	.075	-.270**	.151**
	Sig. (2-tailed)		<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.032	<.001	<.001	.096	<.001	.002
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	414
Q17_2Transmission control measures (b) Use of face coverings	Pearson Correlation	.507**	1	.403**	.357**	.362**	.213**	.141**	.309**	.363**	.182**	.140**	.190**	.102*	.336**	.185**	.045	-.218**	.191**
	Sig. (2-tailed)	<.001		<.001	<.001	<.001	<.001	.002	<.001	<.001	<.001	.002	<.001	.023	<.001	<.001	.315	<.001	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	414
Q17_3Transmission control measures (c) Enhanced cleaning regime	Pearson Correlation	.378**	.403**	1	.494**	.532**	.376**	.176**	.312**	.398**	.252**	.191**	.163**	.051	.329**	.193**	.118**	-.260**	.270**
	Sig. (2-tailed)	<.001	<.001		<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.253	<.001	<.001	.009	<.001	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	414
Q17_4Transmission control measures (d) Enhanced hand washing facilities	Pearson Correlation	.350**	.357**	.494**	1	.494**	.315**	.270**	.312**	.284**	.233**	.195**	.174**	.037	.327**	.182**	.084	-.234**	.218**
	Sig. (2-tailed)	<.001	<.001	<.001		<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.412	<.001	<.001	.063	<.001	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	414
Q17_5Transmission control measures (e) Provision of hand sanitisers	Pearson Correlation	.282**	.362**	.532**	.494**	1	.298**	.116**	.295**	.353**	.219**	.177**	.203**	.016	.291**	.210**	.108*	-.349**	.238**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001		<.001	.010	<.001	<.001	<.001	<.001	<.001	.727	<.001	<.001	.016	<.001	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	414
Q17_6Transmission control measures (f) Enhanced ventilation	Pearson Correlation	.228**	.213**	.376**	.315**	.298**	1	.301**	.346**	.257**	.244**	.237**	.211**	.110*	.282**	.243**	.126**	-.123**	.218**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001		<.001	<.001	<.001	<.001	<.001	<.001	.014	<.001	<.001	.005	.006	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	414
Q17_7Transmission control measures (g) Formation of work team bubbles	Pearson Correlation	.205**	.141**	.176**	.270**	.116**	.301**	1	.369**	.123**	.144**	.089*	.169**	.122**	.228**	.193**	.139**	-.082	.093
	Sig. (2-tailed)	<.001	.002	<.001	<.001	.010	<.001		<.001	.006	.001	.048	<.001	.007	<.001	<.001	.002	.068	.060
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	414
Q17_8Transmission control measures (h) Reduction of number of workers for specific tasks	Pearson Correlation	.331**	.309**	.312**	.312**	.295**	.346**	.369**	1	.348**	.355**	.257**	.237**	.138**	.409**	.334**	.195**	-.107*	.177**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	<.001		<.001	<.001	<.001	<.001	.002	<.001	<.001	<.001	.017	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	414
Q17_9Transmission control measures (i) Remote working for office staff	Pearson Correlation	.266**	.363**	.398**	.284**	.353**	.257**	.123**	.348**	1	.234**	.155**	.186**	.047	.352**	.285**	.143**	-.180**	.188**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	.006	<.001		<.001	<.001	<.001	.291	<.001	<.001	.001	<.001	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	414
Q17_10Transmission control measures (j) Staggered start and finish times	Pearson Correlation	.194**	.182**	.252**	.233**	.219**	.244**	.144**	.355**	.234**	1	.527**	.187**	.063	.338**	.266**	.104*	-.093*	.181**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	.001	<.001	<.001		<.001	<.001	.161	<.001	<.001	.020	.038	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	414
Q17_11Transmission control measures (j) Staggered start and finish times	Pearson Correlation	.157**	.140**	.191**	.195**	.177**	.237**	.089*	.257**	.155**	.527**	1	.139**	.033	.311**	.266**	.027	-.067	.163**
	Sig. (2-tailed)	<.001	.002	<.001	<.001	<.001	<.001	.048	<.001	<.001	<.001		.002	.464	<.001	<.001	.550	.135	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	414
Q17_12Transmission control measures (k) Testing on site	Pearson Correlation	.190**	.190**	.163**	.174**	.203**	.211**	.169**	.237**	.186**	.187**	.139**	1	.081	.246**	.274**	.038	-.076	.156**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.002		.073	<.001	<.001	.396	.089	.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	414
Q17_13Transmission control measures (l) Vaccination on site	Pearson Correlation	.096*	.102*	.051	.037	.016	.110*	.122**	.138**	.047	.063	.033	.081	1	.042	.015	.024	-.028	-.012
	Sig. (2-tailed)	.032	.023	.253	.412	.727	.014	.007	.002	.291	.161	.464	.073		.350	.741	.589	.529	.806
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	414
Q17_14Transmission control measures (m) Access restrictions to canteen, site, changing facilities	Pearson Correlation	.253**	.336**	.329**	.327**	.291**	.282**	.228**	.409**	.352**	.338**	.311**	.246**	.042	1	.381**	.081	-.107*	.158**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.350		<.001	.072	.017	.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	414
Q17_15Transmission control measures (n) Changes to shared accommodations	Pearson Correlation	.165**	.185**	.193**	.182**	.210**	.243**	.193**	.334**	.285**	.266**	.266**	.274**	.015	.381**	1	.201**	-.078	.191**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.741	<.001		<.001	.082	<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	414
Q17_16Transmission control measures (o) Any other measures (please state)	Pearson Correlation	.075	.045	.118**	.084	.108*	.126**	.139**	.195**	.143**	.104*	.027	.038	.024	.081	.201**	1	.004	.089
	Sig. (2-tailed)	.096	.315	.009	.063	.016	.005	.002	<.001	.001	.020	.550	.396	.589	.072	<.001		.934	.071
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	414
Q17_17Transmission control measures (p) None of the above	Pearson Correlation	-.270**	-.218**	-.260**	-.234**	-.349**	-.123**	-.082	-.107*	-.180**	-.093*	-.067	-.076	-.028	-.107*	-.078	.004	1	-.226**
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	.006	.068	.017	<.001	.038	.135	.089	.529	.017	.082	.934		<.001
	N	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	497	414
Safety Leadership	Pearson Correlation	.151**	.191**	.270**	.218**	.238**	.218**	.093	.177**	.188**	.181**	.163**	.156**	-.012	.158**	.191**	.089	-.226**	1
	Sig. (2-tailed)	.002	<.001	<.001	<.001	<.001	<.001	.060	<.001	<.001	<.001	<.001	.001	.806	.001	<.001	.071	<.001	
	N	414	414	414	414	414	414	414	414	414	414	414	414	414	414	414	414	414	414

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

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

The correlation between the risk transmission control measures and safety leadership

Appendix 3 - Qualitative data extracts

Theme / Research Question	Data	Participant / Data Source
Broad findings construction context	I think we're quite tightknit as an industry. So, you know, it's the kind of industry where a lot of people know a lot of other people in different businesses, it's quite incestuous in a way. So, you know, we do have a lot of contact with our competitors, I think we're fairly consistent and I think, as I say, I'd like to think we're leading and certainly that's how it feels.	Interview 6 (Tier 2/Sub Materials HSEQ Director)
	When we come on site, we are being used to wearing PPE. So, we are used to putting masks on helmets, gloves, glasses and stuff. So, we are in that that routine, and when you are in a routine is just becomes natural.	Interview 2 (Tier 1 Ganger)
	On a site office, excluding people that work in the head office, on a site office versus onsite, there's two different mentalities, I'm sure you're probably getting this, so whilst you are out and about in the air when you're onsite, it's harder to control the COVID-19 protections, whereas in an office it's easier. So, I'd felt more …arguably you could see more protection in the office versus onsite.	Interview 12 (Tier 1 Planner / office worker)
	You're obliged to work in close contact with people a lot of the time, particularly for labourers and the like. If they are picking up heavy loads, they can't do it on their own, they've got to have a workmate with them. They might to work within the two-metre rule that sort of thing.	Interview 8 (Tier 1 Permits Manager)
	I think in some noisy environments people naturally when they're talking together will get closed together which, obviously, makes it very difficult, and if you're talking to somebody you tend to be face-to-face as well, not back-to-back, or side-by-side, so yes, I think that can be a problem for us.	Interview 6 (Tier 2/Sub Materials HSEQ Director)
	Two metres socially distanced on site was a challenge. A lot of the tasks you need to be close, so a lot of the way that people have done work for their whole careers they had to change. Some of it actually came out for the better and we'll continue to do that once COVID-19 has gone and once we don't need to socially distance. But that was probably the biggest challenge was trying to get people to social distance on site. You had to police it a lot. But now it is just the norm	Interview 10 (Tier 1 Project SHE Manager)

	as I say, but at the start there was a lot of policing and you had to be like hoy, [whistling], come on, you know	
	So, within the construction industry, once you've found a method of doing something, and this goes for every company, there's certain elements of work that are always one exactly the same because it's been found to be the safest way to do it, most cost-effective way. But what you find now with social distancing, we revisited those jobs and looked at different ways of doing them to include social distancing, less contact or minimising the contact time, introducing different tools to sort of mitigate that.	Interview 11 (Tier 1 Construction Manager)
Transmission mitigation approaches	No, certainly in our offices and in our weighbridges et cetera then yes, we encourage windows open and strong ventilation. In some of our more modern office facilities opening windows isn't an option, so we've had to change our ventilation systems to make sure we've got more airflow. And improved the filtration processes so as we're filtering out more of the bugs where we're recycling air.	Interview 6 (Tier 2/Sub Materials HSEQ Director)
	I'm sure all of the data will come out in time, to how much of this is spread by air and how much of it is by touch because we concentrate a lot in the workplace on those touch points. We didn't compromise our fire safety but what we did a lot of very quickly is we put automatic door closers, so I've forgotten what they call them now, so there's a latch on the bottom of the door which you can keep the door open and if the alarm sounds it automatically closes.	Interview 9 (Tier 2/Sub Equipment HS Director)
	Going back to a machine operator, if a machine operator went down with COVID-19 we have these sanitiser bombs. So, you put it in a machine, set it off and it just sat in there and we just leave the machine stand for 72 hours before somebody else get into it. And where possible it was…that machine was for that man, there was no swapping of drivers in machines. So, we just tried to keep one man one machine. He had all the cleaning equipment, he had to clean it before and after his shift. If he was going to go into the fitting shop or a fit was going to go in there the driver had to clean it before the fitter went in there. Once the fitter had finished, he'd have to wipe it down. So, that's how we try to manage that.	Interview 2 (Tier 1 Ganger)
	The hygiene, we have cleaning materials there for the operators to use, our workforce to use. So, whether they're using it you can't really police that all the time, can you? But I think…they are there, whether people are using it 100 per cent all the time is another question.	Interview 2 (Tier 1 Ganger)
	So, if someone tests positive, we do like an internal contact tracing exercise, identify people that have been in close contact, and very few	Interview 17 (Tier 1 Package

	people that have been identified as having been in contact with someone have actually caught it.	Manager)
Transmission mitigation approaches (RQ1)	We've carried out a number of testing things, random ones. I mean, I've got a box of test kits in my drawer here. But we did carry out... There was a couple of times where we felt that the numbers onsite of people that have got symptoms, got tested and had left, and then with the close contact thing, the numbers were getting so high that twice we actually... Because we're right next to Grosvenor Square, what we did was when everyone came in, we planned it the day before, broke people down into groups, you look after these people, you look after these people, we took over the square and we tested them in groups from 6am in the morning out in the park. And only if they tested negative were they allowed into site. And we did that on two occasions just to try whittle out anybody that put us at risk. And each time we picked up... I mean, there was one time we picked up seven people that had no idea and then there was another time I think we picked up for or five.	Interview 11 (Tier 1 Construction Manager)
	They've chosen not to be vaccinated. We've had a case on one of our sites where somebody went down with COVID-19. So, straightaway we said, right then, the two lads who haven't been vaccinated they've got to go home and get a PCR test and they've got to stay away. That didn't go down too well but we've said, listen, if you are not vaccinated you could potentially close the site down. And I think the penny's dropping with them. So, you know, I don't know what your thoughts are on the vaccination, I don't know if you've been jabbed, but my thoughts are, if I was allowed to do it, no jab no job, that's what I would be.	Interview 4 (Tier 2/Sub Plant SH Manager)
	100% it's travel. I know that put a lot of anxiety in a lot of the team in terms of, you know, after like the first main lockdown. It wasn't necessarily actually in the physical workplace but it's the travelling getting there, you know, getting on…it's like, you know, we space our offices out so everyone's far apart, all that kind of great stuff. But then to go into work or get home on a packed commuter train that's delayed, so you're squashed like sardines. And then it's like, well, what's the point?	Interview 13 (Tier 1 Design Manager)
Transmission risk perception (RQ2)	I suppose there is *[a risk]* of catching it at work. To be honest because wherever you're going to be it's…I don't think there's any safe place.	Interview 2 (Tier 1 Ganger)

	Slightly less than ten per cent of our workforce have…that we know, have had it, there's probably more but we didn't know early on 'cause the testing wasn't available to us. Each of those people we ask, where they think they've got it from, and we track if we've had numerous cases at each individual location. On all but a very few cases there's not been multiple cases and in the vast majority of cases, people highlight that it's somewhere at home, a spouse or, you know, husband, wife, child that they suspect they've got it from. So yeah, we know that we're not big at passing it on but, you know, we can never be sure.	Interview 6 (Tier 2/Sub Materials HSEQ Director)
	When the pandemic initially kicked off, we were…I wouldn't say we were lucky because we had every…we had procedures in place, but we didn't have many incidents, we didn't have many cases. The second wave we had a couple. But the last wave now has sort of…we have had a…we're seeing more, but I think that's because restrictions have been lifted and people are out mingling, you know, shopping, you can go to the football matches, rugby matches, into pubs. So, I think that's why we're…because people…because the restrictions have been lifted and people are more socialising, aren't they?	Interview 4 (Tier 2/Sub Plant SH Manager)
Transmission risk perception (RQ2)	In the beginning adherence was very, very good. And again, since we've…since society has opened up and restrictions have been lifted people are getting…it doesn't help when you turn the news on and you see, well Boris had a party last year, and so and so and so. That is where we're…you know, we're finding it hard.	Interview 4 (Tier 2/Sub Plant SH Manager)
	My own personal opinion is that I think a lot of people have sort of taken their foot off the pedal anyway and relaxed. I think some people are fed up with the whole thing, some people don't take it seriously and I think a lot of people really don't care anymore, especially with the new variant where generally, the sort of consensus of opinion is that it's not as aggressive, it doesn't affect you as much, it's more like a bad cold and people are prepared to take that risk and just catch a bad cold or flu-like symptoms, I think.	Interview 11 (Tier 1 Construction Manager)
	I think it's an all-or-nothing, really, the restrictions. I think things worked well at first because it was strict, but then when it, sort of, changed in roles, and one role one week, and one role another week, and I think people just got de-sensitised and fed up with it all, now.	Interview 16 (Tier 1 H&S Manager)
Safety compliance,	At first like the people above didn't really expect there to be that	Interview 1

working from home and mental health (RQ3)	much animosity. I said 'it's cause you've made a big deal about people working at home, you should give both parties the equal respect from mental health point of view on both aspects'. So that was the hardest part.	(Tier 1 HSE Manager)
	But there's always been the things in construction with us and them, isn't there, between the office people and the site people. And I started off my career as a labourer, so I know it's there. So, yeah, I just don't think it did any favours in terms of the general site culture and trend in the industry. But yeah, they're just our people, so next time I think I'd just push our clients and say, if you want them on site then we need to be able to get out and see them.	Interview 5 (Tier2/Sub Labour – Health, Safety & Wellbeing Manager)
	I think everyone, every sector, every company has now realised that working from home can be really beneficial.	Interview 10 (Tier 1 Project SHE Manager)
	I would say that there's a lot of people not got on with working from home. You know, the splitting of the teams and stuff like that. That's affected some people. You talk to the people...	Interview 11 (Tier 1 Construction Manager)
	I think…you're a lot more about measuring performance and measuring output when people are working remotely, et cetera, and so, sort of, setting up key targets and deadlines and measuring and all the rest of it is far more important in managing people now than it, sort of, previously was, I think. It's still a challenge but I think it's…we've adapted to it essentially. Definitely.	Interview 7 (Tier 2/Sub Drilling Deputy Project Director)
	I think most people were on board because they knew that that we had no choice, you know. Not only were we following rules that we had to follow, that were laid out by the government, but we're doing this to keep you safe, we're doing this to keep everybody safe. And if you want to come into work, then you're going to have to do it. Because if we don't, everyone's going to get it and the site is going to be closed for longer	Interview 15 (Tier1 Office Manager)
	We didn't really have any difficulties during because it's very strict, like it's just black and white. Yeah, if you don't like it, go, basically.	Interview 20 (Tier 1 Planner)
	Adherence to the rules. Just like, a belief in the workforce that there's even a point in doing them, which will be a kind of a challenge in	Interview 5

	itself. Lack of information from the government, clear guidance, we've no…no…worth of vaccinations. A lot of what our site guys, because they're different cultures, are not going to uptake vaccination. So, absolutely there, do we say that you need to mandate it? And, if you mandate it and they all leave, then how do we manage that back fall of workforce that we don't currently have already with the skill shortage?	(Tier2/Sub Labour – Health, Safety & Wellbeing Manager)
	I think the main challenges, I suppose for me anyway would be, as time goes on, it's nearly two years now, as time goes on, as I say, everybody is sick of it, they just want to move on, they want things to get back to normal. So, I think if there was another big outbreak and if there was a lot of high deaths and having to go back into a lockdown and having to go back into that, it would be extremely hard for people, including myself.	Interview 14 Tier2/Sub Civils – Project Support Co-ordinator)
Leadership attributes and supporting others (RQ4)	Some people are very good at working from home and they have a regimented routine. So, they treat it like they're going to work. So, they'll get up in the morning, they'll get dressed to go to work and they'll go into a separate space within their home, which they'd treat as an office. And then they'll stop for their lunch, as they would at work or whatever, and treat it like a workplace. Whereas others, they're at home that effectively, yes, they're working from home but they're at home, they're not in an office space and then do things differently. There's no... It's not organised, it's not as regimented as it would be at work. And I think they don't deal with it quite so good as the people that... You know, we have this conversation about certain people that even though they're at home, they'll put a tie on, right, and then when they've finished the day, they'll take the tie off, and then they know they've finished work.	Interview 11 (Tier 1 Construction Manager)
	It's lots of Teams meetings, which his fine. From my personal experience is it's twofold, manager level down to me, I felt I had to probably…not work harder, that's what I'm trying to say, but I felt that I needed to be viewed as doing work, yeah? And how I could measure that. So, I'm working from home not, you know, what can I…how can I prove that I've done X, Y, and Z from home, yeah? And I think that's probably goes the same way for me down, right I know that Fred, Jim, and Steve are at home, and I've tasked them to do X, Y, and Z, now if they finish that will they just have the…will they have the hindsight to go, well I've not finished this I now need to look at that, I'll start this. Or is it, well I've done this in two hours, tell you what I'm going to go and cut the grass, or walk the dog, you know? Cause I work hard when	Interview 19 (Tier 1 MEP Package Manager)

	I'm onsite, am I getting perceived differently, are we being watched, is big brother watching us, yeah, all these other added little pressures that come into play.	
	Work started allowing us to have a bit more of a flexible arrangement with work, so depending on your role, you can basically communicate with your line manager and agree something. So some people in the office must be onsite five days a week, others might be three days a week, I've agreed with my line manager I can stay at home one day a week, which before the pandemic, that was never allowed, it was, you must be onsite every single day. So yeah, meetings have returned back to the office, we're still doing a lot of stuff online, because obviously not everyone's still back full-time, but where we can we're having meetings in the office now.	Interview 21 (Tier 1 Design Manager)
Leadership attributes and supporting others (RQ4)	To be honest, if anything like I, I've seen a bit of an uptake in productivity. If I've got, like, my safety boys are sitting at home instead of in the office where people are in and out. She is bombarding me, as if, it's like, she's my manager, you know, she's on it. So, I think we're quite good in that regards.	Interview 5 (Tier2/Sub Labour – Health, Safety & Wellbeing Manager)
	I'm not 100 per cent we get the quantity from the guys who are working from home that we would have had in the office. So certainly, in the office we you're hearing things reminding you of other things you need to do, bouncing ideas off people in the workplace that sort of thing, you don't get any of that.	Interview 8 (Tier 1 Permits Manager)
	Presence as well, like just people's presence. I think that you can't quantify that but, you know, if you have senior people and things like that, just the aura and presence, it definitely lifts people. And again, that's another thing that you lose, so yeah.	Interview 13 (Tier 1 Design Manager)
	Lead by example, I suppose. Clear, visible leadership would be the one for me. Practice what you preach, be seen to be leading by example. So if I	Interview 2 (Tier 1 Ganger) Interview 3 (Tier 12/Sub EE HSE Manager) Interview 9

	turn up in a depot I've got all my PPE on, I'm wearing my facemask, I'll happily bump elbows with people but I won't shake hands, I'll remind people, probably not too distant there. And I think you've got to lead from the front, you've got to reinstate all of those behaviours and if you're expecting somebody to portray those behaviours then you absolutely have to be leading by example.	(Tier 2/Sub Equipment HS Director)
	Following the rules. I'm always a great believer of leading by example. And for me, I think that's the most important thing that a leader can do. Even, you know, however...wherever they get to find out in terms of the parameters for the measures, if it gets followed by the top, then it trickles down for everyone else.	Interview 13 (Tier 1 Design Manager)
	I suppose it's being present on site with people and, you know, showing your face, making sure that people know that you're there as well.	Interview 3 (Tier 2/Sub EE HSE Manager)
	Our guys were on site and I just thought, well it's not fair for me to be in the house, if they're out on site I should be out on site. We should be seen and be out there. Like I said to you earlier on I was two weeks at home. Working at home wasn't for me. I'd…so I wanted…if our people are on the site…and fairness to the top directors, they're out and about all the time, so if our people are on site we should be on site.	Interview 4 (Tier 2/Sub Plant SH Manager)
	They have to enforce, I suppose they have to be the one with the stern voice to say, look you need to wear your mask, you need to social distance, even one of the days last week, there was a guy who wasn't feeling well, one of the site team, he was in the office, he had tested negative and he had tested a few times but he still wasn't feeling well and the manager just said, look you have to go home, you can't be in here really, you could test positive this evening and you're putting us all at risk, so for yourself and for us, you need to go home. So, there has to be someone there with a strong voice to say, you need to do this and the whole way through, it wasn't an easy job, it wasn't an easy task	Interview 14 (Tier2/Sub Civils – Project Support Co-ordinator)
	We need to be out there with our workforce if…if they're telling us that something isn't working, then like, yeah, okay, you need to actually make a thing of it to them and be like, okay, right, this isn't working, I get it. And you need to bring it, feed it back. You need to consult with them consistently. Like, not just like, okay, here's an e-mail briefing. Two months later, here's another one, any issues ring us. Like, no, you need to be ringing them, you need to be checking the	Interview 5 (Tier2/Sub Labour – Health, Safety & Wellbeing Manager)

	observations that are coming in, the feedback from site. You need to be trending that. And then, I think we just, I think everyone needs support to do their role; so, I think we didn't realise how much trust we could put in our foremen and our supervisors and yeah, so yeah, so I think that was really good like, do you know. So, I think just empowering people as well to take a lead on stuff like that. I think that…and that…	
	I've noticed from a managers' perspective is that they've been more human if you know…they've been more, you know, considerate of various other…working from home constraints, issues with illness, that kind of stuff, so…	Interview 12 (Tier 1 Planner / office worker)
	And we introduced time to talk Fridays where we said, forget work, go and make a brew. We even sent tea and coffee making facilities, not facilities, ingredients, along with biscuits and said, take the time to talk to your colleagues, sit down, have that biscuit. It was all branded up, it's time to talk, and so on and promoting those conversations and people have said that they've definitely benefited.	Interview 9 (Tier 2/Sub Equipment HS Director)
	Something we have done is we have brought external, like motivational speakers in that talk about mental health. So, there is a company called, State of Mind, which are ex rugby players who have went through a bad time, and they come in and they tell their story, and it is basically, it is mainly about being in a masculine world, men don't like to talk, blah, blah, blah, because obviously construction is mainly men, but there is quite a lot of women here and it does apply to them as well, that it is okay not to be okay. So, we brought them in, they have done a few talks and that went down really well. Through that quite a few people actually came forward to myself and some of the other mental health first aiders, you know, to say, I am struggling, I do need help. So, that was good.	Interview 10 (Tier 1 Project SHE Manager)
Outcomes (RQ5)	It's…one thing I would say is an increase in consideration of peoples' mental health and those things, they've definitely tried to make me, you know, make people feel as safe as possible and considered as possible, more as people, as everyone going through it.	Interview 12 (Tier 1 Planner / office worker)
Impact on traditional health and safety (RQ6)	The obviously the sickness would have gone up through the roof because we as a business we would have had so many people have COVID-19 and be off that we wouldn't have normally done. We've had no-one go off with the flu though. So swings and roundabouts.	Interview 1 (Tier 1 HSE Manager)

	There's certainly more of a, even if it's a cold they are keeping away and working from home whereas before they would have just come in. Normally workmates, they can't afford not to lose a day's work sort of attitude. Whereas now if they have a sniffle people are automatically think you have got COVID-19, keep away from me, if you know what I mean.	Interview 8 (Tier 1 Permits Manager)
	Other than them being on sick pay we actually pay them full pay, so they proactively reported. I don't necessarily think that probably worked to our advantage in that we probably had the same number of reports as colleagues in the central and west section, so I don't think that was probably value for money in reality, but it certainly created a positive reporting culture put it that way.	Interview 7 (Tier 2/Sub Drilling Deputy Project Director)
	Touch wood, we're improving. We're having…still having silly incidents but we're not having any serious accidents. So, we are improving as a group. So, I don't know whether that's down to COVID-19 or as to whether it's the work we've put in the previous years. So, I would like to think it's through the work we put in previous years.	Interview 4 (Tier 2/Sub Plant SH Manager)
	I know across the project and across the company it was deemed that in the beginning of this year there was a rise in incidents. I don't really think that is attributed to COVID-19, but certainly there was a rise in the statistics as it were, just of minor incidents.	Interview 7 (Tier 2/Sub Drilling Deputy Project Director)
	Yeah. This year we've had a good number of them and a good number of lost time incidents, three of which, one was a broken foot, another one was a broken wrist and there was one more, I can't remember, it was a sprained ankle. And three of those, I always remember, the root cause for that was people trying to lift and move things on their own because they were too nervous to ask for help in case they were coming into distance with people. Yeah, because people are thinking, oh, I'll just do it myself. Because, either one, they are nervous about getting next to people, which is something I've seen even in things that haven't been accidents. But, when I ask people, like, why are you doing it like this? Or, do you know, they don't want to get near people. Or, two, they are worried they are breaking the site rules and they are going to be in trouble. Or, three, they're like, I cannot be arsed to go up to find a mask and have to disinfect, you know what I mean.	Interview 5 (Tier2/Sub Labour – Health, Safety & Wellbeing Manager)
	Yeah, we talked this through long and hard. I think the good patch was because everybody was much more aware of social distancing,	Interview 6

	people were really switched on, and people were aware of their personal spaces and looking after each other, so I think there was some real positive behaviours kicked in. I think then people got tired, people didn't have holidays, people were, you know, the number of people we had carrying ten- or 12-days holiday over from one year into the next because they simply didn't have the opportunity to take them or didn't want to take them 'cause they couldn't do anything with them. So, I think people were tired, people were fatigued, people were fed up with the rules and the fact they couldn't live their normal lives. And I think all of those things eat away at our, you know, parts of our brain that then allow us to make bad decisions and incidents occurred. But it's difficult to say exactly what it was, that's what we think.	(Tier 2/Sub Materials HSEQ Director)
	It makes it a touch more difficult on site, where we may have increased numbers, where we would originally, for a particular task, expect to see a certain number of people doing it, where we may have had to have reduced that number, but I think that's more of a slow down in productivity as opposed to a safety risk.	Interview 17 (Tier 1 Package Manager)
	I mean, as an industry, you know, we have quite strict health and safety guidelines to follow, so no change, really. It's something that everyone is used to managing on a daily basis.	Interview 16 (Tier 1 H&S Manager)
	I feel the site is the safest place including what we are doing on site, it's monitored, it's regulated, we inspect everyone. Everyone is at a level where their competency is checked. I observe other areas and other sites and it is quite frightening what people get up to and what they do. Yes, it's tier one construction, so it's the best of the best.	Interview 18 (Tier 1 H&S Manager)
Technology (RQ7)	If I was looking for even glints of positives, I think the way that we've reacted with technology, it's probably driven us forward, you know, in two years we've done what would have taken us 10 or 12 if we hadn't have had this rocket called COVID-19, injecting some pace into us. So yeah, I genuinely think it has stepped us forward, both as a construction, you know, industry and wider society, I think it's really moved us forwards in a number of ways.	Interview 6 (Tier 2/Sub Materials HSEQ Director)
	We had lessons learned where people that we used. For instance, the app and that went a little bit Pete Tong people just putting it in their locker and then somebody else would put theirs in the locker and then there would be closer than two meters and then, well! So we had some learning curves early on, as you can rightly imagine so.	Interview 1 (Tier 1 HSE Manager)
	In some of our blockworks, we've introduced watches that are	Interview 6

	distance monitors, so if you get within two metres of somebody your watch buzzes… Yeah, I've been onto site, I was a doubter, I have to say, as to whether they would be…or whether they would just, you know, fade into insignificance. But having gone round the sites and witnessed people using them, they are still quite effective actually, even a number of months later, so yeah, I have to say they work better than I thought they would.	(Tier 2/Sub Materials HSEQ Director)
	Nothing I can think of as a new technology we've, kind of, adapted one of the other…around some of our paving gangs, then we've got around the pavers, we've got lights that project onto the ground to keep two metres away.	Interview 6 (Tier 2/Sub Materials HSEQ Director)
	We've changed all the taps in the toilets so that they're on the sensors. So, you walk in, you don't have to touch the tap, it just automatically comes on.	Interview 11 (Tier 1 Construction Manager)
	We've followed the government guidance by the letter, so initially all of our collections and deliveries became contactless very quickly, if you came to a depot you were required to park up outside and stay outside, your equipment will have been allocated to a non-contact bay so you will have collected the equipment, you will have loaded it onto your own vehicle and will have done all of this through the internet, through PDAs and no-touch technology.	Interview 9 (Tier 2/Sub Equipment HS Director)
	We actually got these things for the door handles as well, and it's like a cover that goes on the door handle, and somehow it has got this stuff inside it that gets rid of 99.9 per cent bacteria and COVID-19 apparently. Then after a while there is a little…there is almost like a little dot on it and that goes red when you need to change it. So, any visitors that come to site, and for a period we were doing everyone, we had the temperature gun, still using that for visitors.	Interview 10 (Tier 1 Project SHE Manager)
	I've never seen these air purifiers before.	Interview 13 (Tier 1 Design Manager)
	Yes, I guess, technology-wise, it's seen a massive change in behaviour.	Interview 7 (Tier 2/Sub Drilling Deputy Project Director)

Appendix 4 108 Scenarios of the five SCMs

Scenario	FC [0, 0.5, 1]	Va [0, 0.5, 1]	SD [0, 0.5, 1]	Ve [0, 1]	I [0, 1]
1	0	0	0	0	0
2	0	0	0	0	1
3	0	0	0	1	0
4	0	0	0	1	1
5	0	0	0.5	0	0
6	0	0	0.5	0	1
7	0	0	0.5	1	0
8	0	0	0.5	1	1
9	0	0	1	0	0
10	0	0	1	0	1
11	0	0	1	1	0
12	0	0	1	1	1
13	0	0.5	0	0	0
14	0	0.5	0	0	1
15	0	0.5	0	1	0
16	0	0.5	0	1	1
17	0	0.5	0.5	0	0
18	0	0.5	0.5	0	1
19	0	0.5	0.5	1	0
20	0	0.5	0.5	1	1
21	0	0.5	1	0	0
22	0	0.5	1	0	1
23	0	0.5	1	1	0
24	0	0.5	1	1	1
25	0	c	0	0	0
26	0	1	0	0	1
27	0	1	0	1	0
28	0	1	0	1	1
29	0	1	0.5	0	0
30	0	1	0.5	0	1
31	0	1	0.5	1	0
32	0	1	0.5	1	1
33	0	1	1	0	0
34	0	1	1	0	1
35	0	1	1	1	0
36	0	1	1	1	1
37	0.5	0	0	0	0
38	0.5	0	0	0	1
39	0.5	0	0	1	0
40	0.5	0	0	1	1
41	0.5	0	0.5	0	0
42	0.5	0	0.5	0	1
43	0.5	0	0.5	1	0
44	0.5	0	0.5	1	1
45	0.5	0	1	0	0
46	0.5	0	1	0	1
47	0.5	0	1	1	0

48	0.5	0	1	1	1
49	0.5	0.5	0	0	0
50	0.5	0.5	0	0	1
51	0.5	0.5	0	1	0
52	0.5	0.5	0	1	1
53	0.5	0.5	0.5	0	0
54	0.5	0.5	0.5	0	1
55	0.5	0.5	0.5	1	0
56	0.5	0.5	0.5	1	1
57	0.5	0.5	1	0	0
58	0.5	0.5	1	0	1
59	0.5	0.5	1	1	0
60	0.5	0.5	1	1	1
61	0.5	1	0	0	0
62	0.5	1	0	0	1
63	0.5	1	0	1	0
64	0.5	1	0	1	1
65	0.5	1	0.5	0	0
66	0.5	1	0.5	0	1
67	0.5	1	0.5	1	0
68	0.5	1	0.5	1	1
69	0.5	1	1	0	0
70	0.5	1	1	0	1
71	0.5	1	1	1	0
72	0.5	1	1	1	1
73	1	0	0	0	0
74	1	0	0	0	1
75	1	0	0	1	0
76	1	0	0	1	1
77	1	0	0.5	0	0
78	1	0	0.5	0	1
79	1	0	0.5	1	0
80	1	0	0.5	1	1
81	1	0	1	0	0
82	1	0	1	0	1
83	1	0	1	1	0
84	1	0	1	1	1
85	1	0.5	0	0	0
86	1	0.5	0	0	1
87	1	0.5	0	1	0
88	1	0.5	0	1	1
89	1	0.5	0.5	0	0
90	1	0.5	0.5	0	1
91	1	0.5	0.5	1	0
92	1	0.5	0.5	1	1
93	1	0.5	1	0	0
94	1	0.5	1	0	1
95	1	0.5	1	1	0
96	1	0.5	1	1	1
97	1	1	0	0	0
98	1	1	0	0	1
99	1	1	0	1	0
100	1	1	0	1	1
101	1	1	0.5	0	0
102	1	1	0.5	0	1

103	1	1	0.5	1	0
104	1	1	0.5	1	1
105	1	1	1	0	0
106	1	1	1	0	1
107	1	1	1	1	0
108	1	1	1	1	1

Appendix 5 - Notes on the application of soft systems methodology

Soft systems methodology (SSM) is an approach to 'tackling problematical, messy situations of all kinds'; it was developed by Peter Checkland (and colleagues) at Lancaster University Management School during the 1970s and is widely viewed as useful in tackling complexity, particularly in policy problems. SSM draws on the scholarship of systems engineering but is distinctly different in that it acknowledges the 'world-view' of social situations as being distinctly different from the reductionist view that often dominates individual and group thinking. In this report, we do not set out to deploy the full range of methods available within the SSM paradigm, but it is helpful to understand the seven-stage process that is generally applied when enacting SSM in a similar context.

SSM Stage	Description
Identifying the problematic situation that it is desired to intervene in	Reimagining construction project delivery in a post-pandemic economy
Researching the situation and building a 'rich picture' (interpretive representation) of it	Using data obtained via literature review and survey, a graphical representation of the factors that are relevant to our understanding of the above
Selecting perspectives and building 'root definitions' (key processes that need to take place within the desired system)	The root definition succinctly describes the system identified in (1). The CATWOE mnemonic provides one mechanism for formulating a root definition (Open University, nd) Customer: Who are the clients, beneficiaries, victims (of the system)? Actors: Who conducts the activities in the system? Transformation: What specified elements are changed by the system (i.e., how are inputs transformed into outputs)? Worldview: What is the thinking that justifies the transformation? Owners: Who can stop this activity or demolish the system?

	Environment: What constraints will hinder the activities of the system? The impact of COVID-19 on the construction sector and the wider implications of this on the Government's ambition to 'Build Back Better' from an infrastructure perspective
Developing a conceptual model of the change system	Causal Loop Diagrams (CLDs) are used to conceptually model dynamic systems in a holistic manner, mapping how variables (i.e., factors, issues, processes) influence one another. These diagrams are particularly useful in uncovering a system's underlying feedback structures, and in identifying high and low leverage intervention points in a system.
Comparing the model with the real-world situation	Co-production with industry professionals (sense-making)
Defining the changes to be implemented	Determining the relevance of loops in the conceptual model and identifying the presence of factors that show high levels of inter-connectedness
Taking action	Production of policy, primary and secondary legislation, government spending

In summary, SSM attempts to promote learning and understanding of the problem situation, rather than set out to answer a pre-defined problem statement. The complexity of the construction industry lends itself to SSM in that it provides

Rich pictures

A Rich Picture is an attempt to capture everything that could be relevant to a particular situation or problem; they are generally described as a method for representing situations of complexity by enabling issues, risks, connections, conflicts, desires, beliefs and motivations and other features of a system to be articulated in a way that is reflective of a consensus. Graphical techniques work well in situations where volatility, uncertainty, complexity, and ambiguity exist and enable the exploration and research about an issue. It is often used as the first stage in assessing a problem or situation.

Causal loop models

Causal loop models are widely used in soft systems methodology to explain how cause-and-effect relationships relate to a wider system of factors. As the name

indicates, causal loops illustrate causality between variables in a qualitative way using a standard nomenclature (taken from Haraldsson's "Introduction to System Thinking and Causal Loop Diagrams" (2004) [69].

Symbol	Description
→	The arrow shows a causality. A variable at the tail causes a change to the variable at the head of the arrow
→ +	A plus sign near the arrowhead indicates that the variable at the tail of the arrow and the variable at the head of the arrow change in the **same** direction. If the tail increases, the head increases and vice-versa.
→ -	A minus sign near the arrowhead indicates that the variable at the tail of the arrow and the variable at the head of the arrow change in the opposite direction. If the tail increases, the head decreases, and vice versa
	The letter RB" inside a loop of *n* variables indicates a balancing effect – this means that the system moves in a direction towards equilibrium or fluctuation about a point of equilibrium
	The letter "R" inside a loop of n variables indicates a reinforcing effect – this means the system is moving in the direction of systematic growth or decline

Causal loops occur with feedback linking individual variables together, and when put together, forms one loop. This loop is a system – if that is what the boundaries dictate – however a larger system will then have several loops interconnected. Therefore, it is imperative to determine the appropriate number of variables that will be considered in the system and the system boundaries, as a system that is too complex can cause more misunderstandings when its purpose is to provide clarity. This is especially relevant for infrastructure projects, where the extensive number of variables make defining the system boundaries a difficult task. Hence the next section will summarise the variables identified in the literature and provide justification for the ones chosen to be used for the conceptual model

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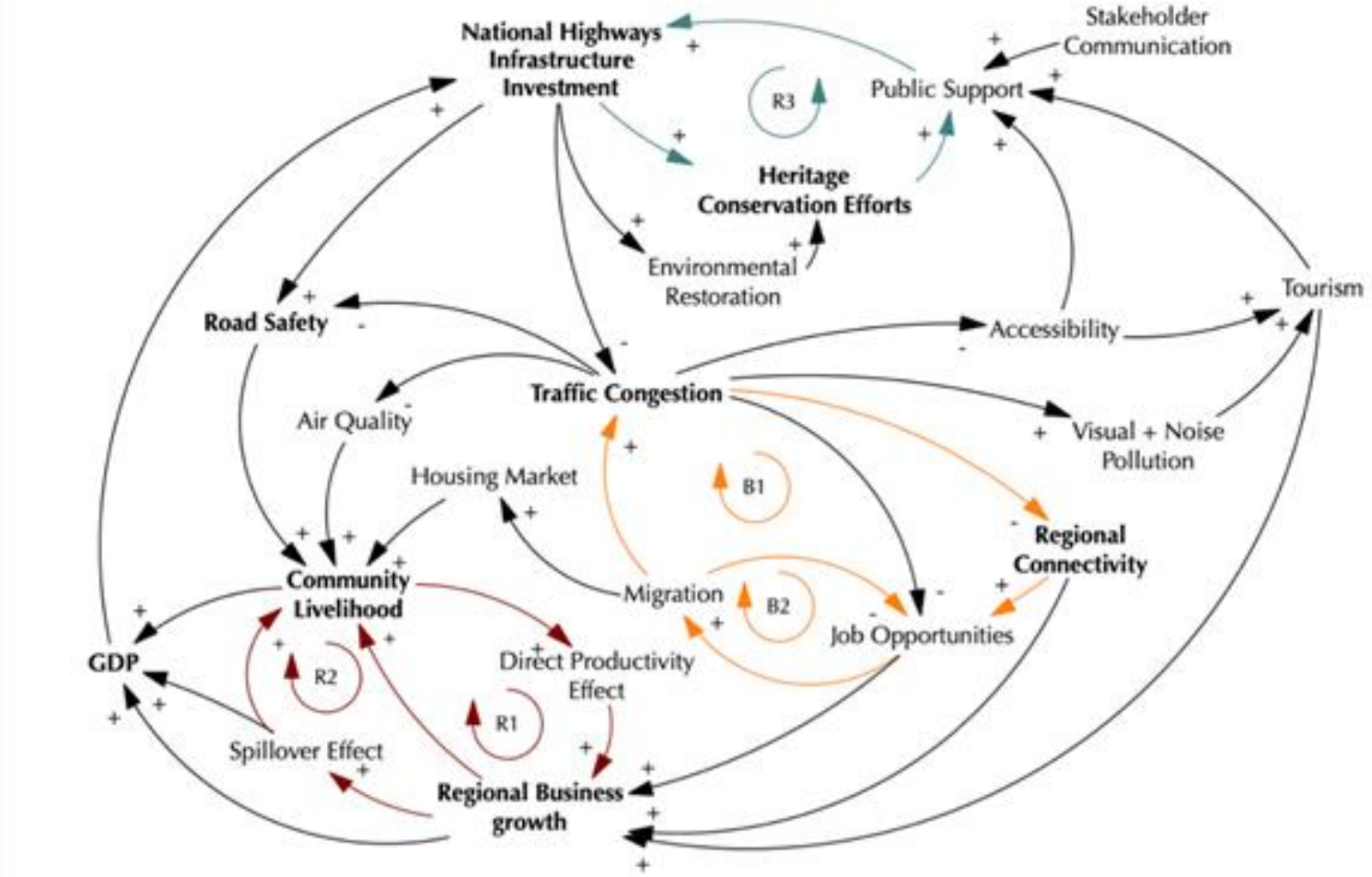

Example Causal Loop Diagram for National Highways Infrastructure investment (Reference: Prakash, S.B. Kirkham, R. J. Nanda, A., and Coleman, S. (2022) Multi-dimensional impacts of highways infrastructure investment; a system thinking approach to three cases in the National Highways Complex Infrastructure Programme, Project Leadership and Society (in press))

Appendix 6 – Case studies

Housing People, Building Communities

Housing People Building Communities (HPBC – formerly Liverpool Habitat for Humanity) is a charity dedicated to building affordable housing for low-income families. Their main 2.2-acre site, is in the Granby and Toxteth districts of Liverpool, was donated by the Roman Catholic Archdiocese. All the homes are built using volunteer labour (known as 'sweat-equity') that complements a small core professional construction team. The charity has sought to leverage the benefits of its status by acquiring donated construction materials where possible. The initial phase included plans for 32 houses – the first nine of which facing were completed in 2008.

HPBC Kingsley Road Housing Scheme

Most of the families living in the first phase have no prior experience of housebuilding or formal construction skills. The charity provides a detailed construction programme which enables the home partners to deliver up to 90% of the total construction works. This has obvious benefits including the simplification of the supply-chain and reliance on sub-contractors. Several of the charity's core team are qualified plumbers and electricians, and these provide specialist expertise, and formal Gas Safe installations are 'bought in'. HPBC also recruits other volunteers to help. These are not people earmarked to live in the finished homes – the charity works with local construction training colleges, universities, and students from abroad, who work on site to help the home partners deliver their programme of works.

Volunteers from the armed forces have also aided with the construction of the external works including driveways and drainage via the Military Aid to the Civilian Community (MACC) initiative.

All the homes have three bedrooms with living room and kitchen on the ground floor; and the bedrooms and a bathroom on the first floor. The design is flexible, allowing home partners to adjust the layout (i.e., open plan lounge/kitchen). The construction of the roof is such that it is easily convertible into additional living/sleeping space.

The main structural design is timber frame; the first nine homes used off-site frames; whereas the remaining 23 homes use frames that are constructed in-situ. Concrete composite wall cladding is used, with interlocking concrete tiles on the roof.

Funding for the first nine houses came from a variety of sources including Merseyside's Housing Market Renewal Initiative, the NewHeartlands regeneration initiative, gifts in kind, donations, and, as each property was completed, from the sale of the homes. Initial funding for staffing, to develop the project, came from the former Maritime's Heartlands Charity. The initial phases of the project were stalled by the costs associated with infrastructure to service the development; this was overcome by the Military Aid to the Civilian Community (MACC) initiative. A partnership has also been established with The Sanctuary Group housing association, which is part funding the latest homes; HPBC has secured a loan from Liverpool City Council (secured by the value of the first nine homes) to provide it with sufficient working capital. Third-sector involvement and charitable giving has formed a crucial aspect of the project, for example

- £30,000 worth of drainage supplies was donated by Balfour Beatty/Birse Civils, and other significant donations have come from Wienerberger, Bisque Radiators and Whirlpool.
- The local 'Pret A Manger' provides daily lunches for the volunteers.
- The 500 hours of 'sweat equity' contributed by each family entitles them to £10k towards their deposit. Shared equity mortgages can also be accessed – thereby making the homes affordable to families on low incomes.

In terms of cost and construction management;

- The Sanctuary Group provides £85,000 to deliver each home.
- It costs HPBC £65,000 to construct each unit.
- Each home has approximately 116m^2 of accommodation space – giving a per-square-metre cost of approximately £560.
- The surplus £20,000 covers HPBC's overheads including: staffing; hire of office facilities and storage space; power and water for the site.
- Final costs range between – £117,000-£120,000.
- Construction quality is monitored by a 'Clerk of Works' and a Surveyor. They also produce valuations for the funding partners so that money can be drawn down as required.

‘**Habitat for Humanity**’ organisation has operated in the UK for some considerable time and has developed an approach to the delivery of social housing in concert with third sector organisations such as churches, community groups, charities, and local authorities. The organisation has delivered several small-scale projects, including in partnership with the London Borough of Barking and Dagenham, which involved refurbishment of existing buildings on East Street in Barking to provide affordable care leaver’s accommodation.

LendLease has developed a corporate approach to social value by appointing a ‘social value manager’ as part of the core project delivery team; their new build prison at the site of the former HMPYOI Glen Parva is expected to create 100 new jobs created of which are at least 25% will be ex-offenders or offenders on ROTL (released on temporary license). At the Perry Barr scheme (formerly the Commonwealth Games site) LendLease reported the following social value performance metrics in April 2022:

- 512 new jobs have been created (128% of target of 400 jobs)
- £253,346,871 local spend within 30 miles (186% of £136,061,500 local spend target)
- 2,308 volunteering hours have been achieved (231% of target of 1000 hours)
- 1,325 people upskilled on site (133% of 1,000 target)
- 40,350.5 work placement hours achieved (384% of 10,500 hours target)

Lendlease has also signed up to the ‘Birmingham Business Charter for Social Responsibility', with an action plan aligned with 32 social value targets in collaboration with the local Employment Access Team (EAT) – this is designed to stimulate employment, education and training opportunities in the Birmingham and West Midlands area.

Hodgkinson Builders was founded in Derby in 1990 as a small bricklaying business and has grown to become a significant player in the social and affordable housing sector, making up 95% of all their projects to date. The company has actively sourced sites that are in genuine need of regeneration and has delivered > 500 homes across the UK. The company sponsored a ‘white-paper’ which reports on research undertaken by the University of Derby; it focuses on housing in general and social housing, as well as housing supply, the importance of skills and apprenticeships, solutions, and modern methods of construction. The report highlights the importance of social housing within the UK economy in providing much-needed houses and roofs over people’s heads.

The scale of the challenge facing the social housing sector is evident in the growing problem of homelessness here in the UK; data published by the charity ‘Shelter’ in December 2021 shows that more than 274,000 people were homeless in England,

including 126,000 children. There is an urgent need to tackle this problem through rapid and significant improvements in the availability of affordable, quality housing. We also know that employment is widely accepted to be crucial to reducing homelessness, yet there appears to be little evidence of a coordinated construction industry response to tackling this problem, particularly in the context of young homeless people. It seems perfectly reasonable to suggest that investment in social housing through targeted actions that mobilise and empower those at risk of homelessness will deliver wider societal benefits. This requires a system thinking approach, which recognizes that role of the construction industry in tackling entrenched social challenges including poverty, crime, and social inequality.

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Leadership

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The PROTECT COVID-19 National Core Study on transmission and environment is a UK-wide research programme improving our understanding of how SARS-CoV-2 (the virus that causes COVID-19) is transmitted from person to person, and how this varies in different settings and environments. This improved understanding is enabling more effective measures to reduce transmission – saving lives and getting society back towards 'normal'.

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