Thomas Ashton Institute

PROTECT
A COVID-19 National Core Study

Keeping the UK Building Safely: a scoping study

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'.

Construction workers across the UK have played a vital role in keeping the country running during the COVID-19 pandemic. This research report describes a scoping study aimed at improving understanding of the construction sector's efforts to build a 'COVID-secure' workplace. The study was carried out by researchers from the Thomas Ashton Institute and was completed in July 2021. The researchers carried out: a rapid review of previous studies investigating transmission; a survey and interviews with four principal contractor organisations; and interviews with representatives from the Health and Safety Executive (HSE)'s Construction Division and the Unite Union. The researchers identify six key themes in the industry's response to reducing COVID-19 transmission: contractual partnerships; organisational culture; communication; multi-level challenges; context of the sector; and best safety practice and technology use. The report includes two case studies of construction sites with some of the measures used to reduce COVID-19 transmission.

This report and the research it describes were funded by the PROTECT COVID-19 National Core Study on transmission and environment which is managed by HSE on behalf of HM Government. Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect Government or HSE Policy.

Keeping the UK Building Safely: a scoping study

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Executive summary

Construction activity in the United Kingdom (UK) accounts for a significant proportion of the overall economy, generating c. £117bn in Gross Value-Added terms; it is the fourth highest sector (by GVA) after professional & business services (£224bn GVA), financial services (£135bn GVA) and digital/technology (£135bn GVA) and represents 6.1% of Gross Domestic Product (GDP). **The sector is crucial to the post-COVID-19 economic recovery of the UK**.

The investigation underlying this scoping report was structured around five key work-steams identified through engagement with HSE and industry stakeholders**: transmission, technology, data and simulation, leadership**, and **construction project delivery.**

Our evidence base is obtained from survey and interview data gathered from four principal contractor organisations. Thematic analysis of the data revealed 6 focuses and 18 sub-themes - highlighting practical challenges facing the sector in the transition to a full 'reopening' of the UK economy.

It is clear, from the evidence we present in this report, that **'Keeping the UK Building Safely'** requires a system thinking approach to capture the complex interactions within the sector and with wider society. We show that 'construction sites' are but one part of many potential chains of transmission and that social, legislative and political influences – most of which exist beyond the bounds of enquiry in this report - are antecedents to a safe and bio-secure construction industry.

Thematic analysis revealed 6 global themes and 18 sub-themes that highlight practical challenges facing the sector as it prepares for the reopening of the UK economy.

1. **The context of the construction sector** - from large multinational companies to small firms and individual tradesmen, the UK construction industry is characterised by fragmented supply chains, which contain a myriad of contractual inter-relationships generally delivering low profit margins. The highly varied nature and size of construction activities and sites, from large infrastructure projects and city-centre multi-storey commercial developments to house building and routine maintenance, required tailored COVID-19 secure working arrangements. Although largely successful in limiting transmission of COVID-19 within the workplace, these arrangements have sometimes conflicted with contractual pressures to maintain construction productivity and in some situations may have created difficulties in sustaining non-COVID-related safety practices. The diverse character of the construction

workforce, and the variety of the location and types of construction work, poses challenges for limiting virus transmission beyond the construction site - for example whilst travelling to and from workplaces and during afterwork socialising or living arrangements.

2. **Organisational culture**: The existence of a well-established safety culture within the construction industry, with clear mechanisms for recording, reporting, and responding to safety issues, facilitated a flexible and prompt response to the challenges caused by COVID-19. Existing safety related procedures were adapted to monitor COVID-19 cases, to undertake risk assessments and to implement precautions against virus transmission. Industry led guidance in the Construction Leadership Council Site Operating Procedures, whilst helpful, needed flexible interpretation to be applicable to the specific requirements and limitations of the circumstances of individual construction sites and processes. Further adaptations were often necessary as behavioural responses and practical issues emerged and as understanding of COVID-19 improved.

3. **Communication**: Effective communication about COVID-19 risks and responses and about resulting changes in working practices were achieved using both established mechanisms for safety related briefing and workforce engagement. Further, the industry used complementary messaging and leadership, including innovative communication channels used to overcome virus transmission restrictions on travel and face –to face meetings. Generally, good relationships within the supply chain and open two-way communication throughout management levels and with the workforce, helped foster clear understanding of risks and responsibilities and was effective in countering misinformation. However, some unease and dissatisfaction within parts of the workforce arose from, what they perceived to be, apparent inconsistencies in Government and in other official advice and statements. These appeared to stress the need to limit virus transmission by maintaining safe working practices and indicated limited effectiveness of face coverings in combating transmission, whilst at the same time urging construction work to continue to help support the economy. Consequently, some of the workforce felt their health was being put at risk more than was the case in other sectors of the economy, or more than ‘office based’ colleagues who were able to work from home.

4. **Best safety practice and technology use:** Some good practice has been developed in adapting working methods to reduce COVID-19 risk, but there is mixed evidence regarding their impact on other aspects of construction safety, with concern that in some instances practical interactions and behavioural responses have compromised safe working practices. Extensive use has been made of IT to facilitate home working, reduce the need for travel and to maintain good communications within organisations and throughout the

supply chain. Some use has also been made of technology to assist in monitoring possible COVID-19 within the workforce and to help with risk assessment and planning adaptations to work plans and working practices. The use of other established technology, such as proximity sensors, has been limited, in part by concern that they can induce a false sense of security and reduce compliance with other safe practices. Potential uses of more advanced technology to help planning safer construction methods or to reduce workforce exposure have been limited by their cost, lack of commercial availability, the time needed for their development or worker training or application. The use of virus testing and contact tracing are overwhelmingly dominant but there is very limited evidence of the use of the resultant data in simulation and modelling techniques to inform transmission risks mitigation. The main reasons for this are insufficient skills and knowledge and cost concerns although participants expressed willingness to adopt simulation and modelling techniques in the future, if they could be used effectively and in a reliable and timely manner.

5. **Contractual partnerships**: There is apparent uncertainty regarding the contractual implications of COVID-19 and its impacts on delays to construction work along with additional costs involved in achieving safer working practices. In particular, the applicability of 'force majeure' provisions within construction and associated insurance contracts are a source of dispute. Generally, main contractors and their subcontractors have worked effectively together to respond in a positive way to COVID-19, seeking to prioritise issues of workforce health and safety above those of maintaining productivity. However, the response of construction clients has been rather mixed: some have sought to exert pressure to minimise delays and costs potentially compromising workforce safety; other clients have been inconsistent in their responses, with disrupted communications and changes of attitude; yet others have been overly cautious, sometimes insisting on measures that were ill-suited to the practical circumstances of a particular project or worksite.

6. **Multilevel challenges in responding to COVID-19**: Challenges in responding to COVID-19 have arisen at various levels within the construction process, organisations and workforce, and have evolved over time as the pandemic and responses to it have progressed. Initially, substantial variations arose in the attitudes and reactions of different contractors, their clients and individuals within both management and the general workforce. A more consistent response was achieved at industry level with the help of guidance from the Construction Leadership Council and then within much of the workforce through effective dialogue and communication. Effective adaptations to team working, modified methods of working on-site and homeworking where practicable have all helped reduce COVID-19 risks but have faced a variety of challenges in their adoption. There is some indication

that, with the passage of time, some responses to COVID-19 have become less effective, with a reduction in compliance, and adverse impacts have emerged affecting both working effectiveness and wider construction safety. In addition, issues of mental health and impacts of wider changes in society, such as school closures, have arisen and have had adverse effects in construction.

Construction workers across the country have played a vital role in keeping the country running during the COVID-19 pandemic. Much of their work is critical in supporting people's everyday lives. Behavioural change and workforce engagement are key COVID-related compliance strategies to manage and maintain workers' health and safety; there are challenges for leaders in managing impact on employee wellbeing and traditional health and safety.

Introduction

This report is commissioned by the Health and Safety Executive (HSE) and contributes to the PROTECT COVID-19 National Core Study on transmission and environment. PROTECT is managed by HSE on behalf of the UK Government, and is part of the COVID-19 National Core Studies programme led by the Government's Chief Scientific Adviser, Sir Patrick Vallance.

The programme 'Keep the UK Building Safely' (KUBS) aims to improve our understanding of the construction sector's efforts to build a 'COVID-secure' workplace; the evidence gained will provide future insights into a sustained re-

opening of the economy and support the UK's recovery through increased productivity - working safely has never been as crucial as it is now.

Accelerating productivity in the construction sector is a common governmental strategy where infrastructure investment is authorised as a deliberate economic stimulus. The recently published National Infrastructure Strategy[1] and the Analysis of the National Infrastructure and Construction Pipeline 2020/21[2] set out the UK government's ambition to deliver a total of 173 individual projects and 95 programmes across economic and social infrastructure, in the region of £29 billion - £37 billion. This ambition must be delivered with the ambition to maintain a world-class health, safety, and welfare record; with the wish to balance the desired acceleration in productivity with an on-going commitment to implementing the highest safety standards across the entire sector. The historical downwards trajectory in accident and fatality data suggests that ongoing reforms in construction standards have delivered significant benefits – but the onset of the pandemic, and its legacy, may create new threats to the industry. A series of recently commissioned government reports place significant emphasis on transformation in the construction sector; notably the Transforming Infrastructure Performance (TIP) report[3], which sets out a safety-oriented vision for the industry including:

- Industry led Innovation: delivering greater investment in the development and commercialisation of digital and manufacturing technologies, to significantly improve productivity, the quality, sustainability and safety of infrastructure and buildings.
- Skills for the Future: increasing investment in skills development and adopting a more strategic and co-ordinated approach to recruitment, and equipping workers with the skills and related training such as health and safety.

In this scoping report, we seek to characterise the construction industry's response to the pandemic through the lens of four principal contractor organisations operating across the UK; and use the evidence collected to produce a roadmap for necessary research to deliver recommendations for bio-secure working. It is important to note that the Site Operating Procedures (SOP) referred to in this report are based on Government guidance on Working safely during Coronavirus (Covid-19) - Construction and other outdoor work in England; other restrictions and advice may apply in Scotland, Wales and Northern Ireland, as well as in areas subject to a localised lockdown.

Our researchers identified five work-streams as the basis of the methodology (Table 1).

[1] https://www.gov.uk/government/publications/national-infrastructure-strategy
[2] https://www.gov.uk/government/publications/government-construction-pipeline
[3] https://www.gov.uk/government/publications/transforming-infrastructure-performance

KUBS Work-streams	Aim(s)
1. Transmission	To synthesise the evidence collected from a scoping review, stakeholder engagement and sector specific interviews to examine the risks of virus transmission in the construction sector. This will include investigating perceptions of organisational leaders in the four large construction companies relating to transmission, mitigation, measures, adaptations, and challenges in responding to COVID-19
2. Technology	To investigate how protective equipment, health monitoring or tracking, and 'removing the human from the work task' could be used. Furthermore, to identify opportunities for technology as a solution to shield the workforce from the effects of COVID-19. A technology scoping exercise through mixed methods of a literature review and user-centred engagement with key construction industry stakeholders
3. Data and simulation	To conduct a data audit and simulation modelling scoping through stakeholder engagement, conducting interviews with industry partners and conducting systematic literature reviews
4. Leadership	To synthesise evidence from stakeholder engagement and interviews with industry partners and to explore leadership and governance attributes / requirements and good practice that can enable effective management of COVID-19 risks. To understand how individual and organisational resilience has emerged over the course of the pandemic and how implementing change is linked to effective organisational/task design in support of organisational change – from this, to generate insights that support and recommend organisational change alongside healthy and safe working, whilst being sustainable and agile.
5. Construction project delivery	To assess the impact of COVID-19 on project delivery routines through analysis of survey and interview data and the presentation of case studies and industry data accessed through participants and the ESRC funded Project X[4]

Table 1: KUBS Work-streams

The evidence we have gathered identifies examples of participants' perceptions of 'what works?' in the mitigation of virus transmission; this analysis is positioned within a future need's assessment identified by our industrial partners as the basis for a roadmap to reducing hazards and the achievement of a safe and secure working environment.

[4] The Economic and Social Science Research Council (ESRC) funded Project X has identified several challenges across four areas of project delivery in government, as part of a submission to the Public Accounts Committee enquiry into 'lessons-learned from major project delivery' https://committees.parliament.uk/publications/4491/documents/45207/default/

Four Tier 1 main contracting organisations participated in the research; we present evidence gathered through a series of surveys and interviews; seeking to identify the mechanisms that have been initiated to close-off transmission routes on sites and across the value chain – the aim being to capture examples of new safe working protocols and identify how behavioural insights are shaping workplace design in the context of the Construction (Design and Management) Regulations 2015. Coalescing our behavioural expertise enables us to characterise how different work streams can be adapted to manage infection pathways.

The Thomas Ashton Institute

The Thomas Ashton Institute is a collaborative partnership between the Health and Safety Executive (HSE) and The University of Manchester. It is an interdisciplinary research institute concerned with the understanding of failures that occur in the world of work leading to injury or ill-health.

Our vision is to draw on the combined knowledge and experience of The University of Manchester and HSE to deliver research, learning and regulatory insights that widen the global conversation to enable a better working world.

Our work is grounded in social responsibility to inform and improve industry practice and regulatory intervention through research, teaching and learning (PhD, postdoctoral, CPD), as well as data and data analytics.

Further, we have world-class facilities and minds addressing real world regulatory issues with academic rigour to combine regulatory experience and innovative research. Our combined knowledge and expertise are unrivalled and trusted since our work is rooted in decades of regulatory knowledge and cutting-edge research, and we endeavour to be deeply engaged with industry, workforce, and other stakeholders to make sure we have impact and relevance. We also ensure our relevance by aligning with government strategies – for example, the Industrial Strategy objectives of helping ensure healthy and safe deployment of new technologies. We believe that these key partnerships help our work address current issues and identify emerging ones.

The UK construction sector and the impact of the COVID-19 pandemic

The UK construction industry

Construction activity in the UK accounts for a significant proportion of the overall economy, generating c. £117bn in Gross Value-Added terms; this is the fourth highest sector after professional & business services (£224bn GVA), financial services (£135bn GVA) and digital/technology (£135bn GVA) and represents 6.1% of Gross Domestic Product (GDP).

The sector enjoys a strong regional presence with 2.2m of employment opportunities (7% of total UK employment) spread uniformly across the UK regions, although current data shows that larger firms are disproportionately headquartered in the South of England. A mix of large international firms as well as small-medium enterprises (SMEs) make up the c.330k of UK businesses registered with Her Majesty's Revenue and Customs (HMRC); c.20 of these enjoy turnovers > £1bn.

The construction industry is a major player in the delivery of government priority projects and programmes; this is reflected in total government spending across the sector (c. 30% of all orders in 2018). The most recent 'pipeline' data published by the Infrastructure and Projects Authority (IPA) suggests that the Government's ambition to continue investing in the country's infrastructure is set to ramp up significantly, in support of national endeavours such as 'levelling-up' and regional strategies such as the 'Northern Powerhouse'[5].

The IPA forecast £29 billion to £37 billion of new contracts across economic and social infrastructure will be brought to market over the next year. The publication of the pipeline[5] and increased granularity of project information is designed to provide the construction industry with 'better visibility and certainty of current and future project flow, to help companies, rebound from this crisis.'

The recent publication of the National Infrastructure Strategy and the Construction and Infrastructure Pipeline illustrate why the sector is critical for delivering on the government's objectives and post COVID-19 recovery, including supporting levelling up, infrastructure plans (including the 300k housing target) and net zero.

The UK construction sector is diverse in nature - this is reflected in Office for National Statistics (ONS) data, which is organised into seven categories; property development, general builders, building and civil engineering contractors (the focus of this study), non-residential building, housebuilding, civil engineering, and specialist trades, of which there are 30 specified categories ranging from demolition, temporary works, plumbing, heating, etc. (Table 2).

Category	Description
Development	The organising of building projects for residential and non-residential buildings bringing together financial, technical and physical means.
Non-residential building	Non-residential commercial buildings – e.g., buildings for industrial production, hospitals, primary, secondary, and other schools, office buildings, hotels, stores, shopping malls, restaurants, airport buildings, indoor sports facilities, parking garages, warehouses, religious buildings, and arts, cultural or leisure facilities buildings

[5] https://www.gov.uk/government/publications/national-infrastructure-and-construction-procurement-pipeline-202021

Category	Description
Residential building (house building)	Residential domestic buildings – e.g., all types of residential buildings, and remodelling or renovating existing residential structures
General construction for civil engineering	New work, repair, additions and alterations, the erection of prefabricated structures on the site and construction of temporary nature
Heavy constructions	Motorways, streets, bridges, tunnels, railways, airfields, harbours and other water projects, irrigation systems, sewerage systems, industrial facilities, pipelines and electric lines, outdoor sports facilities, etc.
Allied construction activities	The construction of parts of buildings and civil engineering works including activities that are usually specialised in one aspect common to different structures, requiring specialised skills or equipment, such as pile-driving, foundation work, carcass work, concrete work, brick laying, stone setting, scaffolding, roof covering, etc.
Building finishing and building completion activities	Installation of utilities that support construction typically performed at the site of the construction) including plumbing, installation of heating and air-conditioning systems, antennas, alarm systems and other electrical work, sprinkler systems, elevators and escalators, etc.

Table 2 ONS Classification of construction sector

Construction Sector Deal

A safer construction sector is crucial to realisation of the industry's potential. Higher standards of health and safety will make the industry more attractive, help retain staff, and create a productive and sustainable sector. The recently published 'Sector Deal'[6] highlights significant improvements in performance in relation to health and safety in the past decade but cautions against complacency. The final report of the 'Independent Review of Building Regulations and Fire Safety'[7] also call for reform in learning and development to drive improvements in competence and to 'create a culture geared towards continuous improvement, better performing products and greater innovation'.

Key areas for improvement are standardising work-related health and safety training for employees, supporting longer term **physical and mental health**, and improving working environments. The Health and Safety Executive's Construction Industry

[6] https://www.gov.uk/government/publications/construction-sector-deal/construction-sector-deal#fn:8

[7] https://www.gov.uk/government/publications/independent-review-of-building-regulations-and-fire-safety-final-report

Advisory Committee (CONIAC), which includes industry and trade union representatives, is working with the Construction Industry Training Board (CITB), the Construction Leadership Council (CLC) and companies to drive improvements in working practices across the value chain. The structure and organisation of the construction industry in the UK is often described as 'fragmented' – this presents challenges in embedding a safety focused culture through the supply-chain. The construction industry is characterised by a high proportion of self-employment (36% in Q2 2019), this compares with the whole economy mean of 13%[8]. It is widely accepted that reforms to sub-contracting practices (the propensity) is the antecedent to positive change; notably in building contracts where levels of self-employment are proportionally higher relative to civil engineering.

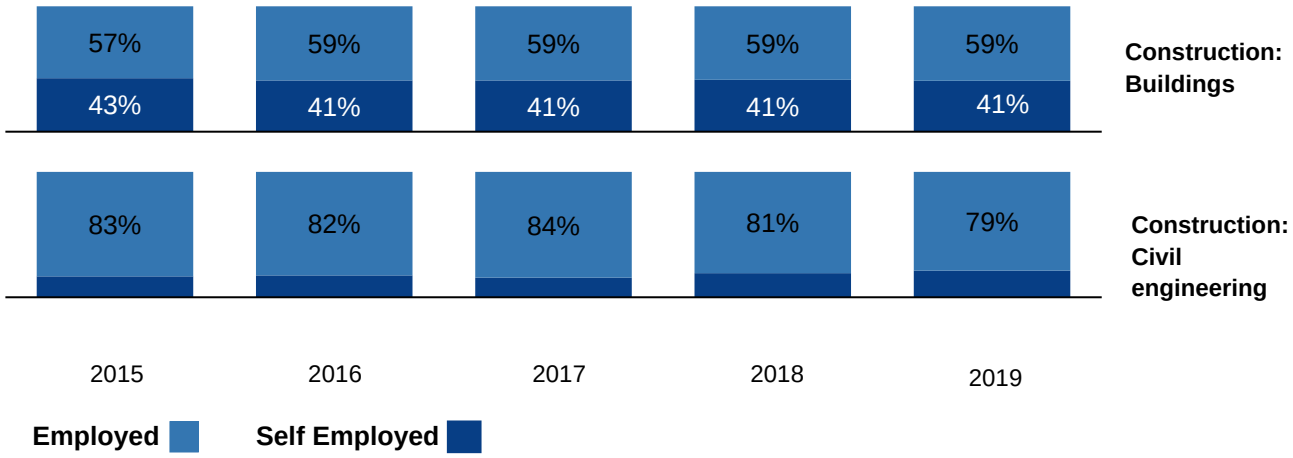


Fig.1: Comparison of proportion of employed/self-employed in building and civil engineering, 2015-2019 (Source; ONS)

[8] https://commonslibrary.parliament.uk/research-briefings/sn01432/

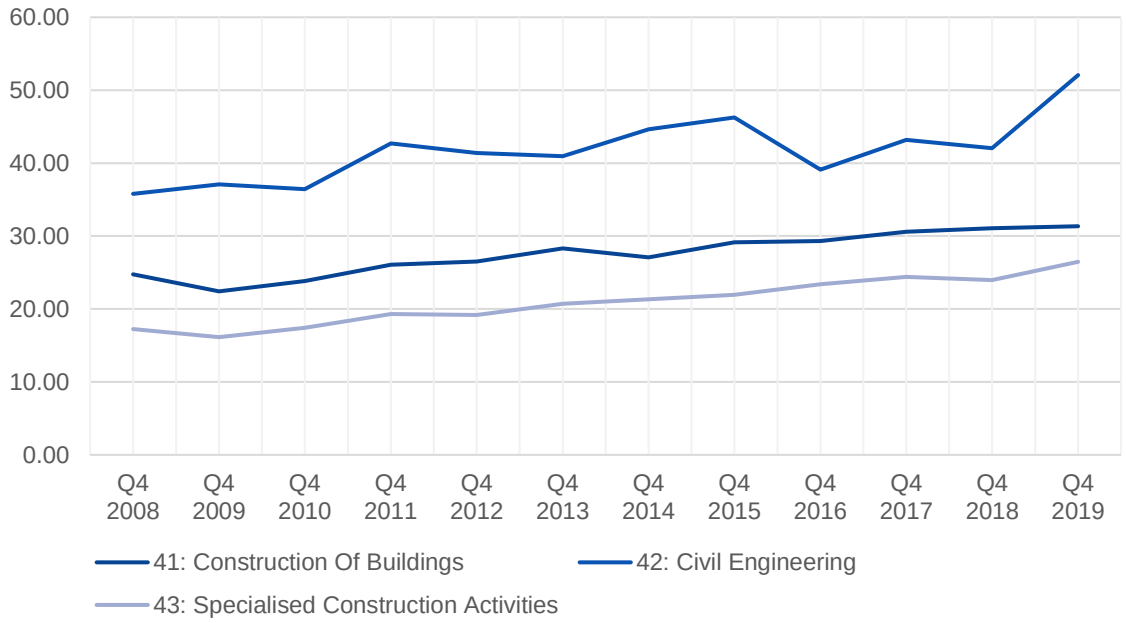


Fig 2: Output per hour, seasonally adjusted, current prices, UK, 2008 to 2019 (Source; ONS)

The civil engineering industry saw a sharp increase in productivity as measured by output per hour in 2019 (Fig 2). This shows that the civil engineering sector is likely to be a significant focus of government spending, post-pandemic and will include megaprojects such as HS2, Lower Thames Crossing and A303 Stonehenge Tunnel.

The impact of COVID-19 on the UK construction sector

Construction workers across the country have played a vital role in keeping the country running during the COVID-19 pandemic. Much of their work is critical in supporting people's everyday lives. This ranges from building hospitals, to maintaining crucial transport and utilities networks, and ensuring buildings are kept safe.

The construction industry was experiencing significant challenges before the onset of the COVID-19 crisis; the collapse of the Tier 1 contractor Carillion in 2018 illustrated that some companies with large-scale contracts, including 'safe' government projects, were just as susceptible to insolvency as small-to-medium sized enterprises. The average pre-tax margin of the top 10 UK contractors was -0.1% for 2018/19.

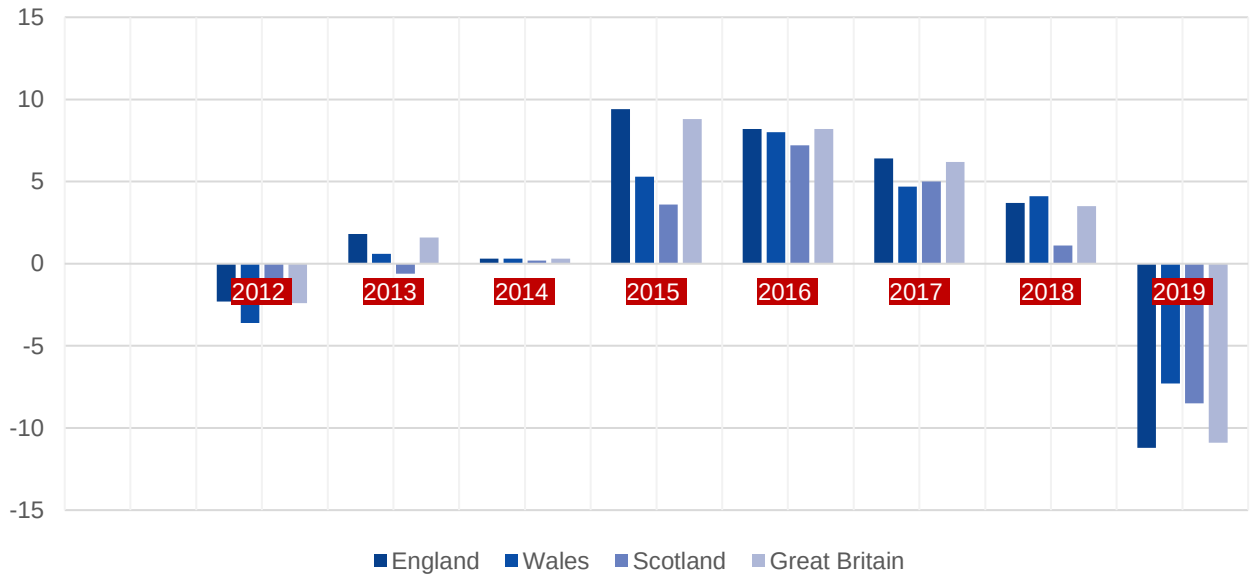


Fig 3: Year-on-year growth in the total number of construction firms, percentage difference, Great Britain, 2012 to 2019, (Source: ONS)

The initial closing and then re-opening of construction sites by means of social distancing measures means that construction output is forecasted to be c. 15% lower than pre-pandemic levels, this will likely aggravate recovery from what is already a relatively weak situation.

This will further limit the speed at which each part of the construction sector supply chain can return to 'normal' operation which has the knock-on effect of continuing to affect the pace of supply chain recovery. Since these adjustments will not occur simultaneously, there is a risk that near-term shortfalls in manufacturing capacity may occur posing a risk of price inflation.

The impact of reduced cash flow on clients and the construction supply chain may lead to sub-optimal payment practices, despite the availability of initiatives such as project bank accounts. The disbenefits may be compounded further down the supply chain in so far as financial insecurity experienced by workers is concerned.

Delays, schedule over-runs and RICS adjudication referrals

A recent government assessment of c. 5,000 construction contracts in 2020 shows that work packages valued at > £50m faced schedule delays in the range of 4% - 19% and cost escalation in the range of 6% - 9%; these are often antecedents for contractual dispute and litigation. The Government has said that it recognises a need to support industry participants (parties to contracts) in resolving disputes during the pandemic; the Cabinet Office published guidance on 'responsible contractual behaviour' with the intention of mitigating against the disbenefits of protracted disputes, prevention of unnecessary insolvencies and sustaining the long-term viability of contracts and businesses. The government has, in addition, commissioned reviews into procurement arrangements and the contract terms that it

offers to suppliers as a means to facilitate their adaptation to the COVID-19 environment, and new ways of working to support economic recovery. Furthermore, the government has initiated 'Project Speed' with the intention of accelerating project delivery in government, and In February 2021, the Rail Project Speed (Swift, Pragmatic and Efficient Enhancement Delivery), programme, which is jointly run by the Department for Transport (DfT) and Network Rail (NR).

Mental health and work-related stress

This is relevant in the context of increasing awareness and concerns for mental health amongst the construction workforce in the UK. Research conducted by the Electrical Contractors Association (ECA) and the Building Engineering Services Association (BESA), highlighted in the May 2020 Chartered Institute of Building (CIOB)[9] report into mental health, reveals issues into late payment practices on the mental health of workers within SME's. The study found that 92% of surveyed businesses encountered payment issues, with 65% reporting that late payment was a frequent problem. Late payments often lead to business owners sacrificing their own salary; 1 in 10 of surveyed businesses said that they were forced to pay their 'directly employed staff' late. Amongst other findings, 80% of individuals said that they had experienced stress, 40% experienced anxiety and/or panic attacks, and 36% experienced depression.

"Systemic problems, such as long supply chains, the withholding of payments, slim profit margins and job insecurity all go towards increasing stress and anxiety."

Kevin Fear, Health and Safety **Strategy Lead, CITB (Source: CIOB)**

"Getting regular, reliable work can be difficult, and the lack of job security can contribute significantly to poor mental health"

"Work can be away from home in an unfamiliar area, away from the normal support network of family and friends.

"Long hours, tight deadlines, and the pressure of keeping family, bosses, contractors and clients all happy can be too much."

Michelle Finnerty, Marketing Manager of the Lighthouse Club), a charity providing emotional and financial assistance to the construction community. (Source; CIOB)

Where payments are in dispute and cannot be resolved through the normal mechanisms of the contract, parties may opt for adjudication. The purpose of adjudication is to determine reasonable and expeditious decisions on construction contract disputes, usually within a 28-day timeframe. Royal Institution of Chartered

[9] https://www.ciob.org/industry/research/Understanding-Mental-Health-Built-Environment

Surveyors (RICS) data on the number of adjudication referrals evidences how previous 'crisis' periods tend to lead to an inversely proportional relationship between construction output (decreasing) and adjudication nominations (increasing). The current data suggests that this trend is being maintained.

Likelihood of exposure to SARS-CoV-2 virus in the construction sector

Evidence gathered by government suggests that a person's occupation may have an important bearing on the probability that they will be exposed to the SARS-CoV-2 virus and become infected. Occupational risks are also echoed in the reported variations in hospitalisation and mortality rates in different occupations[9]. The research relating to this has limitations in that it did not consider where the infections were likely to have come from (i.e., community and not work transmission). Furthermore, the study did not consider the worker profile of people in the sectors covered in the study (i.e., was there a higher prevalence of people with underlying health conditions, comorbidities etc. that may lead to increased susceptibility to the disease).

The government messaging in the initial phases of the pandemic focused on encouraging the workforce to 'stay at home' where possible; this was problematic in the construction sector given the nature of work and may explain the policy decision to allow construction to continue during the first and second 'lockdown'. Analysis of the labour force survey data from April 2020 (during the first lockdown) showed nearly half (46.6%) of people in employment did some of their work from home, with the vast majority (86.0%) of these homeworkers stating that this was because of the coronavirus (COVID-19) pandemic. People aged 16 to 24 years were less likely to do some work from home.[10]

The ability to work from home is not usually an option for individuals working in the elementary or skilled construction trades. Senior professionals in the industry tend to be encouraged by employers to work from home where possible; project managers being one example. Analysis published in early 2021 signifies those occupations requiring higher qualifications and more experience were more likely to provide homeworking opportunities than elementary and manual occupations[10].

In addition to reductions in risks of workplace transmission home working will also reduce associated risks such as those from using public transport and increase transport system capacity for those who have no choice but to travel. ONS data (27-31st January 2021) shows the number of people who report going to their workplace at least one day a week when they could work from home full time is 25%.[10] (see Fig 3 and Table 3).

[10] https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/conditionsanddiseases/articles/coronavirusCOVID19roundup/latest

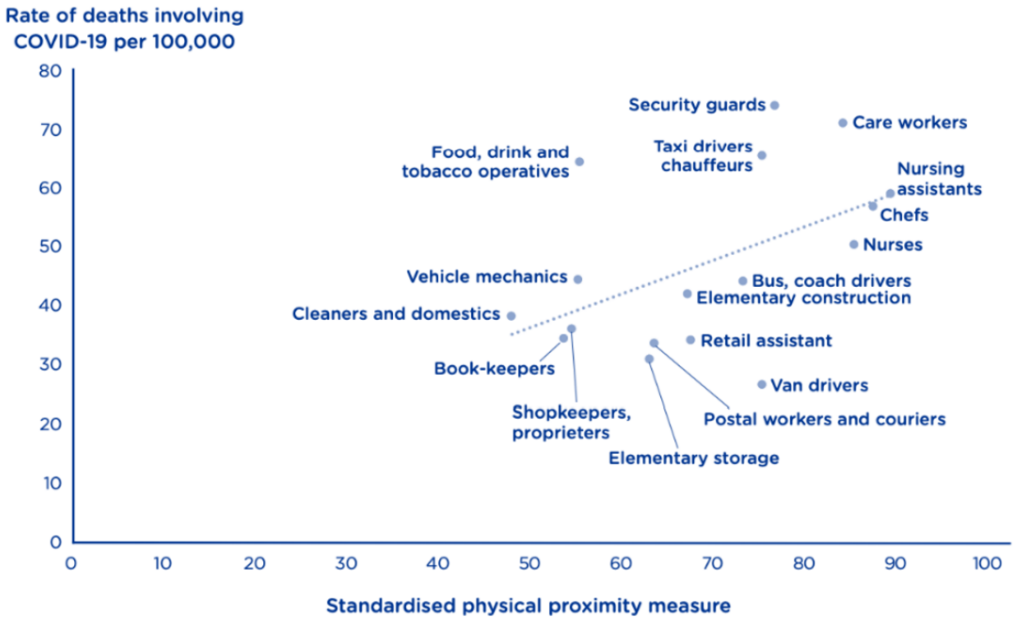


Fig 3: Age standardised male mortality rates (per 100,000) at ages 20 to 64 in 17 high risk occupations by proximity to others, based on deaths involving COVID-19 registered in England and Wales between 9 March 2020 and 25 May 2020[11]

SOC individual occupation	Description	Deaths	Rate	Lower Confidence interval	Upper Confidence interval
1122	Production managers and directors in construction	33	20.7	14.1	29.4
2436	Construction project managers and related professionals	2	:	:	:
5249	Electrical and electronic trades n.e.c.	22	38	23.6	57.9
5250	Skilled metal, electrical and electronic trades supervisors	5	:	:	:
5311	Steel erectors	2	:	:	:

[11]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/965094/s1100-COVID-19-risk-by-occupation-workplace.pdf

5312	Bricklayers and masons	18	32.4	18.9	51.6
5313	Roofers, roof tilers and slaters	19	100.5	55.8	163.6
5314	Plumbers and heating and ventilating engineers	31	24.3	16.3	34.6
5315	Carpenters and joiners	60	43.1	32.8	55.6
5316	Glaziers, window fabricators and fitters	9	:	:	:
5319	Construction and building trades n.e.c.	85	40.1	32	49.7
5321	Plasterers	11	38.5	18.9	69.2
5322	Floorers and wall tilers	8	:	:	:
5323	Painters and decorators	56	47	34.9	61.8
5330	Construction and building trades supervisors	6	:	:	:
8141	Scaffolders, stagers and riggers	8	:	:	:
8142	Road construction operatives	6	:	:	:
8143	Rail construction and maintenance operatives	4	:	:	:
8149	Construction operatives n.e.c.	22	23.7	14.6	36.3
8229	Mobile machine drivers and operatives n.e.c.	16	44.2	24.9	72.3
9120	Elementary construction occupations	70	82.1	63.9	103.7

Table 3: Average mortality rate 31.4 deaths per 100,000 men aged 20 to 64 years

Standard Occupation Classification (SOC) Code	Standard Occupation Classification (SOC) Title	Number testing positive	Sample size	% Testing Positive	Lower Confidence Interval (95%)	Upper Confidence Interval (95%)
1122	Production managers and directors in construction	12	338	3.55	1.85	6.12
2436	Construction project managers and related professionals	8	208	3.85	1.67	7.44
5249	Electrical and electronic trades n.e.c.	10	159	6.29	3.06	11.26
5313	Roofers, roof tilers and slaters	5	74	6.76	2.23	15.07
5314	Plumbers and heating and ventilating engineers	14	419	3.34	1.84	5.54
5315	Carpenters and joiners	30	564	5.32	3.62	7.51
5319	Construction and building trades n.e.c.	40	828	4.83	3.47	6.52
5322	Floorers and wall tilers	5	58	8.62	2.86	18.98
5323	Painters and decorators	9	290	3.1	1.43	5.81
8149	Construction operatives n.e.c.	7	200	3.5	1.42	7.08
9120	Elementary construction occupations	12	224	5.36	2.8	9.17

Table 4: Percentage of people testing positive for the Coronavirus (COVID-19) for a number of construction occupations (Unweighted) in England between 1 September 2020 and 7 January 2021 (ONS infection survey)

Data presented to the Scientific Advisory Group for Emergencies (SAGE) in February 2021[12] suggests that employees who are less likely to be able to work from home have higher COVID-19 mortality rates than those that can. Elementary

[12] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/965094/s1100-COVID-19-risk-by-occupation-workplace.pdf

occupations have the highest age standardised mortality rate and comprise low skilled manual labour occupations that are unlikely to be able to be conducted from home.

The same data also suggests that occupations which involve working practices characterised by closer physical proximity to others tend to have higher COVID-19 mortality rates. The relative risks will depend on the type of contact (colleagues/public), the frequency of contact, the duration of contact, and the likelihood that the contact is infected.

Construction Leadership Council (CLC) Site Operating Procedures (SOP)

The Construction Leadership Council (CLC) is a representative body whose mission is to provide sector leadership to the industry, it is co-chaired by Anne-Marie Trevelyan (Minister for Business and Industry, Department for Business, Energy, and Industrial Strategy) and Andy Mitchell, CEO of Tideway. In response to the pandemic, the CLC published the Operating Procedures (SOP) – sector specific guidance on the implementation of the Government guidance on Working safely during Coronavirus (COVID-19). The objective is to introduce consistent measures on construction sites of all types and sizes and to support employers and individuals in complying with the guidance.

Working safely during COVID-19 in construction and other outdoor work – COVID-19 secure guidance for employers, employees and the self-employed

HM Government issued new guidance in May 2020 - this sets out how employers can open and maintain workplaces safely while minimising the risk of spreading COVID-19. The document provides generic guidance and identifies practical considerations of how mitigations can be applied in the workplace. Social distancing is a key focus – it explains how employers and employees may ensure compliance with social distancing guidelines (2m apart, or 1m with risk mitigation where 2m is not viable).

Research Methodology

Our approach

The research team adopted a methodology analogous to rapid evidence assessment principles. Qualitative evidence syntheses, which often features in systematic reviews of qualitative research literature, is useful in situations where researchers seek to explore individual participants perceptions and experiences of their working environment and the wider setting. A qualitative evidence synthesis integrates the depth in understanding of complex experiences and opinions together with evidence from other sources such as literature reviews and contextual factors relevant to the domain of study. In this research, a six-stage approach is used:

- Scoping reviews investigating transmission of C19, technology and leadership in the construction sector.
- Initial evidence gathering questionnaire – issued to pre-selected research participants.
- Pre-interview survey design pilot and deployment to pre-selected research participants.
- Semi-structured interviews with organisational leads from major construction companies.
- Thematic analysis of interview data.
- Evidence synthesis.

Overview of research methods

Scoping review

A rapid review of previous studies investigating transmission was completed to collate evidence from academic studies, policy and guidance documents and opinion from sector leaders. We adopted the rapid review method outlined by Khangora et. al. (2012)[13] to synthesise evidence from different sources and identify critical themes from the data to create an evidence summary and inform future research. This approach enabled us to produce an evidence summary that was timely and accessible, drawing on the evidence available from different sources to inform the

[13] Khangura, S., Konnyu, K., Cushman, R. et al. Evidence summaries: the evolution of a rapid review approach. Syst Rev 1, 10 (2012). https://doi.org/10.1186/2046-4053-1-10

design of the stakeholder engagement and semi-structured interviews for the sector ‘deep dive’.

Pre-interview survey

Pre-interview surveys were developed based on the evidence from the scoping review to gather initial data from stakeholders in the construction sector (see Appendix 9 for interview questionnaire). Stakeholders of the four participating construction organisations were invited to complete the surveys in advance of the semi-structured interview stage. 16 stakeholders from the four participating construction companies were invited to complete the survey in advance of the semi-structured interview stage. A total of eight stakeholders provided responses on behalf of their organisations and all four construction companies were represented in the data. The responses to the pre-interview survey, and the evidence identified from the rapid review of previous studies, were used to inform the interview schedule (see Appendix 1 for the sector ‘deep dive’ stage of the research and provided initial data for the evidence synthesis.

Qualitative semi-structured interviews

The qualitative interviews provided a method to conduct a ‘deep dive’ to investigate the perceptions and views of leads in the construction sector. A stakeholder network provided advice for designing the interview schedule and interviews with representatives from four construction companies involved in delivering diverse construction programmes were set up (see Appendix 9 for interview schedule). Interviews were conducted using videoconferencing and lasted approximately one hour. The eight stakeholders from four participating construction companies who completed the pre-interview survey took part in this interview stage. Participants from the same construction company were invited to be interviewed individually or jointly, resulting in five interviews overall. Each interview was conducted by two researchers with field notes and audio recording available for analysis. The interview schedule prompted discussion in three topic areas: (i) views of monitoring and mitigating virus transmission; (ii) data collection, analysis and technology and (iii) management, leadership and implementing adaptations.

Sampling

Interview participants were selected through a purposeful sampling approach facilitated by existing collaborative arrangements in the Thomas Ashton Institute. In practice, participant requests were issued to a pre-selected group of Tier 1 contracting organisations who then identified the most appropriate individual(s) to participate in the interviews. These stakeholders included senior managing roles, such as project director, senior health and safety managers and advisor, senior manager for data insight, technology and digital infrastructure. In addition, we sought insights from HSE construction inspectors and a trade union representative at senior level in the construction sector.

Qualitative research often deploys purposeful sampling in the context of qualitative evidence synthesis - one of the fundamental arguments supporting purposeful sampling approach is that 'it is not meant to be comprehensive in terms of screening all potentially relevant sources of data, mainly because the interest of the authors is not in seeking a single 'correct' answer, but rather in examining the complexity of different conceptualizations'[14]

Thematic analysis

Thematic analysis was conducted by researchers using the field notes and audio files to generate a set of global, organising and basic themes. These were reviewed and refined in discussion with the wider research team and stakeholder network. The themes were presented in tabulated form to enable theme development and identify patterns across the data set (see Appendix 1). The results of the thematic analysis are shown in Fig. 5; 6 global themes and 18 organising themes were identified. A range of thematic coding approaches are available such as hierarchical levels or category classes (e.g., basic, organizing, and global themes) to discriminate between abstract and concrete textual content. A basic theme is "the most basic or lowest-order theme that is derived from the textual data," an organizing theme is "a middle-order theme that organizes the basic themes into clusters of similar issues," and global themes "are super-ordinate themes that encompass the principal metaphors in the data as a whole" (see Attride-Stirling, 2001, p. 388 in Armborst, A. (2017) 'Thematic Proximity in Content Analysis', SAGE Open).

Project organisation

The work of this project is organised across 5 distinct work-packages (WPs); each led by a member of the Thomas Ashton Institute at The University of Manchester with ongoing and substantive involvement of a discipline expert civil servant in the HSE Science Division (Fig 4). Project Management workstreams are distributed across The University of Manchester and HSE Science Division and operate within the prescribed governance mechanisms of the Thomas Ashton Institute.

[14] Benoot, C., Hannes, K. & Bilsen, J. The use of purposeful sampling in a qualitative evidence synthesis: A worked example on sexual adjustment to a cancer trajectory. BMC Med Res Methodol 16, 21 (2016). https://doi.org/10.1186/s12874-016-0114-6

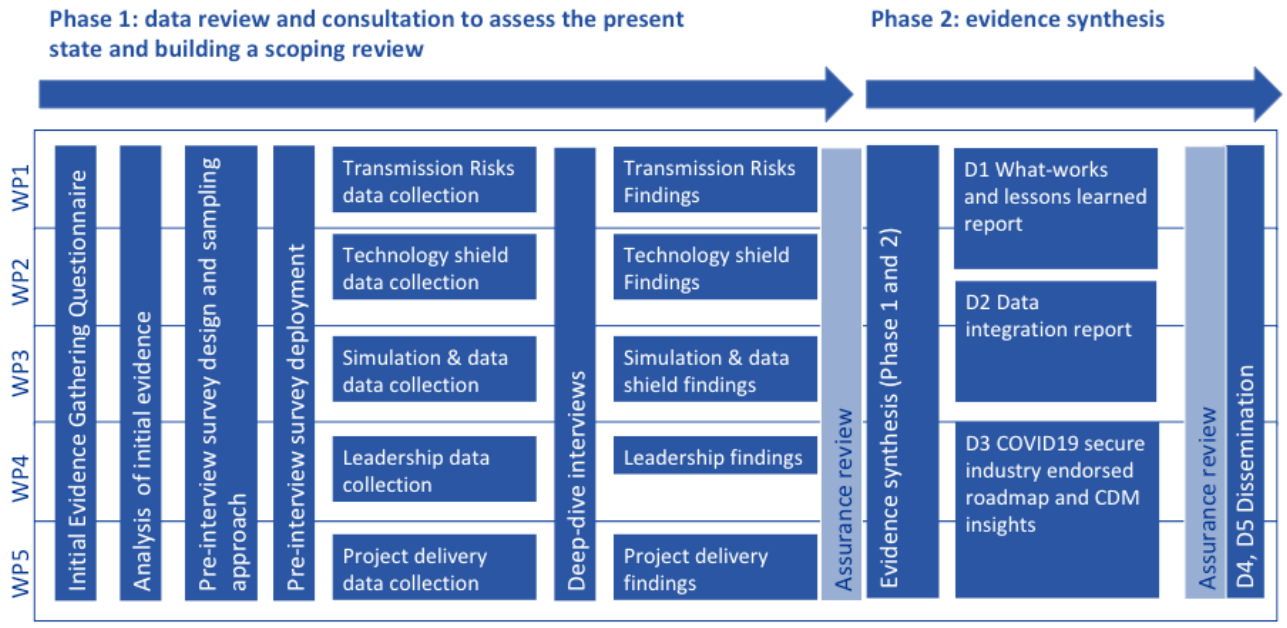


Fig 4. Research Methodology

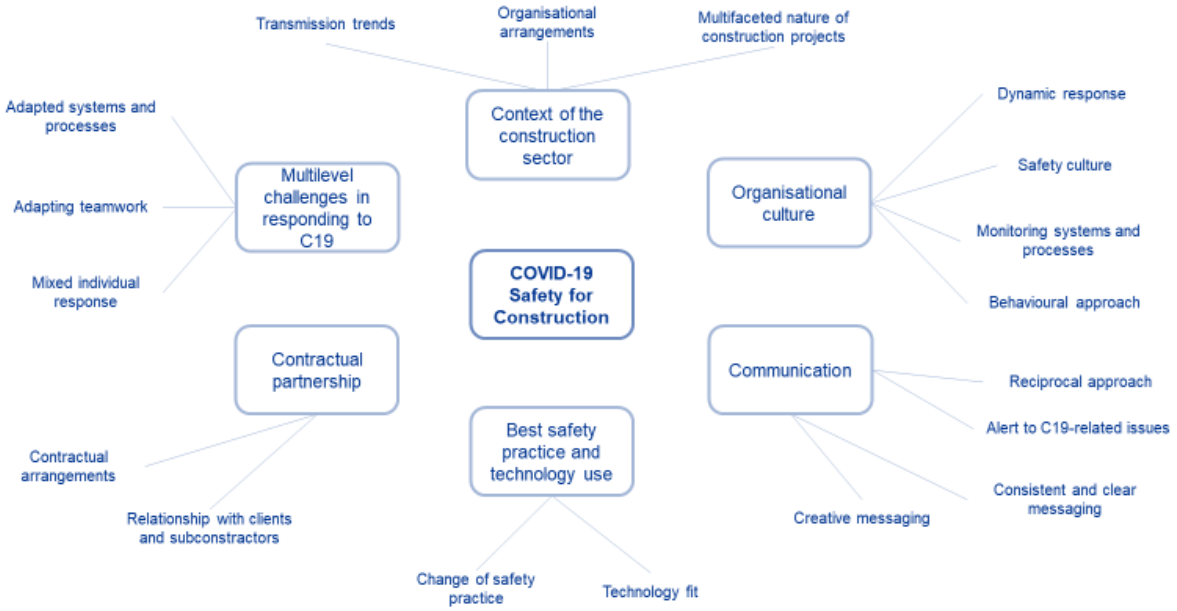


Fig 5: Global and organising themes from interview analysis.

Transmission

Introduction

Summary from rapid review of the evidence relating to transmission and leadership:

1. Clusters of COVID-19 suggest that construction can be a high-risk workplace, but issues of workplace culture and socio-economic factors complicate the picture.

2. Consistent COVID-19 safety measures were quickly introduced but were difficult to monitor.

3. Unanticipated benefits of changes in working practice from introducing COVID-19 measures.

4. Complex organisation of construction projects potentially impedes consistent use of measures.

5. Continued commitment to safety and engagement with workers is essential to manage safety compliance and wellbeing to reduce transmission.

Stakeholder interviews provided the opportunity to hear perspectives of managers and safety adviser representatives of the participating organisations in managing the risk of COVID-19 transmission. The findings from qualitative interviews reflect their understanding of the specific risks of transmission and the approaches that helped to mitigate these risks. The conversations revealed the challenges of adapting to keep workers as safe as possible when the threats were difficult to gauge, but also highlighted the dynamic and prompt responses that companies made, whether closing sites, introducing different work patterns or enforcing new working practices. The key findings for WP1 are presented using the perspectives of representatives from the construction sector.

How did the representatives describe their understanding of the transmission risks?

Construction is an occupational sector that includes a diverse range of occupations and activities that present varied challenges for adapting to reduce transmission of COVID-19. At the broadest level, work in the sector may necessarily preclude essential measures such as social distancing. Consequently, organisations had to adapt the official guidance to suit a variety of contexts found on their sites, depending on a thorough understanding of the transmission risks, as presented at the time, and knowledge of the work demands and workflow. The stakeholders described an intense, and rapid process of gathering information on the virus, interpreting, and adapting guidelines based on workplace risk assessments and disseminating changes in workplace practice through the organisational hierarchy.

Organisations described their understanding of transmission as assisted by their strong safety culture, enabling them to act quickly and ‘be ahead of the game’. They described utilising their management hierarchy to communicate quickly and

effectively as safety is a core role for all managers and employees within the workplace. They expressed themselves as operating as a safety critical industry, able to employ routine good practice and access expertise inside and the organisation and from a wider network to help understand threat and adapt practice.

As the pandemic progressed, understanding of the risk of transmission was challenging given changes in advice from scientific and professional guidance. The lack of conclusive evidence about the best measures to mitigate transmission in specific settings generated a degree of fear and confusion, for example, managers could not determine, and therefore present a confident message about, how much 'mask' wearing reduced the risk in activities involving proximity of workers.

Stakeholders provided very few examples of outbreaks suggesting work related transmission in the construction sector. Where these outbreaks emerged, the interviewees suggested that transmission was more likely to be associated with shared living conditions, transport to work and visiting the pub after work, than with the actual construction site. If transmissions did occur on site, these were thought to be linked to enclosed spaces such as offices, canteens, or tunnelling.

The culture within the construction sector was portrayed as providing both a context where individuals comply to safety requirements and a workforce that likes to 'congregate' and therefore increasing the risk of transmission. Improving the understanding of the risk of transmission of the whole workforce, including in some instances subcontractors, was a priority and stakeholders talked confidently about managing communication.

How did the representatives describe the mitigation and measures used?

Organisations expressed the top priority for mitigating the risks as behavioural change across the organisation. In one example, the stakeholder described the benefits of using a behavioural programme that they routinely employed for developing coaching and supervision to support managers to work safely. Other organisations talked about 'open conversations' with workers to encourage safe practice and openness about risks, fears and non-compliance.

There were positive descriptions of managing virus transmission with the 'moral driver' of caring for employee welfare, rather than the driver of productivity taking precedence. Other positive comments related to building partnerships between work packages and subcontractors to address safe practices. COVID-19 prompted people to express the need to act collectively to keep safe.

Contractual arrangements created tensions for the companies, largely in relation to clients, who did not act in partnership with construction companies. Responses of clients were described as (i) acting as if COVID-19 was not impacting project deadlines and apply pressure for completion of projects, (ii) acting in a risk averse way and creating unnecessary barriers to arrangements, (iii) introducing measures that did not fit with the working context of the company/project.

What did the representatives consider were the major challenges for the construction sector?

The variety of jobs and tasks undertaken within the sector creates difficulties for clear and consistent guidance. There is not a one-size-fits-all set of regulations and therefore, timely interpretation of the issues and guidance is essential, but depends on arrangements that enable prompt decision making and implementation.

Influencing worker behaviour outside the workplace, at home and socially, is not part of an employers' responsibility but wider behaviour became an anxiety because of implications for workplace, both in terms of transmission and capacity to undertake the work.

Interviewees reported that logistics of arranging COVID-19 measures were often challenging, such as 'test and trace' on site. In addition, some considered that certain measures required by clients were inappropriate and/or time consuming to implement (NHS T&T), inappropriate for the work being undertaken (proximity monitors) or encouraged a sense of false security so that workers dropped their guard (testing).

How did representatives describe supporting employees, including those identified as vulnerable?

Stakeholders considered that mental health issues were a concern during the lockdown, with examples of home working isolation, fear of staying off work and losing an income, and 'macho culture' that presumed that individuals were invincible and not at risk.

Our conversations indicated that people deemed to be at high-risk were generally managed on a case-by-case basis with managers encouraged to support individual team members to find solutions to the threat of COVID-19 for those who were vulnerable or had family members shielding.

Workplace adjustments included changes in work patterns (e.g., staggered start times), restricting visitors, working from home where feasible, adjusting travel arrangements, cleaning regimes, face coverings, changes in gang sizes and outdoor briefings.

Technology shield

Introduction

Work package two (WP2) of this programme of research focussed on the use of technology as a shield to prevent the transmission of COVID-19 such as robotics; wearable health monitoring and proximity sensors. It conducted literature reviews in these areas and took information from interviews from five management level

employees from the four construction industry partners to ascertain the use and potential for COVID-19 protection from technology. Its main conclusions are summarised in Fig 5, which confirms that face covering technologies are in widespread use or have little potential to decrease the transmission of COVID-19. Robotics and wearables have low usage but have medium to high potential to create safer working environments to keep the construction sector working. Due to high cost and training implications, it is felt that the potential for robotic technologies is lower than that of relatively cheaper more user-friendly wearable technology. It is recommended that future work is conducted to explore the use of wearables to mitigate the risk of virus transmission and improve productivity with the construction sector workplace.

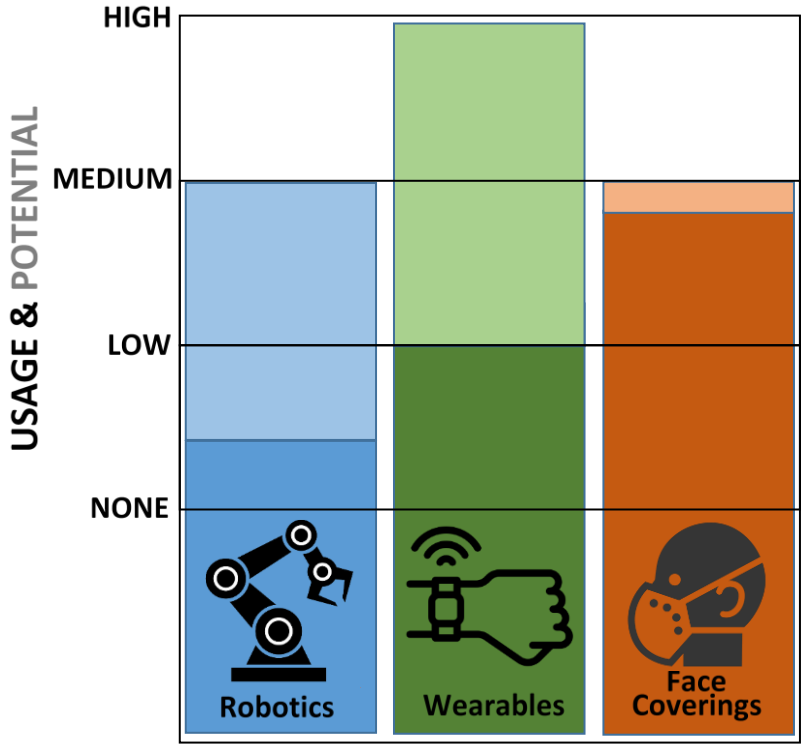


Fig 5. Usage and potential of technology in in the construction sector

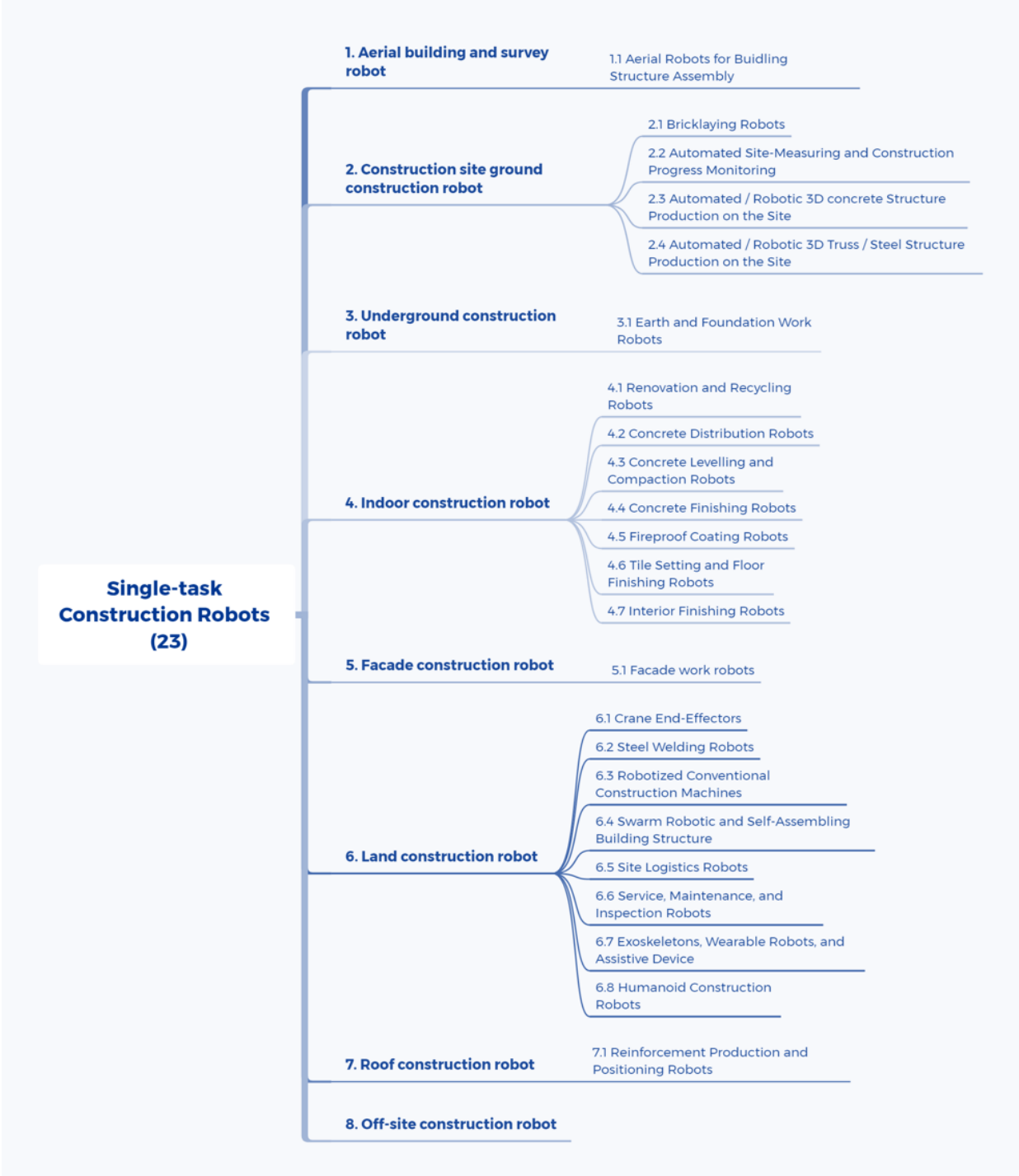
Taking the human out the loop - Robotics

Robotic systems have the potential to 1) increase social distance; 2) reduce the required number of workers; 3) facilitate the work to be conducted remotely; and 4) reduce the time for the activity, key goals defined by the UK Governments *Working safely during COVID-19 in construction and other outdoor* work document[15].

Through a systematic review of the literature, eight themes and 23 categories of construction robot were identified (see Fig 6) – this suggests that limited new

[15] *Working safely during COVID-19 in construction and other outdoor work*, E.I.S.a.D.f.D. Department for Business, Culture, Media & Sport Editor. 2020, HM Government: GOV.UK.

technologies have been developed since Bock and Linner's 2016 review[16]. According to the Technology Readiness Level (TRL) standard[17], we identified 6 robotic systems (see Fig 7) at TRL8-9 which are commercially available to the construction industry as either a product or a service.



[16] Bock, T. and T. Linner, *Construction Robots: Volume 3: Elementary Technologies and Single-task Construction Robots*. 2016: Cambridge University Press

[17] Mankins, J.C., *Technology readiness levels.* White Paper, April, 1995. **6**(1995): p. 1995.

Fig 6: The 8 themes and 23 categories of robotics for construction.

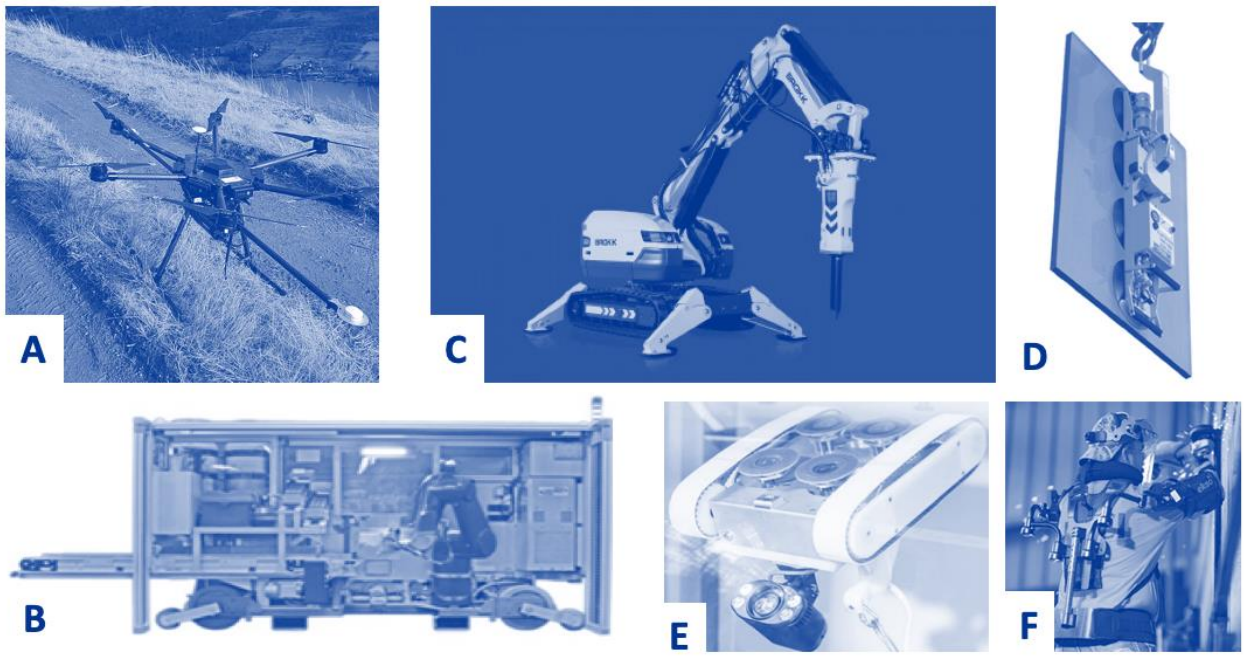


Fig 7 – Commercially available robotic systems for the construction Industry. A) Aerial robotics for surveying[18], B) Robotics for bricklaying[19], C) Robotics for excavation and demolition[20], D) Robotics for roof construction e.g. roof glass installation[21] E) Façade inspection robotics[22], F) robotic exoskeletons[23].

We undertook five interviews within the four construction companies exploring the industry's awareness, perceived benefits, and barriers to adoption of robotic technologies. We conclude that there is some limited awareness of robotic systems but there are perceived barriers in terms of the economic feasibility and a workforce skills gap.

In conclusion the potential for robotics in the construction industry is high but at the present time the systems commercially available do not appear to offer a significant benefit as a technology shield to prevent the transmission of the virus.

Video Conferencing Technology has proven an efficient and widely used method to help reduce human contact and the spread of COVID-19 within industries. The construction industry like many others has embraced this technology demonstrating success in facilitating collaborative remote working.

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[18] *Innovair*. Available from: https://www.innovair.co.uk/services-drone-survey

[19] *Construction Robotics SAM100*. Available from: https://www.digitaltrends.com/cool-tech/sam-bricklaying-robot-6x-faster-than-you-can/

[20] *BROKK*. Available from: https://www.brokk.com/uk/product/

[21] *GLASS VACUUM LIFTERS*. Available from: https://www.ggrgroup.com/products/glass-vacuum-lifters/.

[22] *INVERT ROBOTICS*. Available from: https://invertrobotics.com/

[23] *eksoBIONICS*. Available from: https://eksobionics.com/ekso-evo/

Proximity monitoring and health monitoring sensors

A review of the literature to identify measurable physiological parameters which could be monitored and were indicative of someone with COVID-19 was conducted. Furthermore, we investigated the feasibility and potential benefit of wearable devices, sensors and portable technologies that can measure or monitor these physiological measures.

Evidence showed that heart rate (HR), heart rate variability (HRV), respiratory rate, temperature, and blood oxygen saturation (SpO2), blood pressure and cardiac output can help people recognize early symptoms of COVID-19 and monitor their physical condition[24][25]

We have categorised the technologies based on the type of data measured or monitored. We gathered the views of five people from the four construction companies about the potential adoption of these technologies. Table 3 illustrates the results of this activity.

Five issues related to proximity monitoring or health monitoring technology emerge from the interviews:

- temperature testing and monitoring and the SARS-CoV-2 lateral flow test are the most used methods to find workers who are asymptomatic.
- industry online systems are used to report and update COVID-19 issues.
- some construction companies used wearable devices or proximity sensors, but they commented that efficient technology was required to not to adversely affect productivity; but to the authors knowledge wearable sensors have not been used within a construction environment for COVID-19 control so it is unknown whether these will be reasonably practicable.
- most construction companies had a positive attitude towards using more technology (not only a positive attitude against COVID-19), but also using engineering solutions to get people out of confined spaces and other danger.
- the main barrier of using more technologies in industries is the high cost.

[24] Quer, G., et al., *Wearable sensor data and self-reported symptoms for COVID-19 detection.* Nature Medicine, 2021. **27**(1): p. 73-77

[25] Seshadri, D.R., et al., *Wearable sensors for COVID-19: a call to action to harness our digital infrastructure for remote patient monitoring and virtual assessments.* Frontiers in Digital Health, 2020. **2**: p. 8.

The cost of regular COVID-19 lateral flow tests is a barrier for the construction industry to further adopt testing. Nevertheless, wearable technologies have significant potential as a technology to detect potential early signs of illness and thus promote action to prevent transmission. The cost benefit of these, technologies, however, is yet to be determined and the collection, monitoring and usage of personal data poses ethical questions regarding personal privacy.

Face Coverings

Face coverings are not classed as personal protective equipment (PPE) because:

- there is no need to conform to a manufacturing standard
- they do not provide protection for work risks such as dust and spray.

Face coverings are mainly intended to protect others and not the wearer. When used correctly they cover the nose and mouth, which are the main sources of transmitting SARS-CoV-2. The risk of COVID-19 infection at work should be managed by following the right controls, which should be identified using a suitable and sufficient risk assessment.

PPE for protection against COVID-19 is generally only required for certain healthcare activities. Therefore, in the construction sector the expectation was that employers would provide the same PPE as they would have done before the pandemic. Furthermore, there was no requirement to provide alternative PPE and the hierarchy of control should have been used to indicate that any form of PPE should be regarded as a last resort after the risks have been assessed. HSE[26] and UK Government legislation[27] provided guidance for employers on the expectations for a "COVID-secure risk assessment; this included the UK construction sector they managed risk (primarily) through social distancing, hygiene, and other measures identified through the hierarchy of control. Within the four industry partners who contributed to this study, it was reported that face coverings were used in some project work places as a risk control measure for COVID-19.

This report highlights that face coverings alone do not provide full protection against airborne viruses such as COVID19. and that further research is needed into new materials and face covering construction to produce more efficient and sustainable solutions.

[26] Health and Safety Executive. *Using PPE at work during the coronavirus pandemic*. 2021; Available from: https://www.hse.gov.uk/coronavirus/ppe-face-masks/index.htm

[27] *The Health Protection (Coronavirus, Wearing of Face Coverings in a Relevant Place) (England) Regulations*. 2020 [cited 2021 March 16th]; UK Statutory Instruments 2020 No. 791 PART 2 Regulation 3]. Available from: https://www.legislation.gov.uk/uksi/2020/791/regulation/3/made

Table 4. Early COVID-19 symptom indicator

Data Measured	Early symptom of COVID-19		Technology		Advantages	Disadvantages	Implementation barriers	Have used in industry (Y/N)	Potential usage
	Symptom	Capability (Prevalence)	Device	Data quality / accuracy repeatability					
Body temperature	Persistent high fever (≥37.8C)	78%[28]	Thermometer	High[29][30]	1. Low-cost 2. Easy to measure	1. Easily affected by the intensity of people's daily activities. 2. Easily affected by the working environment.	1. Relate to ethics for data sharing	Y	Limited usage
			Wearable devices		1. Easy to measure			N	Limited usage
Heart rate (HR)	High heart rate	30.3[24]	Apps	Medium	1. Easy to measure	1. Easily affected by the intensity of people's daily activities.	1. Worker may become used to and ignore the data	N	No usage
			Wearable device	High [29] [30]	1. Easy to measure			N	Limited usage
Blood oxygen saturation (SpO_2)	Hypoxia / Low SpO_2 (<95%)	35.3%[31]	Pulse oximeter	High	1. High accuracy	1. Inconvenient to carry	1. Inconvenient for workers to wear during working 2. May Reduce the work efficiency	N	No usage
			Wearable devices	Low [29]	1. Convenient to use 2. Workers can wear it when work	1. The data may be inaccurate or unstable	1. Worker may become used to and ignore the data	N	No usage
Respiration Rate	Difficulty breathing / shortness of breath / cough	57% [28]	Specific wearable devices for respiratory rate measurement	High	1. One of the most common symptom of COVID-19 2. This symptom is easy to be noticed by workers themselves	1. Inconvenient to carry	1. Inconvenient for workers to wear during working 2. May reduce the work efficiency	N	No usage
			Pulse oximeter	High	1. High accuracy result	1. Inconvenient to carry	1. Inconvenient for workers to wear during working	N	No usage

[28] Grant, M.C., et al., *The prevalence of symptoms in 24,410 adults infected by the novel coronavirus (SARS-CoV-2; COVID-19): A systematic review and meta-analysis of 148 studies from 9 countries.* PloS one, 2020. **15**(6): p. e0234765-e0234765.

[29] Hahnen, C., et al., *Accuracy of Vital Signs Measurements by a Smartwatch and a Portable Health Device: Validation Study.* JMIR mHealth and uHealth, 2020. **8**(2): p. e16811.

[30] Natarajan, A., H.-W. Su, and C. Heneghan, *Assessment of physiological signs associated with COVID-19 measured using wearable devices.* npj Digital Medicine, 2020. **3**(1): p. 156.

[31] Brouqui, P., et al., *Asymptomatic hypoxia in COVID-19 is associated with poor outcome.* International Journal of Infectious Diseases, 2021. **102**: p. 233-238.

					2. This symptom is easy to be noticed by workers themselves		2. May reduce the work efficiency		
Position / contact tracking	/	/	Video / CCTV [32]	High	1. Remote monitoring / inspection	1. Additional installation time 2. Cost 3. Maintenance	1. Policy of personal data sharing / risk of information leakage 2. Reduce the trust between employers and employees 3. Extra cost for device, installation and maintenance	N	No usage
			Drones [32]	High	1. Increases the speed of surveying 2. Reduce risk to people	1. Required high skilled staff to control 2. Work efficiency is affected by weather	1. Policy of personal data sharing / risk of information leakage	N	Limited usage
			Autonomous vehicles [32]	High	1. Real time provenance	1. Relatively high cost	1. May be not suitable for all environment or industries	N	No usage
			Wireless sensor networks [24]	High	1. Benefit for self-reporting 2. Contact tracking	1. Depend on workers' willingness to self-report	1. Policy of personal data sharing / risk of information leakage	Y	Limited usage
Flow test	/	/	COVID-19 test kit	High	1. High accuracy	1. Costly 2. May require outdoor space	1. The cost is high if provide test kit to every employee 2. Require enough outdoor space to set test point	Y	Limited usage

[32] Jean-Philipe Gorce, S.N., Miles Burger, *Safety implication of the rise in industry 4.0 & AI A feasibility study for technologies in the workplace*. 2020, Discovering Safety.

Data and simulation

Introduction

WP3 aims to develop an understanding of the data collected and the simulation and modelling techniques used by the industry to manage the transmission risks at construction sites. The work package also proposes a framework for integrating data from different sources with appropriate simulation techniques (e.g., as those developed in Theme 2 of the PROTECT study) to better manage and predict future transmission risks in construction. Based on a combination of detailed literature review, questionnaire, and interviews, it was observed that traditional data sets (e.g., COVID-19 test results, number of positive cases, and contact tracing) are overwhelmingly dominant. Furthermore, there is very limited application of simulation and modelling techniques for managing COVID-19 transmission risks. The main reasons captured during interviews with sector representatives for this are insufficient skills and knowledge and cost concerns. However, there is evidence that some construction contractors are willing to adopt simulation and modelling techniques in the future, provided that high risk areas and effective on-site epidemic prevention measures can be identified in a cost-effective and visualised way. In the following sections, the results of the literature review are first presented. This is followed by the findings of the questionnaire and interview data collection involving the four Tier 1 contractors. The final part of the report on this work package proposes a framework for future activities based on quantitative model which align well with the ones developed in Theme 2 of the PROTECT study.

Findings from the literature review

A literature review was first conducted to understand how simulation and modelling techniques are used within the construction industry to manage COVID-19 transmission risks. The initial review scope focussed on the construction industry and COVID-19, but minimal search outputs were obtained, thereby triggering a scope expansion to all sectors. Owing to the similar transmission patterns of COVID-19 and other airborne diseases such as influenza, studies related to influenza were also incorporated to enhance the development of a more holistic view that is not restricted to a single industry and infection type. The detailed review process is captured in Appendix 2. Based on the review, it was found that the four most used simulation and modelling techniques are: 1) SIR/SEIR modelling; 2) Agent based modelling; 3) statistical modelling; and 4) machine learning.

SIR/SEIR modelling

SIR and SEIR modelling are mathematical modelling techniques in which the population is assigned to compartments with labels in order – for example, Susceptible, Exposed, Infectious, or Recovered. The flow patterns of people progressing between the compartments are indicated in the order of labels; for instance, SEIR means people are first at the stage of being susceptible, followed by being exposed, infectious, and finally recovered. The modelling purpose is to estimate the reproductive number, understand the pattern of epidemic spread, and

predict the number and duration of a pandemic. SIR/SEIR models' core required data on individual confirmed cases including confirmed cases, severity status and date of recover, discharge, or death. This modelling technique is particularly useful for predicting transmission at a meta-population level and has been widely used by epidemiologists for over 100 years[33]. The technique's main drawback is that it requires data from a large population to make the prediction and cannot simulate the impact of complex interventions (e.g., voluntary home isolation, school closures, etc.) on disease spread across different social and spatial scales[47].

Agent-based modelling

An agent-based model (ABM) is a class of computational models that simulate the simultaneous operations and interactions of multiple agents (e.g., human and its environment) to recreate and predict the appearance of complex phenomena. It is a kind of a microscale model, and the simulating process is one of emergence, which can be expressed as 'the whole is greater than the sum of its parts'. ABM was used to predict the spread of disease in time series and evaluate the impact of different interventions on epidemic outcomes. Consequently, it can help find the most effective one from a suite of interventions. ABM has been widely used in the research on the construction industry to simulate construction activities[34,35]. A few studies have recently adopted ABM to simulate the spread of the virus in the industry[36,37], which outlined the potential of using ABM to evaluate the impact of different epidemic prevention measures in construction sites on health risk and worker performance. The key advantages of ABMs are that they can stimulate complex social interactions, individual and collective behavioural adaptation, and different intervention measures[38], and the agents' interactions can be visualised on the open-source modelling platform such as NetLogo. The main drawback is that it relies on the quality of assumptions put in the model.

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[35] T. Ji, H.-H. Wei, and J. Chen, "Understanding the effect of co-worker support on construction safety performance from the perspective of risk theory: an agent-based modeling approach," *Journal of civil engineering and management,* vol. 25, no. 2, pp. 132-144, 2019.

[36] F. Araya, "Modeling the spread of COVID-19 on construction workers: An agent-based approach," *Safety science,* vol. 133, p. 105022, 2021

[37] E. Cuevas, "An agent-based model to evaluate the COVID-19 transmission risks in facilities," *Computers in biology and medicine,* vol. 121, p. 103827, 2020.

[38] A. Adiga, J. Chen, M. Marathe, H. Mortveit, S. Venkatramanan, and A. Vullikanti, "Data-Driven Modeling for Different Stages of Pandemic Response," *Journal of the Indian Institute of Science,* vol. 100, no. 4, pp. 901-915, 2020/10/01 2020, doi: 10.1007/s41745-020-00206-0.

Statistical modelling

Statistical modelling includes techniques such as regression and structural equation modelling. It is a mathematical model that embodies statistical assumptions that idealise the data-generating process[39]. It usually specifies a mathematical relationship between various variables, both random and non-random. This type of model is purely phenomenological. Key associations of essential factors are examined to estimate epidemiological parameters or predict disease risk, but mechanisms of transmission processes are not considered[40]. The advantages of statistical models are the effectiveness and efficiency in short term forecasting projections[52] and are easy and fast to build up. The main limitation is that it overly simplified the relationships among the variables in the model.

Machine learning

Machine learning (ML), as a part of artificial intelligence, help build models to make predictions or decisions by using computer algorithms that improve automatically through experience based on sample data, known as "training data", instead of being explicitly programmed to do so[41]. The model aims to predict transmission growth rate in time series, analyse interventions as well as contact tracing. Machine learning models are particularly useful in forecasting and short term projections[52]. Techniques such as artificial neural networks (ANN) have the ability of self-learning without prior knowledge, and thus their application in the prediction of infectious diseases has become increasingly prominent[47]. These models have used a wide variety of data for conducting prediction, including (i) social media data, (ii) weather data, (iii) incidence curves and (iv) demographic data[47]. The main challenge of using ML is that it highly relies on a considerable amount of data.

Full details of the above four modelling techniques are listed in Appendix 2.

Findings from the questionnaire and interviews

The findings of the questionnaire and interviews with the Tier 1 contractors are presented below.

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[39] D. R. Cox, *Principles of statistical inference*. Cambridge university press, 2006

[40] A. D. Becker, K. H. Grantz, S. T. Hegde, S. Bérubé, D. A. T. Cummings, and A. Wesolowski, "Development and dissemination of infectious disease dynamic transmission models during the COVID-19 pandemic: what can we learn from other pathogens and how can we move forward?," *The Lancet Digital Health,* vol. 3, no. 1, pp. e41-e50, 2021/01/01/ 2021, doi: https://doi.org/10.1016/S2589-7500(20)30268-5.

[41] T. M. Mitchell, "Machine learning," 1997.

Data management

The most useful COVID-19 related data that the construction contractors have collected right from the pandemic outbreak until date are COVID-19 cases, transmission records, COVID-19 related policies and guidance, other firms' approaches to managing COVID-19, and feedback on transmission control. The COVID-19 cases refer to confirmed and potential cases involving people in self isolation and those at higher risk due to their interactions/contact with confirmed cases. Several participants echoed that the data related to COVID-19 cases have been of immense help, especially regarding tracking trends and workload smoothening. Furthermore, one of the contractors mentioned that *"with that data, we track trends… how fast is increasing rates of infection and so on and so forth".* Another contractor expressed that *"(we) track labour levels, forward planning to make sure that where our projected labour levels, where our actuals are against projected".* Contractors also focused on COVID-19 transmission. By tracing contracts, they attempted to predict *"potential hotspots"* and then investigate *"where people have been"*. These two types of data suggest that the sample contractors have conducted basic COVID-19 related data collection, using a contractor's words: *"fairly binary, pretty organic"*.

Additionally, the contractors have further gathered COVID-19 related policies and guidance, such as site operating procedures (SOPs) issued by the Construction Leadership Council in the UK, and other firms' approaches for better planning, monitoring and control decisions. One contractor explained that *"we compare notes in terms of what they're doing, after which I'm able to take a view on that and say, would I go down the same route or not"*. Two contractors mentioned that they collected feedback to evaluate their transmission control.

Three out of the four contractors interviewed stated that there are data gaps for making COVID-19 monitoring and control decisions. The main gap identified is related to their inability to obtain concrete contact tracing records. For instance, for people who were picked up due to not signing into the QR code system, one contractor said the only thing that they can do was *"very simple investigation… (by asking) simple questions such as where have you been?* Some expressed that they have data gaps, but it was not easy for them to identify these gaps. One contractor explained that it is *"probably because we really focused on making sure that we have got the evidence to say that it was not in the workplace, we might not be asking the right questions"*. This is not surprising since the data that is being collected is basic.

Modelling and simulation techniques

None of the contractors uses any modelling or simulation techniques to assist with COVID-19 transmission risk analysis or prediction or COVID-19 risk monitoring and control. However, except for one contractor who claimed they do not need such techniques, the other three contractors are interested in using such techniques. Two of the three contractors were looking forward to using it. One was trying to use it but

failed due to time constraints. The other one is keen on modelling/simulation techniques; as expressed by the contractor, *"it would be amazing if we could… they will be brilliant"*. The contractors expressed interest in the following features of modelling/simulation techniques: (1) being easy to use (2) ability to integrate data, such as integrating sensor data into a model, (3) ability to predict, such as *"productivity drop off rate"*, (4) ability to facilitate planning, such as estimating labour needed, and (5) visualisation. The main requirements for visualisation were picking up *"those real hotspots*" and geographical locations. One contractor expressed interest in being able to see *"where people have been and potential transmission routes and groups that may or may not be affected"*.

Data management challenges and lessons learned.

There were three types of challenges regarding data management, and these are: the challenge of data collection, data analysis, and using modelling/simulation techniques. The main challenge of data collection was that the contractors only had limited ability to collect real-time data. For example, the contractors have been receiving weekly updates of COVID-19 situations. Contractors also mentioned the challenge of identifying data gaps, limited contact tracing ability, and the issue of COVID-19 testing accuracy. In terms of data analysis, the challenge is predicting the trend and identifying *"real hotspots".* Furthermore, the contractors found several challenges regarding applying modelling/simulation techniques to assist data management. The development of modelling is time-consuming and could be associated with significant costs. They also expressed having limited knowledge regarding how to use modelling and simulation techniques.

The contractor's lessons learned from data management were the needs and potential benefits of using simulation/modelling techniques, the appreciation of lifetime observation on the site, and a better way to use data. For instance, with the help of a modelling company, one contractor realised the potential benefit of using simulation/modelling techniques could be facilitating project planning, such as *"how many ... passenger hoists we would need… how efficient we could be"*. One contractor reflected that that tracking positive cases daily is extremely useful as it enabled the team to make better management decision (e.g., job allocation to workers). Another contractor stressed that they became more capable of utilising data in *"a proactive way, not a reactive way"*, such as "*looking for those weak signals"* and predicting what might happen. These lessons learned further align with the potential benefits of simulation/modelling techniques and the significance of data management for contractors.

Information sharing

All the contractors have an existing online system for data sharing. They have added a new section for sharing COVID-19 related information. As this contractor explained, *"a dedicated Coronavirus section (has been) set up on our internal Integrated*

Management System (IMS); So, as soon as you go in there, you can get all the latest information, all the latest updates, all the latest anything, absolutely everything".

Information sharing system contributed to better monitoring, planning, and control, which has helped tackle coronavirus spread. The COVID-19 reporting allows the construction contractors to monitor the trends and risk levels and enable close oversight, even from the company's executive team. This system helped the contractors develop "forward planning" and control, such as keeping employees safe. This is highlighted by the quote below taken from one of the interviews.

"I use the Power BI (i.e., a business analytics service) to track labour levels, forward planning, to make sure that where our projected labour levels, where our actuals are against projected… I'm tracking that to make sure that staying on track. That means I've got enough car parking spaces making sure I've got one per person… I've got enough welfare, that I've got enough testing facilities that I've got enough drying room capacity."

As the quote shows, this contractor used the system to track labour levels and ensure that the welfare capacity is sufficient by "forward planning". By doing so, people could have safe social distances, which in turn contributes to mitigating the risk of the prevention of transmission. Furthermore, some contractors mentioned that COVID-19 related guidelines, such as the SOPs, were shared with the workforce. The guidance helps people to *"know what to expect and what we need them to do" (Interview 2) and "keep(s) us safe during this pandemic"*

Full details of the interview codes are listed in Appendix 3 to 8.

Summary

Based on the questionnaire and interviews, it was found that the industry is facing the challenges of identifying the high-risk transmission areas and targeted measures to alleviate the risk. To address the issue and make better management decision, three of the four contractors indicated that they are willing to widen the application of simulation and modelling techniques provided that such techniques are cost effective, visual and easy to use. Considering the insights from the interviews in conjunction with the literature review results, this study proposes the simulation/modelling of the transmission risk of COVID-19 using the Agent based modelling (ABM) technique. ABM is selected because of its ability to stimulate how humans interact with others and the environment over time[47] which aligns well with the complexity of construction site activities that are often labour intensive and time and space constrained in nature. In addition, ABM can be a highly visualised and easy-to-use tool once the verification, calibration and validation models are constructed, which satisfied the modelling requirements mentioned by the contractors that are keen to apply modelling or simulation techniques. Furthermore, ABM is already incorporated into WP2 of the PROTECT study led by HSE to predict the

transmission of COVID-19 at population level, which could lay the foundation for developing the agent-based models down to micro-scale, such as construction site.

It is also proposed to simulate the transmission of the virus and construction projects' working progress using ABM from an on-site individual workers' perspective. The agent-based approach explicitly models the individual contact patterns in the modelling so that the epidemic prevention measures can be analysed at a micro-level. An agent-based model consists of three components: 1) agent's properties, behaviours and environment; 2) agents' interactions with environments; and 3) agents' relationship and interactions with other agents[42]. The model will be developed based on the standard procedure recommended by Wilensky and Rang[43]. Using the agent's properties, behaviours and environment as the foundation, we propose a data framework showed in table 1 to build and test an agent-based model in phase 2. The future model can be linked with WPs 1 & 4 to decide the collection of human factors data and WP2 to facilitate the collection of site data by using technologies (e.g. proximity and contact data using wearable devices and CCTV).

Table 4 Proposed data framework for ABM of COVID-19 transmission on construction site

Environment Data	Agent (i.e. workers on site) Properties	Agent (i.e. workers on site) behaviours
For example: • Site layout • Construction type • Scale of the site • Number of workers • Transmission rate • Work location (e.g. indoor/outdoor/underground)	For example: • Workload distribution of the construction site • Schedule of the construction workers • Work type of construction workers • Location and proximity* • Vaccination rate* • Positive cases • Mode of transportation to work*	For example: • Response to the different on-site epidemic prevention measures • Risk perception of getting infected • Safety leadership/culture • Interaction frequency and duration On-site epidemic prevention measures (e.g. wear masks, washing hands, keep social distances)

[42] C. M. Macal and M. J. North, "Tutorial on agent-based modeling and simulation," in *Proceedings of the Winter Simulation Conference, 2005.*, 2005: IEEE, p. 14 pp.

[43] U. Wilensky and W. Rand, *An introduction to agent-based modeling: modeling natural, social, and engineered complex systems with NetLogo*. Mit Press, 2015.

Possible Data Sources: Building Information Modelling (BIM); Construction Management Plan	*Possible Data Sources:* Construction Management Plan; Exemplar technology of WP2; Questionnaire	*Possible Data Sources:* Human factor identified from WP1 & 4; Questionnaire

Remarks: *= data that is not currently collected by the four contractors

Leadership

Introduction

In this theme, we aimed to explore leadership and governance attributes/ requirements and good practice that can enable effective management of COVID-19 risks. We sought to understand how individual and organisational resilience has emerged over the course of the pandemic and how implementing change was linked to effective organisational/task design in support of organisational change. A scoping review of the literature on leadership for COVID-19 safety in construction revealed that there is very limited evidence and evaluation to date on how leadership and messaging can help manage risk and protect employees' health and safety (see Appendix 10) for literature review). Findings from surveys and stakeholder interviews with managers and safety advisers from the four construction organisations provided insight into the role of leadership and governance in enabling effective management of COVID-19. The interviews highlighted the importance of a dynamic response in implementing adequate changes to work practices. Fostering behavioural change and increasing workforce engagement were discussed as key strategies to manage COVID related compliance and to maintain workers' health and safety. The conversations also revealed challenges for leaders to manage effects of COVID-19 on employee wellbeing and the impact on traditional health and safety. The key findings from WP4 are presented below and directions for future research outlined.

Current leadership good practice related to management of COVID-19 risks

Organisations described a flexible and prompt response by management to the pandemic that allowed for quick adaptation to continuously changing Construction Leadership Council (CLC) Standard Operation Procedure (SOP) guidance and national restrictions. Stakeholders described having "*robust enough systems and robust enough control measures in place*". Existing safety governance procedures and incident reporting schemes were described as useful for integrating COVID-19-related information for effective transmission management across site. Some representatives reported setting up dedicated COVID-19 boards to streamline information and manage communication with employees.

A high emphasis on safety and strong safety culture underpinned leaders' responses and enabled them to be "*ahead of the game*" in effectively managing COVID-19 risks and effects. Organisations viewed a behavioural approach to managing COVID-19 transmission as the most effective strategy to control risks and achieve high safety compliance. This was done by "*focussing on using risk assessment and considering the residual behavioural risk*". Investing in behavioural programmes and enabling management to lead behaviour changes were given as examples for cultivating a strong behavioural approach over time.

- There is still more research needed to understand how COVID-19 safety compliance can be achieved long-term and how potential drifts in safety behaviour could be avoided.

Maintaining visible leadership onsite and engagement with the workforce throughout the pandemic were seen as good practice in managing COVID-19 to demonstrate care for workers' wellbeing and safety. Close engagement with their workforce allowed leaders to address workers' concerns and issues with COVID-19 measures which would have not been picked up by official reporting lines. Remote work posed new challenges for leaders to effectively manage employees working from home and required increased efforts to support staff and to strengthen team morale.

- Further research would be needed to explore best practices in managing workforce remotely and potential effects on teamwork.

Balancing traditional health and safety and COVID-19 safety was described as challenging for management. Some representatives reported that the introduction of additional COVID-related safety measures may compromise traditional safety measures or lead to changes of usual safety practices that could pose new risks. However, there was a lack of evidence for impact of controlling COVID-related risks on traditional health and safety.

- Future investigation could provide further insight into the impact of COVID-related risk management on traditional health and safety.

The construction sector involves a wide range of projects and contractual arrangements that present unique challenges for management of COVID-19 risks. The distribution of responsibility for health and safety governance is an important aspect to consider in how effective leadership for managing COVID risks is shaped.

- Future research would benefit from considering different contractual arrangements, supply chains and how leadership responsibilities are shared between (sub)contractors to further explore leadership good practices and contextual constraints.

Adaptations to work design / work practices to support healthy and safe working.

Organisations reported various changes to work practices to control transmission risk onsite, including social distancing measures, cleaning regimes, changes to work procedures (see pre-survey summary table, Appendix 11). Reports of high safety compliance and low number of outbreaks onsite provided support for the effectiveness of changes. The main transmission risk onsite was perceived to be linked to "*office and depot close space*". Concerns were raised by managers about the lack of control over potential transmission risk offsite (e.g., commute to work; social life) which left workers being "*petrified going to or from work*" and could compromise workers' safety in the workplace.

- Long-term effectiveness of adaptations to work practices and safety compliance remain unclear and need to be investigated in the future.

COVID-19 risk management was reported to create new challenges for the construction partnership and in managing clients' expectations for contract fulfilment. Additional time and costs associated with COVID-19 transmission management were named as reasons for delays in project completion and increased perceived pressures for construction partners to balance between safety and productivity.

Applications of novel technology (including face coverings or other controls) to support health, safe, and productive work.

Most organisations reported using face coverings as well as technology for COVID-19 transmission management, e.g., air purifiers, access cards, wearables. Existing data management systems and use of testing also assisted in effectively monitoring COVID-related trends and informing changes to work practices. Novel technology was less frequently applied due to concerns about relevance and practicality for workers to appropriately make use of them (e.g., proximity sensors/alarms; temp checks). Some managers cautioned against an overreliance on technology which could create a "*false sense of safety*" and emphasised the importance of behavioural change in effective transmission management. Insights gathered on technology showed that the main barriers for technology use was related to economic feasibility and appropriate skills. There was limited information, however, on operators' perceived barriers for effective technology use (e.g., risk perception) and the implications for safety compliance.

- Further exploration of how technology can assist in COVID-19 transmission control compliance would be beneficial.

Individual and collective leadership attributes that build resilience for organisational performance.

Stakeholders considered their key responsibility as leaders was to act as a "*moral driver*" in managing COVID-19 by prioritising employee wellbeing and safety over productivity. Managers raised concern for employees' mental health which was affected by COVID-19 fatigue, financial pressures, and lacking home-life balance. As mentioned above, continuous engagement with employees was seen as crucial in managing employees' anxiety and providing support for the workforce. Management overload due to additional COVID-19 management demands was mentioned to affect leaders' own wellbeing and leadership behaviour. Some examples were also given that indicated that stronger collective leadership emerged over the course of the pandemic: "*we were faced with adversity and we came together as a really tight team*".

- Given the limited information, future research would be needed to gain deeper understanding of the nature of leadership attributes and mechanisms that facilitate high organisational performance.
- The concern over COVID-19 effects on employees' mental health and safety behaviour should be explored further to advance insight into how individual and collective resilience could be strengthened.

To identify organisational level strategies that build organisational resilience and agility for operations.

Stakeholders reported effective measures across the organisation to ensure COVID-19 safety which enabled them to continue business operations and avoid high numbers of transmission outbreaks. Being a safety-critical industry, organisations could employ their routine good practice approach to manage COVID-19 and respond in a proportionate, but science-led manner. As one stakeholder described: "*As a business, it's everyone's communicating, getting everything checked, everyone's been looked after [and] having risk assessments completed*". Good relationships with subcontractors helped clarify responsibilities and facilitated prompt implementation of changes onsite.

- Due to continuous changes, the longevity of strategies and effects on organisational resilience or agility for operations are still unknown and would need further investigation.

Organisations adopted very similar communication strategies that were characterised by consistent, simple, and clear messaging ("*one version of the truth*"). Using single communication channels and creative messaging were mentioned to be beneficial in providing clear guidance and achieving good compliance. Stakeholder emphasised the importance of continuous reinforcement of messaging and fostering a "*speak-up culture*" through open conversations with employees to identify potential fears or issues which were "*only [found] out by listening to what people were saying*".

To develop insights on current good practice for health and safety (H&S) Governance to support strategic alignment of H&S and wider business performance.

Some representatives reported that the introduction of COVID-19-related measures has had positive impact on wider H&S governance, being "*the best year*" for health and safety. Higher vigilance and more rigorous risk assessments may have provided opportunities to enhance health and safety governance.

- There was limited evidence for good practice and a need for further exploration of how health and safety governance can be strengthened to align with wider business performance.

As noted in point (i) management reported it was challenging to balance traditional health and safety and COVID-19 safety, with the introduction of additional COVID-19-related safety measures. Some representatives reported potential for traditional safety measures to be compromised or usual safety practices to change which could pose increased risks. However, there was a lack of evidence for impact of controlling COVID-19-related risks on traditional health and safety.

- Future investigation could provide further insight into the impact of COVID-19-related risk management on traditional health and safety.

Case studies

Google HQ, Kings Cross, London (LendLease)

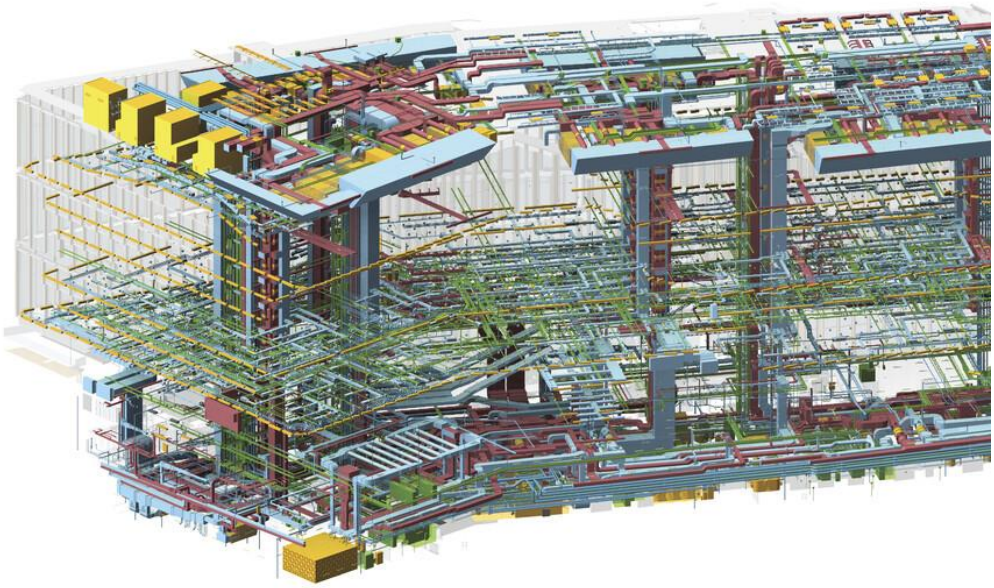


Fig 8: The relationship between structure, mechanical and electrical requires careful design to ensure safety during construction (credit Atelier Ten)

Google's new UK headquarters at King's Cross in London utilises a large area of land adjacent to London Kings Cross railway station; the scheme design is for c. 60,500 sqm of commercial office space, across 11 storeys with retail and leisure accommodation.

The structural strategy features a mix of permanent concrete floor structure and semi-permanent timber floors. The concrete floors span the full width of the building, and are constructed using bespoke pre-stressed, precast panels supported by a steel frame super-structure. The design features off-site construction methods to enable schedule acceleration and mitigate against hazards arising from the use of (e.g.) formwork in near proximity to the operational railway. The site location is bounded by existing assets forming access routes into the King's Cross station complex and associated Network Rail property including the permanent way and associated infrastructure such as OLE and signalling equipment. The site is challenging due to the typical constraints of a central London location.

LendLease COVID-19 site strategy at Kings Cross

Management staff (Lendlease, Client, Consultants and Trade Contractors) deployed wide-spread use of ‘Google Meet’ and ‘Microsoft Teams’ for remote video conferencing - thus reducing the volume of personnel required to travel to site and site offices. Automated fever detection systems mounted adjacent to security turnstiles monitor the temperature of all staff entering the site; the equipment removes close human contact from the alternative hand-held trigger devises. Trigger temperatures are relayed to an adjacent manned security desk for review.

Key construction challenges

- Ability to maintain 2m social distancing particularly where some activities require workers to operate in proximity for safe working practices to be maintained.
- Ensuring sufficient competent supervision and management in the event of personnel reductions through COVID-19 illness or isolation.
- Reduction in skills base if those with high level skills are placed in quarantine after travel or are non-UK nationals who choose to return home.
- Ensuring basement/confined areas have adequate ventilation.
- Complacency and the on-going challenge of ensuring the hazards are at forefront of everyone's minds.
- The problem of no 'one-size fits all’ solution for the best combination of protection for each individual worker.

In response to the challenges, examples of the enhanced measures deployed by LendLease on the scheme include:

- High frequency cleaning of all common contact surfaces such as handles, worktops, desks, printers, etc. Register of cleaning times maintained on site.
- All works to be undertaken at 2m from others unless safety prevents, and additional risk assessment/mitigation/approved permits are in place.
- Compliance monitoring via an application on smart phones; this logs breaches and generates data for trend/safety briefing analysis.
- Automated fever detection equipment installed at security entrances and 100% screening of entrants to site.

- Mandatory wearing of a face covering when within the construction site or any associated office/welfare areas except when medical reasons permit or to pause for eating/drinking.

- Automated occupation counting equipment installed to site canteen and changing rooms, which counts occupants and displays an automated sign when maximum occupancy levels are met.

- All canteen and kitchenette equipment are disposable and all self-serve items such as cereals have been replaced with single use grab packs.

- All desks have Toblerone signs identifying if desk is 'Available for Use/In Use/Ready to be cleaned'.

- One-way systems are in place in all corridors and stairs where 2m distancing cannot be maintained. There is an exit only route onto site and an exit only route out of site.

- Health questionnaires are in place and all entrants are checked daily and reminded to log in via Track and Trace.

- QR codes and other COVID-19 related signage is prominently displayed throughout.

H.M. Prison Five Wells, Wellingborough, Northamptonshire

In 2019, Kier was awarded a £253m contract by the Ministry of Justice (MoJ) for a new build resettlement prison in Wellingborough, HMP Five Wells. The prison is the first of a series of prisons to be delivered in the next 5 years by the MoJ and HM Prison and Probation Service as part of the Government's New Prisons Programme. The aim of the programme is to create new prisons which are more efficient, modern, safe, secure and decent, and focused on supporting rehabilitation.

Fig 9. Construction of house-blocks using modern methods of construction

A core feature of the programme is to optimise how the Ministry's assets are designed, procured, delivered and operated, through a Design for Manufacture and Assembly (DfMA) or 'platform' approach. Kier is making extensive use of precast concrete components (15,183 precast panels plus more than 60,000 sub-components), bringing together three separate precast suppliers, Bison Precast, FP McCann and Banagher – a total of six different factories across the country – as well as precast management company PCE. This approach is designed to reduce downside risks in construction and enable innovation and collaboration between Kier and its supply chain partners.

The precast components for cell doors, walls and flooring have all been optimised to avoid follow-on work as far as possible. For each cell, M&E utility conduits and points have been

cast-in, and shower trays are also cast into the floor units. This is designed to reduce on-site trades and will improve serviceability and security.

The Five Wells scheme adopts a ‘digital first’ approach to enable the main contractor to monitor, manage and communicate across the wider team. Standardisation was driven throughout the design to ensure the repeatable use of components. A digital strategy offers benefits in health and safety through improved definition of the construction programme - strategies for lifting components into position, as well as the integration of components such as the prefabricated services (MEP) are potentially achieved in more efficient and integrated way.

The Ministry of Justice is working with Kier and the supply-chain to implement a number of measures that are designed to ensure safe-working practices during the pandemic, consistent with CLC SoP and Cabinet Office guidance on responsible contractual behaviour. Technology solutions in deployment include proximity full use of virtual conferencing technology, on-site robotics (for example autonomous vehicles, scaled robotics for laser scans, drone surveys etc.) and a roll out of personnel tracking, proximity-sensor wrist bands, via Datascope and PowerBI visualisation. Recognising that transmission can be facilitated outside of the traditional ‘site boundary’, COVID-19 risk assessments are in use throughout the supply chain; reviews and audits are conducted by management and the SHE department to assess compliance in addition to a BSI audit also undertaken during pandemic to assess working practices. Promoting good mental health in and across the project was identified as an early priority; Mental Health First Aiders are located on site and alternative shift pattern arrangements have been implemented where beneficial.

Supplementary notes on the experiences of HSE construction division and a trade union manager

Background

This high-level summary covers interviews with four representatives of HSE's Construction Division and a manager from the Unite union. It is important to note that the sample is relatively small. This summary is not intended to provide grounds to extrapolate to the whole construction sector, but to provide further insights from those interacting with the sector. It is also important to note that the perspectives here provide a snapshot in time, approximately one year into the pandemic. Views are therefore framed by the changes and advances in knowledge that have occurred up to this point in time.

Emergent topics of relevance to the project were themed under the following six topics:

- Limited application of the hierarchy of controls
- Good practice
- Key enablers
- Poor practice and barriers
- Challenges
- Suggested improvements / ways forward

It is important to note that the points/perceptions are based on the observations, interactions, and perceptions of the five people interviewed. The perceptions of good practice; poor practice; and challenges etc. are all framed in the context of knowledge and understanding at this timepoint. It may be that these perspectives change as our understanding of COVID-19 develops further.

Interviews were conducted remotely in March 2021 by two members of the project team, and lasted no more than one hour each. The themes and perceptions are as follows:

Limited application of the hierarchy of controls (HoC)

It was noted that rules and guidelines have inherent flexibility, and where more robust control measures are not feasible/practicable, face coverings are the final 'requirement'. Participants acknowledged that this can drive behaviour (individual and organisational) to focus primarily on face coverings, with possibly limited/no consideration of applying the

HoC (*e.g.* focus on administrative controls). Some areas of good practice were identified, which included more robust controls, such as adapting work/task design. It was generally felt that good practice tended to be encountered more frequently on larger sites which are often better resourced, and likely have access to health and safety professionals.

Good practice

Interview participants recognised that there is a perception of flexibility relating to control measures. Good practice was recognised across various sites, such as:

- Provision of well-stocked / frequently re-stocked wash facilities (e.g. paper towels, hot water, soap etc.)
- Knee operated taps
- Perspex screens help separation (e.g. at wash facilities)
- Staggered break times
- Red/green discs to identify when a canteen table/area had been used (disc flipped over from green to red to identify a need for cleaning)
- Use of one-way systems (where possible in buildings)
- Coloured stickers on helmets to help maintain work 'bubbles' to particular areas/building floors etc.
- COVID-19 site inductions
- Maximum person capacity clearly identified (e.g. for canteen use)
- Use of COVID testing at some sites
- Use of temperature checks
- Good cleaning regimes (in between use) such as in canteens
- Rules limiting shared use of tools/equipment
- Management of outbreaks, such as site closures and tracing of close workers
- Development and application of COVID risk assessments
- A single case of use of a filtration system (for a laboratory building)
- Awareness and use of the Construction Leadership Council guidance

Key enablers

Interview participants noted that senior leadership buy-in and support was essential to good H&S performance, both in conventional H&S terms, and during the pandemic. They recognised that leadership can enable good provision of specialist support and resources to sites.

Local level leadership was also seen as critical to performance on sites, ultimately with reliance on site manager(s). It was perceived that sites tended to perform better where

site managers would encourage and reinforce the ‘right’ behaviours, and treated COVID as another risk to be managed.

Some participants believed that worker attitudes towards the pandemic were variable, with some workers perhaps seeing it as a key risk, and others seeing it as ‘an old person’s disease’. It was added that many workers seemed to now (a year into the pandemic) know someone who had been impacted. It was suggested that this may be influencing some to take the pandemic more seriously.

Some pre-pandemic ways of working were recognised as fitting more naturally and easily with the pandemic. For example, family groups working together can more easily operate as a work ‘bubble’.

Poor practice and barriers

Poorer practice was also frequently encountered by interview participants. They recognised that smaller sites (e.g. small house build projects, refurbishments etc.) often demonstrated poorer practice. It was noted that this wasn’t universal, and some small sites did also demonstrate good practice. Participants reported the following examples of poor practice:

- Welfare facilities not considered. This ranged from no provision to more tokenistic provision, where hot water, soap etc. were not restocked.
- At least one example of a face covering being used instead of respiratory protective equipment (RPE).
- No/little consideration of ‘touch points’ with regards to cleaning.
- Overreliance on hand sanitiser gels over provision of suitable welfare facilities.
- Risk assessments not revisited when build projects move from open air environment to enclosed spaces (i.e., when walls/roofs complete), to account of transition from working in open air/ventilated space, to no/reduced ventilation.
- Maximum person capacity limits (e.g. for canteens) surpassing the identified numbers, or not considered at all.
- Apparent lack of focus on vulnerable workers/groups.
- ‘Copy and paste’ of COVID-19 risk assessment templates.
- Not following good hand washing practice if an individual had been wearing gloves (i.e. not recognising hands may still be contaminated, or that there may be cross contamination during glove removal).

Challenges

Interview participants identified several challenges and barriers. These included limited application of the hierarchy of controls, already reported above, as well as the following:

- 'COVID-fatigue' – i.e., dealing with the pandemic over a sustained timeframe. There appeared to be some parallels with the phenomenon of 'risk normalisation'.
- The difficulty on changing lifelong habits (i.e., defaulting to pre-pandemic ways of working/behaviour).
- General attitudes toward the pandemic. It was noted that as with wider society, some individuals either don't see COVID-19 as a risk or are willing to take the risk.
- Site specific challenges, such as difficulty applying one-way systems, good welfare facilities etc. at some sites, particularly older buildings.
- Application of some guidance / rules not deemed practical (e.g., one of the participants referred to time-limited proximity working of 15 minutes when social distancing is not possible).
- Limited control of activities peripheral to work, such as travel and shared accommodation. It was noted that these can play a key role in transmission, but are often not the responsibility of organisations, and not within the remit of inspectors.
- Self-isolating and getting tested may be perceived as disincentivised. For many workers it was noted that no work, equals no pay.
- Displacement of workers due to site closures. It was recognised that due to the above issues regarding work and pay, the closure of a site due to an outbreak may simply result in the displacement of workers to other sites. This may exacerbate issues / transmission.

Suggested improvements / ways forward.

Interview participants recognised that it may help to have more clarity for the sector, with the suggestion that some guidelines and requirements could be more prescriptive. Changes to guidelines and rules over time may have caused further confusion. The transient nature of the industry also results in workers crossing borders of the devolved nations of the UK. They noted that different rules across the devolved nations seem to have added to confusion.

Further guidance and/or case studies were recognised as of potential benefit to the sector. It was added that any guidance or examples would ideally need to be free/easy to access and be specific to the work type (i.e., work being conducted, trade, site size etc.), to ensure it was easy to interpret and apply.

Conclusion

This scoping study has examined the impact of COVID-19 on the UK construction sector through the lens of the experiences of four principal contractor organisations. A multi-methods qualitative approach using survey data, interviews and thematic analysis generated insights into five areas of investigation.

1. **Transmission** – we revealed the challenges of adapting to keep workers as safe as possible when the threats were difficult to gauge, but also highlighted the dynamic and prompt responses that participant organisations made, whether closing sites, introducing different work patterns or enforcing new working practices.

2. **Technology shield** - the use of face coverings alone is not a suitable control measure. Other measures of taking the human out of the loop using robotics or wearable sensing technologies require further development or demonstration of practicability to enable use within a construction environment to reduce the risk of airborne virus transmission.

3. **Data and simulation** - we found that the industry is facing the challenges of identifying the high-risk transmission areas and targeted measures to reduce transmission risk. There is evident enthusiasm for the use of simulation and modelling provided that such techniques are cost-effective, visual and easy to use.

4. **Leadership** - fostering behavioural change and increasing workforce engagement to manage COVID-19-related compliance and thus maintain workers' health and safety are crucial. The data also reveals challenges for leaders seeking to manage effects of COVID-19 on employee wellbeing and the impact on traditional health and safety.

5. **Construction project delivery** – we highlight the tensions that often exists between parties to a construction contract, particularly in the context of a highly fragmented industry characterised by low profit margins. The ability to deliver a bio-secure sector is highly dependent on an industry system that prioritises the welfare of workers. High levels of self-employment may offer the benefits of flexibility but could lead to a dilution in the health, safety, and welfare culture that the sector should aspire to – this is crucial in the context of retention and encouraging the next generation workforce.

Across all packages there was a strong employee and contract-staff voice that reflected their worries about physical and mental health but principally anxiety about economic impact on themselves and their families. We believe this must be addressed in further research to underpin a bio-secure sector post-pandemic.

Thematic analysis of data obtained through survey and interview data identified 6 global themes relevant to 'Keeping the UK Building Safely';

1. **Context of the construction sector**
2. **Organisational culture**
3. **Communication**
4. **Best safety practice and technology use**
5. **Contractual partnerships**
6. **Multi-level challenges in responding to COVID-19**

A further 18-sub themes were subsequently identified; all offer potential future avenues for research to fully map the wider construction supply chain and particularly in organisations operating below Tier 1.

Moreover, detailed studies into the impacts on CDM duty-holders other than the principal contractor organisation should be undertaken, ideally using longitudinal studies. For example, the strategies adopted by clients and project sponsors in relation to their CDM2015 responsibilities. These aim to ensure that any principal designer and principal contractor appointed to a construction project carry out their duties in accordance with government guidance on safe working during the COVID-19 pandemic.

Several recently published reports by The Royal Academy of Engineering[44], Institution of Civil Engineers[45] and the RAEeng[46] into the future of the construction sector advocate for a 'systems-thinking' approach to sector reform. This is crucial to developing our understanding of systemic and in some cases, intractable issues that the industry faces in going forward. The six themes identified in this report encapsulate 'whole of government issues' and thus require co-ordinated ministerial action across departments to

[44] https://www.raeng.org.uk/publications/reports/sustainable-living-places-(1)

[45] https://www.ice.org.uk/knowledge-and-resources/briefing-sheet/a-systems-approach-to-infrastructure-delivery

[46] https://www.raeng.org.uk/publications/reports/infection-resilient-environments

ensure that the sector is best placed to deliver the governments ambitions for a high-productivity sector.

Appendices

Appendix 1: Thematic analysis of interview

Global themes	Organising themes	Basic themes
Theme 1 The context of the construction sector as a diverse occupational setting created wide variation in how response to C19 was managed	a. Construction sector involves wide range of activities that present quite different challenges for managing C19	Distinction between civil engineering projects and building construction projects relating to staff roles (office cf to on-site roles), responsibilities and contractual arrangements with subcontractors Geographical distribution of depots/work sites/ work bubbles Nature of work site, particularly referring to outdoor-indoor activities and the challenges of maintaining social distance for specific tasks Some areas are 'manumatic' and require people to work in close proximity
	b. Varied organisational arrangements creates difficulty in generalising about best approaches to managing transmission	CLC SOP guidance implemented but companies interpreted/adapted the guidance to suit their own context, e.g. some considered use of tech/some PPE as counterproductive in giving a false sense of security Delegation of responsibility for C19 management to Tier 1 contractors occurred in some organisations Each activity/context needed individual risk assessment and management Closer working and more staff in enclosed areas for fit-out activities impeded social distancing measures
	c. Trends observed in transmission and clusters did not occur on the construction site directly	Believed there was little evidence of transmission whilst on the construction site (examples of cases in the workplace related to canteen and office-based staff) Transmission clusters related to home, social activities and travel to/from work, e.g., sharing cars; visiting pub after work; sharing houses Compliance with safety measures achieved on site with the use of monitors/supervisors/observers but believed workers' guard was dropped once off site

		Drift in safety behaviour as pandemic continued; there were examples of people being more fearful and others relaxing. Managers were uncertain around causes and long-term effects of these changes
Theme 2: C19 created challenges at organisational, team and individual level	a. Challenges to systems and processes	Lack of conclusive evidence about what prevented transmission in specific contexts, e.g., do mask work in a fitting out context; how significant is transmission on surfaces? Productivity compromised for safety and implications for client, completing contracts, fulfilling deadlines and costs of overrunning Focus on C19 measures potentially compromised usual H&S measures
	b. Teams were strengthened and weakened by the arrangements introduced for safe working	Strong hierarchy of management to ensure communication with all workers and encourage/monitor adaptations of behaviour at individual level Managers prioritised building teams remotely and keeping in regular contact with employees who worked remotely. There were signs of 'COVID grief' as people felt the loss of team life in the workplace and examples of strengthened team identity and effective teamwork at management level Some examples of divided workforce and resentment relating to home/essential to be onsite roles referred to as 'them and us' mentality emerging
	c. Individual employees in construction were perceived to be struggling with a range of fears from isolation to loss of earnings	Organisations managed vulnerable individuals on a case-by-case basis citing measures such as home working supported by regular remote contact with colleagues. Some adaptions to the workplace were referenced but no rigid rules excluding staff
		Concern for people's mental health raised, relating to (i) under-reporting of illness; (ii) need-to-earn driving attendance on site; (iii) balancing shift work and home schooling/home life ('seven day' work week for office staff); (iv) macho culture creating a belief that workers were invincible, (v) sexism at management level
		Management overload; increased workload/anxiety/access to support/lack of boundaries between home-work with consequent impact on decision making
		Fear of exposure to COVID and unsafe workplaces despite control measures in place,

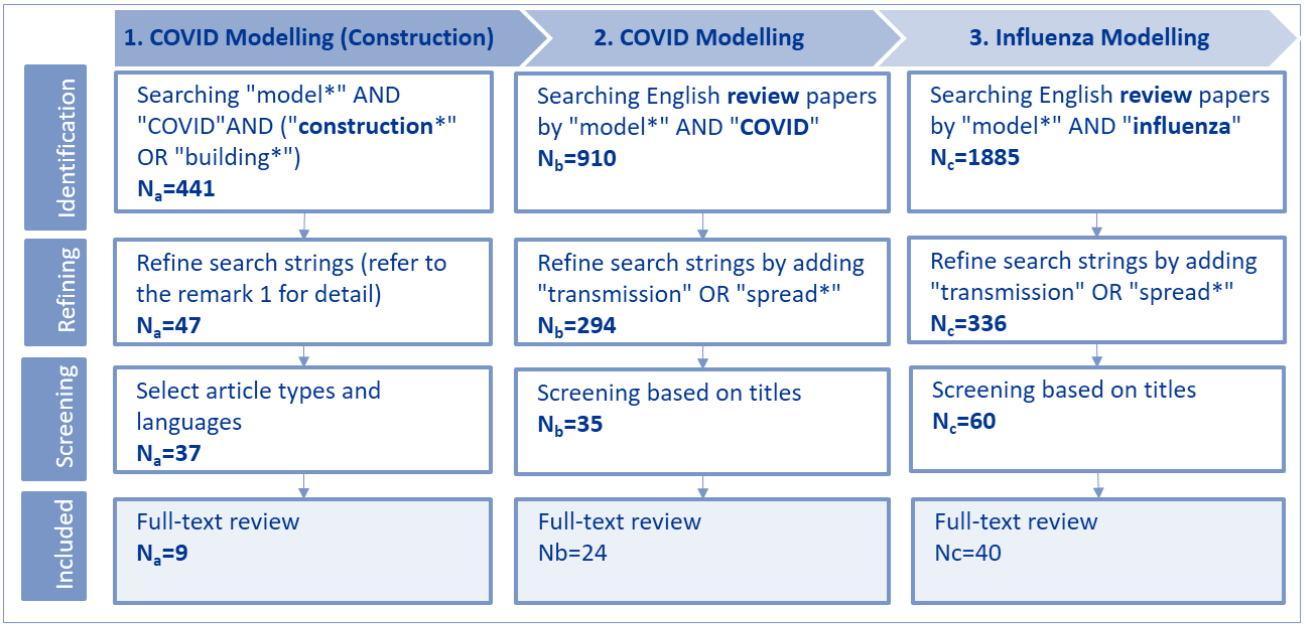
		e.g., reporting issues, probing investigations from police/HSE Anticipated challenges in phased return to work after lockdown
		'COVID fatigue' observed, potentially leading to mishaps in level of alertness and decrease in safety attitudes as C19 continued, although commented that there was little evidence to support this
Theme 3 Organisational culture focusing on supporting behaviour change was powerful determinant of positive response to C19	a. Organistions described a dynamic process for responding to a safety crisis	Decision making was characterised by flexible and prompt responses to C19 challenges/able to react quickly Setting up C-19 boards to manage the information, determine company's response and communicate with employees Set up COVID case managers/observer/COVID marshals
	b. Companies are set up to manage risk and operate safely Safety is core role for managers	Strong safety culture underpinned responses; enabled organisations to be 'ahead of the game'; proud of responding quickly, communicating well, employing network of contacts to agree best practice
		Safety critical industry, able to employ their routine good practice-logical approach, exploiting organisational hierarchy of clear teams and boundaries, with the knowledge to be science-led whilst being proportionate
		Access to expertise inside organisation and from wider network
	c. Usual monitoring systems were considered adequate/existing systems and processes for identifying and managing C19 risk in the construction sector were considered effective	Reporting mechanisms using incident reporting and management structure together with adjusting accordingly e.g., changing testing regime, shelving personal distance meters
		Structures in place to ensure safety, e.g., re-engineering done by supply chain to facilitate measures to manage C19
		Supporting teams across the projects
		Software such as Power BI proved valuable; e.g., use of data for forward planning of labour level, welfare capacity & case management trends
		Measures introduced and monitored by managers across organisation: teams/supervisors/managers/safety officers

	d. Principles and practice underpinning management approach	Organisations perceived the best transmission control was changing behaviour; example of established behavioural programme informing approach that offered coaching/supervision to enable behaviour change
		Emphasised the 'moral driver' so that employee wellbeing became a priority, including arrangements to support the vulnerable and mental health more widely; being alert to mental health issues
		Engagement through 'open conversations' with operatives allowed problems in C19 measures to be revealed without official reporting
		Good relationships with subcontractors and supply chains; clarity about boundaries and responsibilities
		Visibility of leadership, e.g. site visits, engagement with workforce, showing safety measures/controls
		Adapted travel and welfare arrangements made, but could not adapt commuting on PT, socialising and living arrangements
Theme 4 Partnership in the contractual model enhances responses	a. Contractual arrangements created tensions	Limited co-working with clients led to inappropriate arrangements for C10 measures that were not suited to context Partnership with client was difficult as frequent changes in leadership due to C19 and people deployed to other roles Some clients exerted pressure to keep to deadlines/unrealistic expectations, whilst other clients introduced measures that were not suitable for the setting Significant additional costs for clients e.g. test and trace or technology
	b. New challenges in partnerships with clients and subcontractors	Example of risk averse clients, e.g. local authority reluctant to take decisions themselves and employed consultants and advisers that slowed down decision making Other clients were risk oblivious
Theme 5 Consistent, clear and simple communication across the organisation	a. Reciprocal b. Alert to issues	Open conversation with employees Listening for issues/problems Nurturing 'speak up' culture Countering misinformation and fear mongering Information overload (too many notices/warnings), accessibility needs (neurodiverse employees)

	c. Consistent message	Endeavoured to create “healthy unease” to strengthen compliance Strengthening team identity Creating an organisational message Single communication portal Cascading through managers and integrated into usual lines of communication Clear, simple and authoritative about risks Based on CLC, PHE WHO guidance Continuous reinforcement
	d. Creative	Video messages, live chats, video streaming of site visit
Theme 6 Facilitating best practice	a. Impact of controlling C19 on other safety issues	There was a reduction in other safety issues reported by the workforce, which was considered counterintuitive Some examples of the workforce changing usual safety practice that could pose new risks
	b. Technology	Technology applied without consideration of relevance and practicality has created difficulty for workers e.g. proximity sensors/alarms; temp checks,
		Power BI provided excellent software for tracking trends
		Lateral flow testing involved logistical challenges (numbers, location for testing)
		Use single site for information-dedicated safety portal/Teams
		Proximity alarms were not valuable for employees-unacceptable/deemed to get in the way of work
		Modelling of C19 clusters not considered practical/affordable or offer advantages over current monitoring arrangements
		Concern that over-reliance on technology may reduce caution e.g. over-reliance on testing
		MMC will provide standardised components and reduce need for interaction on site. Will depend on innovative organisations to achieve change
		Video walk through to help planning/decision making

Appendix 2: Literature Review

Appendix 2a: Literature Review Process



Remark 1: The search sting was refined to "TITLE-ABS-KEY (("model*" OR "simulat*" OR "predict*") AND ("COVID" OR "pandemic" OR "infectious disease*" OR "communicable disease*" OR "transmissible disease*" OR "influenza") AND ("construction site*" OR "construction work" OR "construction workers" OR "construction industry" OR "construction sector" OR "building construction" OR "building site*" OR "building sector"))"

Appendix 2b Comparison of the four commonly used modelling techniques

Evaluation Criteria		SIR/SEIR modelling	Agent-based modelling	Statistical modelling	Machine learning
Pandemic Stages	Early stage	Yes	No	Yes	No
	Acceleration stage	Yes	Yes	Yes	Yes
	Mitigation stage	Yes	Yes	Yes	Yes
Modelling Purpose	Epidemiological Parameter Estimation	Yes	No	Yes	Yes
	Spatial Spread Across Scales	No	Yes	No	No
	Growth Rate and Time-Series Forecasting	Yes	Yes	Yes	Yes

	Intervention analyses	No	Yes	No	No
	Contact tracing	No	No	No	Yes
Data Needs	Line lists for individual confirmed cases	Yes	Yes	Yes	Yes
	Spatial representation	No	Yes	No	No
	Activity data and representation behaviours	No	Yes	No	No
	Time-series data on disease outcomes	Yes	Yes	Yes	Yes
	GPS traces	No	No	No	Yes
Characteristics	Data Amount Requirement	Small	Medium	Medium	Large
	Population scales	Large	Large and small	Large and small	Large and small
	Consider individual differences and complex interactions	No	Yes	No	No
	Rely on the quality of assumptions	No	Yes	No	No
	Operating speed	Fast	Medium	Fast	Slow
	Consider spatial information	No	Yes	No	Yes
Abilities	Visualisation	No	Yes	No	No
	Easy to use	Yes	Yes	No	No
	Short-term projections	Yes	Yes	Yes	Yes

	Long-term projections	Yes	Yes	No	No
	Understanding the effects of interventions	No	Yes	No	No
Examples of context of application		Australia; USA; China	Construction; Transportation; Hospital	New York city; Retail	Manufacturing; Mining

Appendix 3: Theme one – most useful COVID-19 data

Level 3 code	Level 2 code	Level 1 code	Examples
COVID-19 case	Confirmed case	Positive testing	"… identify whether **people were actually testing positive** or whether they were just, you know, ill at home." (Interview 1) “What we do have is we have a weekly return from contract directors, and that has all the **positive tests**” (Interview 2) “We have a system where anyone **who has COVID**… is **extremely vulnerable** is, is all captured and we can track that on a database.” (Interview 3) “… **any confirmed case** gets reported to us” (Interview 4)
		No. of positive cases	"So our data has been the things that we've been watching the most closely is **the numbers of positive cases** by the project from both the workforce and our own employees" (Interview 1) “We review that on a weekly basis… the **number of cases, how many new** how many are still isolating…” (Interview 4).
	Potential case	People have been in close contact	“And that then drove us to look at Well, if that number of **people have been in close contact** with that number of people." (Interview 1) “We have a system where anyone who has COVID, **has been in contact with someone who has COVID**” (Interview 3)
		Self-isolation	"we looked at the numbers and the contractors that were involved in those particular **self-isolations**. (Interview 1)

			“any confirmed case gets reported to us, we have a, you know, with an Excel sheet, they must complete, they must identify close contacts. And they must tell us **who's isolating**. When cases when tests were completed, when cases were confirmed, isolation periods, etc, etc.” (Interview 4)

Level 2 code	Level 1 code	Examples
Transmission	Contact tracing record	“This is a very simple investigation… **Where have you been? Have you been with a basic version of the test and trace of your life**?” (Interview 2) “Three of those transmissions were to do with **shared use of vehicle on contracts**.” (Interview 3) “Any confirmed case gets reported to us, we have a, you know, with an Excel sheet, they must complete, they must **identify close contacts**.” (Interview 4)
	Transmission record	“In the last 12 months, we've only **had four instances of transmission** within the workplace.” (Interview 3)
COVID-19 related policies and guidance		““So what we've tried to do is take just the **construction leadership councils S(O)P, Public Health England guidance, and WHO guidance**.” (Interview 2) “And they had a what they had was a dedicated **Coronavirus section** set up on our internal IMS system. So, as soon as you go in there, you can get all the **latest information, all the latest updates**, all the latest anything, absolutely everything. The **CLC guidance** or the **SOP compliance guidance and control measures** what this the thought and the silverware and right the way down

	to **first aid procedures** what was required **office procedures**, the anything and everything that you can think of. So so that was massively important." (Interview 5)
Other's approaches	"We talk a lot about his challenges, our challenges, and we **compare notes in terms of what they're doing**. And then I'm able to take a view on that and say, Would I would I go down the same route or not? So there's a good level of I think community to be able to sense check each other's and is a very open sharing environment as well". (Interview 1) "I've got is **a lot of us compared our notes** in terms of pandemic response and what our plans were and how we potentially saw such a thing impacting on our business." (Interview 3)
Feedback on transmission control	"And our **feedback** tells us that we have been operating in a COVID secure manner." (Interview 1) "People were generally grateful that we could carry on working because we're one of the few areas that were allowed to work. The **feedback** we got was all around, **people feel really safe at work** or absolutely petrified getting to and from work." (Interview 3)
Observation reporting	"We've got a dedicated 12, strong behavioural management team… having people carrying out **behavioural observations**… what those observations were, you know, **are people keeping two metres are they wearing a face covering are the washing out**, you know, and throughout the day to capture data, and we got 1000s of data points to say they are they aren't and, and by and large, round about 85, 90% compliance most of the time." (Interview 3)

Appendix 4: Theme two – why collected COVID-19 data is useful.

Level 2 code	Level 1 code	Examples
Tracking	Tracking trends	" And we built in COVID reporting into that, that then allows you allows us to **keep track of every case**, every case that's reported to us through our supply chain, or directly through employees, and every self-isolation as well. " (Interview 1) “With that data, we **track trends**… **how fast is increasing rates of infection** and so on and so forth” (Interview 3).
	Tracking labour levels	“(We) **track labour levels**, forward planning to make sure that where our projected labour levels where our actuals are against projected” (Interview 4).
Tracing	Predicting potential hotspots	“Now, we took a look at that project in particular, and we looked at the numbers and the contractors that were involved in those in those particular self-isolations. And that then drove us to look at… the office may not be clean… So for us, it must be to do with behaviours, or seating or capacity. That will do what it would allow us to focus in on **potential hotspot**”. (Interview 1)
	Tracing contact	“What we do have is we have a weekly return from contract directors… That has helped us in terms of **understanding where people have been**.” (Interview 2)
Facilitating decision-making	Comparing with others’ approach	we talk a lot about his challenges, our challenges, and we compare notes in terms of what they're doing. And then **I'm able to take a view on that and say, Would I go down the same route or not?** So there's a good level of I think community to be able to sense check each other's and is a very open sharing environment as well. (Interview 1) “I've got is a lot of us compared our notes in terms of pandemic response and what our plans were and how we potentially saw such a thing impacting on our business… we sat down and we looked at what we've got… I think we've already got a plan that would work. So if nothing else, it sort of

		confirmed that the approach that we had and what we had in mind **should be at enough** to actually manage the issue." (Interview 3)
	Following guidance	"To be able to then **structure our risk assessment process** around the CLCs guidance." (Interview 1) "There was a standard set at the start of the pandemic…This is the CLC guidance. This is our SOP compliance guidance. This is what this these are the control… And then what we had to do was **implement those across all our depots**." (Interview 5)

Appendix 5: Theme three – most useful COVID-19 data.

Level 1 code	Examples
Data gaps	"Interviewer: Any gaps? Do you feel in your data collection or monitoring or control decisions or anything? Interviewee: Yes, I do… so I speak a lot with [Anonymity]… for example, we talk a lot about his challenges, our challenges." (Interview 1) "I'd say the **will be gaps in there**. But I can't put my finger on one right now." (Interview 2) "For sure, I think, we were **always looking for the lack of presence of something** as well as the presence of it." (Interview 3)
No concrete contact tracing	"We believe drove a potential transmission… So for us, **it must be to do with behaviours, or seating or capacity**. That will do what it would allow us to focus in on potential hotspot". (Interview 1)" "Like people not signing into the QR code that's been picked up… This is a very simple investigation. So we'd do it as we would **an accident investigation, but very much slimmed down, because there's no evidence** together in terms of there hasn't been an accident. There's not a scene, there's not. It's just simple questions of Where have you been? Have you been with a basic version of the test and trace of your life?" (Interview 2)
No gap	"I think the **data we have is pretty much is robust enough**. And I think, say we come out of this. And next year, there's for some god-forsaken reason it happened again, I think what we've got now is more than suitable enough to get us through it." (Interview 5)

Appendix 6: Theme four – modelling/simulation techniques.

Level 1 code	Examples
No modelling/simulation techniques	"we **were trying to use... people movement modelling**... But unfortunately... there were **technical limitations** in what we could do. " (Interview 1) "**We don't** (using modelling/simulation)… So the only people that use BIM will be the designers" (Interview 2 "We haven't used any sort of modelling with COVID". (Interview 3)
Expecting to modelling/simulation techniques	"We then suddenly realised in the benefit, the **benefits** of that (modelling) **were significant**" (Interview 1) "It would be amazing if we could… they will be brilliant" (Interview 2).
No need for modelling/simulation techniques	"I think we've already got a plan that would work. So if nothing else, it sort of confirmed that the approach that we had and what we had in mind should be at **enough to actually manage the issue**." (Interview 3)

Level 2 code	Level 1 code	Examples
Required features	Ability to integrate data	"You could use **sensors**, **you could link those into the model**. "(Interview 1)
	Prediction	"It would also help with things like the reduction in, you know, hoists call numbers. Lift car numbers to **tell you what your productivity drop off rate would be** as well. And if we, if we were able to have that just snap the fingers and just say right we've got all that we can now do that, then **we could most definitely**

		identify high risk areas and project where we would need to then probably slow the works in some areas." (Interview 1) "I think some sort of maybe even if it's as simple as geographical locations, and where people have been and **potential transmission routes and groups, cohort groups that may be affected or not affected**. That will be useful. Because again, we could pick up hotspots." (Interview 2)
	Monitoring and control	Particularly by creating more distancing, analysing each of those tasks as we do, beginning saying well you know you've got five people that need to instal this huge piece of glass, how do we do that, and **keep them safe and distance** and, you know, we stopped them transmitting, you know aerosol and droplet with each other. (Interview 1)
	Visualisation	"You could use sensors, you could link those into the model you could see, you could **map out** your, you know**, your pedestrian traffic**. you can **see where the main points of congregation** are on the job, you could actually use that to tell you **where your busiest areas are, where your most prevalent areas of potential transmission risk could be**. "(Interview 1) "And it would be to **look at those real hotspot**s on the project." (Interview 1) "I think some sort of maybe even if it's as simple as **geographical locations**, and **where people have been** and potential transmission routes and groups, cohort groups that may be affected or not affected. That will be useful. Because again, we could **pick up hotspots**." (Interview 2)
	Simple and easy to use	"So if we, if we had a better system and a reliable system that I'm sure would use it… And it has just be it's **simple**, and it's work." (Interview 2) "It'd be great if we could **get more autonomous things**" (Interview 2)

Appendix 7: Theme five – data management challenges and lessons learned.

Level 2 code	Level 1 code	Examples
Challenge of data collection	Limited ability of collecting real-time data	“What we do have is we have a weekly return from contract directors, and that has all the positive tests, where the scenario that sits behind that, so maybe I mean, one that we picked out… And it turned out that all of these people had all been to the same pub in December.” (Interview 2) “On the basis that you can test negative today, but you could be positive tomorrow, you know, it's that rolling sort of scenario.” (Interview 3) “if there's any trends there, so you know, we review that on a weekly basis.” (Interview 4).
	Challenge of identifying data gaps	“there will be gaps in there. But I can't put my finger on one right now. Again, probably, because… we might not be asking the right questions”. (Interview 2)
	Limited contract tracing	“This is a very simple investigation. So we'd do it as we would an accident investigation, but very much slimmed down, because there's no evidence together in terms of there hasn't been an accident. There's not a scene, there's not. It's just simple questions of Where have you been? Have you been with a basic version of the test and trace of your life?” (Interview 2)
	Data accuracy	“I think we've got on the rapid flow tests, and the rapid flow tested 800 people, the first and about 500 people in the second month, we did about 1400 ish people. We had a 1.01 failure rate across both tests.” (Interview 3)
Challenge of data analysis	Limited trending prediction	“We haven't been able to use it specifically very well, for trending.” (Interview 2)

	Challenge of picking up hotspots	“(We expect) to look at those real hotspots on the project, rather than, you know, walking around and maybe catching people, you know, doing a bit of facade work, where they're congregated or they might be a lunch, etc” (Interview 1).
Challenge of using modelling/simulation techniques	Long model-building time	"we were trying to use... people movement modelling... But unfortunately, it was, it would need the technical process of building that project as a model would probably have seen us through to the end of the project before we were able to use it. " (Interview 1)
	High cost	“we were trying to use movement, movement modelling, people movement modelling… the cost of that was enormous.” (Interview 1)
	Limited knowledge	“So the only people that use BIM will be the designers. So they may be using it to design in COVID… and we don't have the people that know how to use it.” (Interview 2) “Not 100% sure about BIM in terms of because we're outdoors. So I'm not sure what we could get out of that.” (Interview 2)
Lessons learned	Needs and benefits of using simulation/modelling techniques	“How many obviously passenger hoists we would need, because we were building straight up in the air for 62 stories, we have 1500 people on the site, we needed to know how efficient we could be. So we use this mash of mass motion modelling company to help us with that. We then suddenly realised in the benefit, the benefits of that were significant,” (Interview 1) “So if we, if we had a better system and a reliable system that I'm sure would use it… It would be amazing if we could (use any simulation/modelling techniques)… they will be brilliant.” (Interview 2)
	Appreciating lifetime observation on the site	“So there's some observations are around COVID-19. So this is these are really useful for us in terms of what's going on the site, and what's going on in lifetime on the site.” (Interview 4)

	Utilising data proactively	“(For example,) why have we got a low return to work ratio? Why is this? So they're asking the right questions now, based on the data. So we have lots of different sources of data. And depending on what we're looking for what we're looking at, we're looking for those weak signals, right, ready to do something here, or we could predict this might happen, or we think this might happen. So we use data in lots of different ways in a proactive way, not a reactive way.” (Interview 3)

Appendix 8: Theme six – information sharing and impact.

Level 1 code	Examples
Online system for data sharing	“We have an existing incident reporting tool, which is an online platform, which all of our teams across our projects use for any incident. And we built in COVID reporting into that, that then allows you allows us to keep track of every case, every case that's reported to us through our supply chain, or directly through employees, and every self isolation as well. And we're able to then share that with our HR team. And our legal team as well.” (Interview 1) “We have a system… which is what the guys can report issues into. And I had a look at this morning and there's 855 COVID related entries.” (Interview 2) “We have a system where anyone who has COVID, has been in contact with someone who has COVID out to isolate or is extremely vulnerable is, is all captured and we can track that on a database.” (Interview 3) “We use Power BI show current case levels, on each of our projects.” (Interview 4)

	“And they had a what they had was a dedicated Coronavirus section set up on our internal IMS system. So, as soon as you go in there, you can get all the latest information, all the latest updates, all the latest anything, absolutely everything.” (Interview 5)

Level 2 code	Level 1 code	Examples
Monitoring	COVID-19 case monitoring	" And we built in COVID reporting into that, that then allows you allows us to keep track of every case, every case that's reported to us through our supply chain, or directly through employees, and every self-isolation as well. " (Interview 1) “we have a system… which is what the guys can report issues into. And I had a look at this morning and there's 855 COVID related entries.” (Interview 2) “We have a lot of within the business we focus a lot on hazards and observations reporting… We use that as one of our key leading measures, and we have about 114,000 of those reported a year across the business. So how are we track trend where that is where the report is high, low, whether might be little help.” (Interview 3) “So any confirmed case gets reported to us… with an Excel sheet. They must complete, they must identify close contacts, and they must tell us who's isolating. When tests were completed, when cases were confirmed, isolation periods, etc, etc.” (Interview 4)
	Closely overseen from on high	"Interviewee: we've also expanded that to our global alert system. So our... chief executive in Australia... the executive team get that as well... Interviewer: That's closely overseen from on high, really is what you're saying? " (Interview 1)

	Risk level monitoring	"So we use it for (monitoring)… those yellow and green at risk observations, and that more safety in general. So we use that for our observation. So every person that goes out on my site, all of my team have to give observations: save or at risk." (Interview 4)
Forward planning		"I use the Power BI (i.e. a business analytics service) to track labour levels, forward planning, to make sure that where our projected labour levels, where our actuals are against projected… I'm tracking that to make sure that staying on track. That means I've got enough car parking spaces making sure I've got one per person… I've got enough welfare, that I've got enough testing facilities that I've got enough drying room capacity." (Interview 4)
Control	Preventing transmission	"We have a system where anyone who has COVID, has been in contact with someone who has COVID out to isolate or is extremely vulnerable, is all captured, and we can track that on a database… (we) had another place and here's a bubble. So it did break out, we could kind of contain it very quickly, and that's definitely happened." (Interview 3) "The main canteen has got 52 tables that sits for people when we first went into lockdown suddenly that only set 52 people to one person per table. Now we've got screens in so we can get 104 in and then we shifted." (Interview 4) "If we see evidence there, that there's becoming a (outbreak), and we had a big safety pause at the beginning of this year, actually, where we took a week out and we did call the tier ones to account on some of those, this is probably why actually the COVID things are gone down now. Because we've you know, we, we made them review and revise their plans and update them." (Interview 4)
	Keeping social distance	"we've shifted our start and the end of the day and our break times. So we actually now get four times 104 in that main welfare canteen, because you know, we split the day down, and then we've got another we've converted offices on the first floor into a second canteen. And now we've got a third canteen out on site as well." (Interview 4)

Developing awareness for dealing with COVID-19 situation	“So what we've tried to do is take just the construction leadership councils S(O)P, Public Health England guidance, and WHO guidance… This is the source. This is what this is what the research is telling us. This is the best information we can give you, stick with that… people now know what to expect and what we need them to do” (Interview 2) “I think by having that very clear approach, he gave very clear guidance to people. And they got with the programme very quickly.” (Interview 3)
Feeling safe by following shared guidance	“So the standard was set up. This is the CLC guidance. This is our SOP compliance guidance. This is what this these are the control measures that we feel, as a business, will keep us safe during this pandemic. And then what we had to do was implement those across all our depots, all our sites, so, anything that's been kind of like developed or advanced. ” (Interview 5)

Appendix 9: KUBS Pre interview questionnaire

1.	Background	Text
	Name	
	Contact email	
	Contact phone	
	Organisation	
	Key activities of your organisation/range of construction activities carried out b your company	
	Your role	
	Changes in your role since COVID 19	
	Evidence that your organisation has collected about transmission of C19 in the workplace	
2.	Has your company been collecting any data/information from employees to manage the transmission of C19?	Y/N/DK
	If yes, which types of information have you collected? i. Positive C19 tests ii. C19 sickness absence iii.Data on job role / demographic / vulnerable groups iv. Other, please describe	 Y/N/DK Y/N/DK Y/N/DK Text
	If yes, briefly tell us how have you collected the information	TEXT
	Has your company analysed the collected data to manage the transmission risk? If yes, how have you done this?	Y/N/DK Text
	Are you able to share this with us?	Y/N/DK
	Are you able to identify transmission in teams/across sites?	Y/N/DK
	Do you have any specific requirements from subcontracting companies in order to reduce risk of transmissions on site? If yes, -do you have evidence from tests? -evidence from number vaccinated? -evidence from how vulnerable groups are managed? -other, please describe	Y/N/DK Y/N/DK Y/N/DK Y/N/DK TEXT
	Do you take into account views of employees and managers about specific risks of C19 transmission? If yes, how do you take account of views	Y/N/DK TEXT
3.	Your views of monitoring and mitigating COVID-19 transmission	
	Briefly, what COVID related work practice changes have been implemented?	TEXT

	Have you changed any of the measures following the information on the increased infection rates for the new variant?	Y/N/DK
	Do you have any special consideration for vulnerable groups in terms of Age Pre-existing health conditions Ethnicity	 Y/N/DK Y/N/DK Y/N/DK
	Do you measure compliance / non-compliance at your sites	Y/N/DK
	Do you measure compliance / non-compliance at your sites?	Y/N/DK
	Do your mitigation strategies differ between locations?	Y/N/DK
	Has there been any impact of COVID related work practices on traditional health and safety? For example: monitoring of sickness (non COVID) / accidents / near miss rates etc)	Y/N/DK TEXT
	Has messaging about managing risks of transmission been important in changing working practices?	Y/N/DK
	Have employees responded well to messaging? If no, what have been the main issues	Y/N/DK TEXT
	Do you use technology to help manage the risks of COVID-19? Have you introduced any new technology to help you manage the risk pf transmission? If so, what?	Y/N/DK Y/N/DK TEXT

Appendix 10: Interview Protocol

Introduction and participant identification

Explanation of the study: KUBS [what can we learn from the way transmission of C19 has been managed in the construction sector].

We are interested in your views and hunches, as well as information, so please feel free to follow up the things that you have observed or concern you about managing C19 transmission. We'd like to talk to you about your organisation, how you have managed the issues arising from C19 and your views about how the risks have been managed. Our interview is looking at three areas (15 minutes per section):

- How C19 is transmitted specific to the construction sector
- How data and technology have been used to manage the risks of transmission
- How the role of management and leadership has affected working practice and how adaptations have been implemented.

Check consent verbally [each says name and agree to statements]

WP1	**Your views of monitoring and mitigating COVID-19 transmission** a. Thinking about C19 transmission, how safe do you regard working in construction sector and why do you think that? Are there any areas of particular concern related to COVID-19 and why is this? b. Are there any key areas where we need a better understanding of risk of transmission of C19 in the construction sector and why do you think that? (consider travel to and between jobs; facilities/sharing/ventilation; hygiene; compliance; vulnerable workers, temporary facilities/welfare facilities). c. How adequate is monitoring of C19 transmission the sector? What role do you think testing and vaccination plays in managing transmission in the sector? (Generally/across sites / job roles / vulnerable groups). What kind of approaches did you introduce for vulnerable groups? Why did you do this? How successful were these approaches? d. Can you give me any examples of the most successful/ least successful changes in the workplace to manage transmission and why these did/did not work well? What role did standard guidance play? e. Thinking about the barriers to improving C19 transmission in construction, why do you think these are challenging?
WP2 and WP3	**Data collection and analysis, technology** a. Based on your organisation's experience so far in managing the COVID-19, what is the most useful COVID-19 related data your organisation collects in order to plan and put the proper monitoring and control measures in place? Why is it most useful? b. What data gaps are there that hinder your organisation from making sound COVID-19 monitoring and control decisions? c. What modelling/simulation techniques and/or BIM do you use to assist with COVID-19 transmission risk analysis/prediction or for COVID-19 risk monitoring and control? • If not used, would your organisation like to use such techniques and if so what kind of features/functionalities would you require (e.g. the ability to integrate qualitative and quantitative data for prediction, explainability, and visualisation).

	• If your organisation would not like to use such techniques, could you tell us why? d. What assistance do you think would be necessary to increase the use of helpful technology in your sector for reducing transmission of COVID-19? e. What are the challenges and lessons learned by your organisation in the collection and analysis of COVID-19 related data? f. How has COVID-19 related information/data been shared with the workforce and how has the information sharing impacted on transmission?
WP4	**Management, leadership and implementing adaptations in the workplace** a. What is working well (and not so well) in how COVID safety is being managed? How has the management of COVID safety impacted on other aspects of health & safety? (e.g., accidents / near misses, sickness absence, mental health) Why do you think this is? b. How has the health and well-being of managers been affected by COVID working practices? (e.g., working from home vs. working on site) Has leader health and well-being influenced how effectively they perform their jobs? (e.g., how they communicate with their team) c. What is your perception of people's attitudes towards C19 safety in construction? How does this differ across groups (e.g. leaders / supervisors / employees / sub-contractors / job role / vulnerable groups such as workers with chronic health conditions or older workers? d. How have COVID related changes of work practices affected teamwork and team performance? (impact on how teams operate in C19 safe workplace, and on achievement of team performance goals) e. How have you adapted messaging for employees/public in your sector and why did you choose this approach? (content, endorsement, who from, leadership / senior management / supervisor involvement in messaging, role of safety reps) • What has worked well and what has not? • Have you used different approaches to messaging in different sites/job role/ demographics (e.g. vulnerable workers / sub-contractors) and why did you do this? Were different approaches successful?
	In your view, what are the main unanswered issues about C19 in your sector that we should be investigating in future studies?' Follow up points If needed, ask availability for follow-up interview

Appendix 11: Building an understanding of COVID-19 transmission in the construction sector: a rapid review of evidence.

Summary

The evidence review aims to address two questions:

1. What affects the rate of transmission of COVID-19 in the construction sector and what measures have been successful in managing the rate of transmission?

2. What role does leadership and communication play in effectively managing COVID-19 risks?

Following a rapid review of the evidence five themes were identified:

1. Clusters of COVID-19 suggest that construction can be a high-risk workplace but issues of workplace culture and socio-economic factors complicate the picture.

2. Consistent COVID-19 safety measures were quickly introduced but were difficult to monitor.

3. Unanticipated benefits of changes in working practice from introducing COVID-19 measures.

4. Complex organisation of construction projects potentially impedes consistent use of measures.

5. Continued commitment to safety and engagement with workers is essential to manage safety compliance and wellbeing to reduce transmission.

Limitations in the existing research include the following:

(i) Quality of reviews and studies have been questioned (HIQA, 2020).

(ii) Absence of detailed reporting of clusters of COVID-19.

(iii) The assumption that construction is an outdoor activity does not accurately reflect many activities undertaken by construction workers.

(iv) Many factors identified as increasing risk by the ECDC report can apply to the construction sector.

(v) There is limited evidence and evaluation to date in how leadership and communication can help manage risk, and protect health, safety, and wellbeing

(vi) Conclusions that suggest construction is relatively risk free do not accord with the informal evidence from the sector.

Background

COVID-19, a highly infectious virus that came to dominate 2020, escalated into a pandemic in March 2020 (WHO). It demanded rapid responses from governments, scientists and the public. Decisions had to be made based on limited information and understanding of the virus and constant uncertainty about how to manage the risks (Davey Smith, Blastland, Munafò, 2020). The serious repercussions for society and the economy worldwide, has yet to be evaluated, but understanding workplace transmission is essential to reducing the risk from COVID-19 and contributing to a safer society, with implications for 'recovery' of the socio-economic context. In the UK, scientists tracked the transmission of the disease (Wales Online, 2020), revealing the occupations most at risk, frequently related to the role of key workers. However, after a period of national lockdown, as restrictions were eased, there was an imperative to understand the impact of COVID 19 on other occupational groups in order to introduce controls and measures to ensure people were able to return to work safely. Working within the construction sector raised concerns, with employees identified as high-risk (Ramazzini, 2020), but proving a sector where it was difficult to gather accurate information about the reasons for the risk and how successfully it was being mitigated. This paper summarises evidence reporting on COVID-19 transmission in the

construction sector, drawing on a wide range of sources in keeping with the principles of a rapid review (Khangura et al., 2012).

Transmission modes for COVID-19 were originally believed to be person to person contact via respiratory droplets (breathing, coughing, sneezing etc), contact with contaminated surfaces transferring the virus to others through mouth, nose and eyes, and 'aerosol' transmission through breathing in air borne virus (The Lancet, 2020[i]). As knowledge increased, scientists suggested that transmission occurs most frequently through close contact, with surface transmission and airborne transmission less frequently occurring.[ii] Lack of ventilation, time of contact with infected individual and closeness of contact have all been identified as compounding factors. Guidance in the UK includes avoiding crowded spaces, particularly indoors, improved ventilation and mandatory wearing of face masks in public places.

Given that the environmental circumstances are a critical contributor in the spread of the virus, managing the workplace context has been prioritised in aiming to reduce transmission. Such a context is potentially easier to manage and oversee safely than the home, education or leisure setting, but understanding transmission in the workplace is complex. The highest risk occupations, such as health care, have now established practices that protect staff, with the introduction of PPE, but preventative measures for other occupations remain less carefully understood.

The interplay between organisational factors, workplace features and individual behaviour presents a complex context to understand the transmission of COVID 19, creating difficulties in mapping the trends and analysing underlying factors[iii]. Evidence is emerging that occupations that involve close public contact, other than health and social care, represent a high risk for employees (Sim, 2020). However, risks have been identified in less public facing occupations, such as construction, where work is frequently undertaken outdoors, a potentially safer environment. However, the assumption that employees in construction are less at risk is not reflected in some data and understanding the workplace context, which is often organisationally complex with subcontractors (Stiles et al., 2021) and specific risks, such as working in poorly ventilated indoor settings and close contact with others, needs to be investigated (i-

news[iv]) Moreover, the influence of socio-economic factors on employee's actions and beliefs in the construction sector may play a significant role in the way COVID-19 is transmitted. Such issues are harder to quantify, but can be seen in the wider debate from the sector (Unite).

What did we set out to do?

We adopted the rapid review method outlined by Khangora et al., 2012 [v], in order to synthesise evidence from different sources and identify critical themes from the data to create an evidence summary and inform future research in the sector. This approach is intended to produce evidence summaries that are timely and accessible, drawing on the evidence available from different sources. The need for an evidence summary was initiated by the Health and Safety Executive in England, reflecting their experience in the sector and desire to understand the transmission in specific contexts. As the knowledge users, the HSE took a lead role in determining the review questions and informing the interpretation of the findings, as part of the research team shaping the enquiry. The review endeavoured to answer the following questions:

- What affects the rate of transmission of COVID19 in the construction sector and what measures have been successful in managing the rate of transmission?
- What role does leadership and communication play in effectively managing C19 risks?

Systematic searches were undertaken using broad sources of evidence to include empirical studies, guidance and policy documents and media reports, including international items. Given that C19 is a novel situation for society and unknown before 2019, the searches were restricted to the years 2019-2020. The evidence was critically appraised by the authors and the synthesis reported as a descriptive summary with clear caveats relating to the novelty of the context, limited empirical evidence and rapidly changing environment. It was unrealistic to restrict the search to peer reviewed studies given the rapid pace of the emergence of C19 and limited opportunity for research. Electronic databases were used to identify reports, academic papers and grey literature (Google Scholar, Pubmed and PHE specialist COVID-19 evidence reviews database, Public Health England**,** Researchgate COVID-19 research

community). Articles were screened according to inclusion criteria developed for the review: (i) evidence examining transmission of COVID-19 in construction sector workplaces (ii) empirical, opinion, policy and media reports; (iii) published between December 2019 to January 2021. The evidence summary was produced by extracting the objectives, methods and results and presenting these as a themed summary.

Findings

A total of nineteen studies and commentaries were included in the evidence review (Table 2). The evidence was summarised according to five themes:

i. Clusters of COVID-19 suggest that construction can be a high-risk workplace but issues of workplace culture and socio-economic factors complicate the picture
ii. Consistent COVID-19 safety measures were quickly introduced but were difficult to monitor
iii. Unanticipated benefits of changes in working practice from introducing COVID-19 measures
iv. Complex organisation of construction projects potentially impedes consistent use of measures
v. Continued commitment to safety and engagement with workers is essential to manage safety compliance and wellbeing to reduce transmission

Clusters of COVID-19 suggest that construction can be a high-risk workplace but issues of workplace culture and socio-economic factors complicate the picture

Reports and reviews provide a contradictory picture of the risks of increased transmission in the construction sector. However, construction workers are not in the top category for experiencing clusters of COVID-19 (HIQA 2020; ECDC 2020; Leclerc 2020). The Health Information and Quality Authority[vi] published an evidence summary in Nov 2020 reviewing nineteen studies reporting the location of clusters. These were predominantly in household settings, with workplace outbreaks covering a range of sectors, whilst few studies identified construction as particularly at risk. The report outlined that factors related to transmission risk are linked to 'indoor environments, crowds, and prolonged and intense contact with others' (p5). A summary of findings from other studies internationally shows a small number of clusters reported on building sites (1.5%) and concluded that indoor settings were associated with the

greatest transmission, working on the assumption that building sites were purely outdoors (Leclerc 2020). The ECDC (August 2020) report found relatively few clusters in construction, but in examining the factors identified for increased risk of transmission, many of these could apply to employees in the construction sector. Features, including the socio-economic context, that could clearly be present in the construction sector were reported, 'working despite symptoms ('presenteeism'); higher proportions of individuals from lower socio-economic groups, ethnic minorities and those with migrant status; lack of access to hand-washing facilities; inadequate or inappropriate use of personal protective equipment (PPE); exposure to multiple clients; face-to-face contact; congregation; shared accommodation and transportation; and exposure to fomites, such as tools' (P6).

It is interesting to note that figures from England and Wales of deaths from COVID-19 between March and December 2020 (ONS, 2020) reported that men who worked in elementary occupations were a high-risk category (men who worked in elementary occupations (699 deaths) or caring, leisure and other service occupations (258 deaths) had the highest rates of death involving COVID-19, with 66.3 and 64.1 deaths per 100,000 males, respectively). Other studies exist that have hypothesized that construction workers are potentially at risk of workplace transmission. A review of government reports from six Asian countries (Lan et al) notes five high risk occupations (healthcare workers, drivers and transport workers, services and sales workers, cleaning and domestic workers public safety workers) at the beginning of the pandemic, with a relatively small number of construction workers included in the analysis. However, the authors argue that the less obvious occupations may have been at greater risk because of the difficulty identifying transmission routes, use of limited or late implementation of measures and controls, occupations that cannot be done remotely, impact of lower SES and susceptibility to the infection.

Specific concern for the transmission of COVID-19 in the construction workplace was raised by modelling studies from one state in the US (Paco et al, 2020). The researchers theorise what they expect will happen for infection rates among construction workers when COVID-19 restrictions are lifted. They employ several different scenarios, concluding that their projections suggest that there is a higher risk

of severe COVID-19 within construction workforce than non-construction workers. One of the salient features raised by the projections is that construction workers returned to the external workplace whilst other occupations 'stayed home', therefore increasing the chances of being exposed to the virus. Further research from the US (Pasco et al., 2020), examining hospitalisation data in August 2020, found construction workers had significant increase risk of hospitalisation (nearly 5-fold) compared to other occupational groups. They concluded that the transmission risk was increased due to physical proximity on site, prevalence of co-morbidities and lack of access to health care, given the migrant nature of the workforce in the US. These studies, specifically located in a US context and using modelling relevant to this context, provide headline messages, but little detail that can be applied more widely to a UK context.

Consistent COVID-19 safety measures were quickly introduced but were difficult to monitor

After nine months of the pandemic, the UK was still trying to ensure workplace measures were in place to protect employees and understand the clusters of COVID-19. A spike observed in the construction sector was unexpected and described as a surprise to scientists (Personnel Today 2020). Reported in the Human Resources e-newsletter, Union communications and other media sources, the sector was praised for issuing guidance (Construction Leadership Council) but the factors that pose risks have yet to be examined in detail. Poorly ventilated working conditions, poor weather encouraging clustering together to seek shelter from the weather, unregulated labour and many who are self employed and risked financial loss if they are self-isolated, were all potential risk factors (Unite the Union 2020).

Guidance in the UK, specific to the construction sector has been published, through government channels (HM Gov, 2020), sector specific organisations and informal forums. The emphasis from informal forums is on advising construction workers to observe the COVID-19 measures in their social lives as well as in the workplace (Electrical Time 2020), whilst formal guidance proposes a series of principles to help employers manage the context for construction workers as safely as possible.

Unanticipated benefits of changes in working practice from introducing COVID-19 measures.

Results from a qualitative study (Jones, Chow, Gibb 2020) presents a contrasting picture, arguing that unanticipated benefits of the safety measures introduced to reduce transmission of COVID-19, created the opportunity for work to be delivered more efficiently. The research, commissioned by six large construction companies in the UK, reports the findings from qualitative interviews with 33 people on six construction sites. The findings indicate that these companies had responded quickly to the risks of COVID-19, suggesting benefits that included more careful and efficient planning of staff on sites, better engagement with workers and potentially improved health and safety management. The optimistic outlook, as reported by the construction companies, needs corroboration from future studies that are peer reviewed. Given the study reported data during easing from a first lockdown, it may not reflect the issues of COVID-19 as a more permanent risk in society.

Complex organisation of construction projects potentially impedes consistent use of measures.

Opinion from researchers familiar with the sector (Stiles et al., 2021), suggests that the complex nature of the construction industry, based on a hierarchical organisation and subcontractors, potentially impedes implementation of a consistent approach to safety. The authors indicate that effective leadership relating to COVID-19 management may be difficult to achieve across different organisations involved in the same project. They argue that COVID-19 needs to be an integrated part of a general risk management approach, with an emphasis on the practical implementation. As with previous research, this study stands alone, reporting observations and little empirical data at this stage to consolidate these findings.

Continued commitment to safety and engagement with workers is essential to manage safety compliance and wellbeing to reduce transmission.

There is a huge body of research that supports the notion that leadership plays an important role in facilitating safety at work (e.g., Clarke, 2013; Donovan, Salmon, & Lenné, 2016). During the ongoing COVID pandemic, construction employees have relied on their leadership team to engage in effective decision-making and guide them

through changes in work practices. However, there is very little research that can be drawn upon to understand how leadership can specifically contribute to COVID-19 safety in the construction sector. One potential challenge poses the complexity of the supply chain involved construction projects which may contribute to a diffusion of leadership responsibility in driving safety behaviour and differences in safety culture or practices across organisations. In a commentary by research experts for construction sector, the authors highlight the importance of leadership in effective transmission risk management (Stiles et al., 2020). They recognise the influence management has on driving safety culture and influencing safe behaviour to ensure a COVID secure workplace. The authors recommend a higher emphasis on leadership skill development and maintaining leadership visibility and commitment to safety. However, there is a clear lack of research on how leadership best facilitates COVID-secure work practices or what workers' expectations of leaders are to support them through the pandemic. In addition, the continuous uncertainty around COVID transmission risk impedes clear guidance on effective leadership.

The role of effective communication for facilitating safety compliance has also been discussed in the literature. The official guidance published by the Institute of Civil Engineering (ICE, 2020) and Department for Business, Energy, and Industrial Strategy (BEIS, 2020) supports constructive, trust-building engagement between leadership teams and workers. Clear communication with workers and opportunities for participation in decision-making process were recommended to alleviate workers' anxiety around COVID and foster safety behaviour. In terms of academic research, a recently developed conceptual model, the Total Worker Health framework, further supports the idea of clear, consistent, and empathetic communication to contribute worker safety, health and wellbeing during the COVID-19 pandemic (Dennerlein et al., 2020). A participative approach in decision making was also highlighted as a potential strategy to facilitate broader safety culture and employee wellbeing. A qualitative interview study exploring the early impact of COVID-19 on six construction projects provided further support for clear messaging and regular engagement (Jones, Chow & Gibb, 2020). Similarly, an opinion piece by safety professionals specialising in construction safety management (Hollingsworth, 2020) emphasised the importance of

considering employee mental health and providing more opportunities for engagement with employees. They also stress the role of good messaging to adequately inform employee of COVID-related policies and protocols and counteracting the spread of false information. Addressing safety concerns and providing support for mental health were also identified as one of the key actions for mitigating COVID-19 effects as part of an international online survey study with construction industry and academic representatives (Raoufi & Fayek, 2020). However, the focus of the presented literature is primarily on guidance and provides very limited empirical evidence or evaluation.

Limitations of existing evidence regarding transmission of COVID-19.

In the context of construction as a whole sector, there are particular limitations in the existing research: (i) quality of reviews and studies have been questioned (HIQA, 2020) (ii) absence of detailed reporting of clusters of C19 (iii) the assumption that construction is an outdoor activity does not accurately reflect many activities undertaken by construction workers; (iv) many factors identified as increasing risk by the ECDC report can apply to the construction sector; (v) there is limited evidence and evaluation to date in how leadership and communication can help manage risk, and protect health, safety and wellbeing (vi) conclusions that suggest construction is relatively risk free do not accord with the informal evidence from the sector.

To evaluate the risks reported in the construction sector, and accepting limited availability and quality of research studies, we sought out more informal evidence and grey literature. We have done this in the full knowledge that there will be bias in the reporting, particularly when a specific interest is being promoted, controversy has been identified or an interesting social story narrative is revealed. However, the observations of those working in the sector, may also reveal concerns associated with risk of transmission of COVID-19 that merit investigation, in the absence of rigorous research studies. The evidence may include limitations but given that they could add to the developments of hypotheses for future investigation, they are important to highlight in this evidence synthesis.

Further research

Reviewing a selection of evidence relating to transmission of COVID-19 in the construction sector reveals several unanswered questions and issues. As yet, it is difficult to identify how significant the workplace is in reducing transmission and how successful measures are across the many different elements of construction activities. For example, there is to date limited insight into any differences in risk and risk management across construction activities (such as: indoor and outdoor work; across companies of different sizes and contracting levels; between employed and self-employed workers). Relatedly, the review illustrates quite different perspectives from those involved in the sector, with both benefits and concerns raised in the evidence we reviewed. This evidence has been used to design research in the COVID-19 National Programme, particularly in undertaking ‘deep dive’ qualitative studies with key partners in the construction sector to improve understanding of the issues of transmission and mitigation of risks across the construction sector. Whilst this ’deep dive’ provides important insight there is much still to understand with further research needed, for example in the diverse activities and actors working within the construction sector.

Author and title	Date	Focus	Evidence types
Agius, R.M., Robertson, J.F., Kendrick, D., Sewell, H.F., Stewart, M. and McKee, M., 2020. COVID-19 in the workplace. https://www.bmj.com/content/370/bmj.m3577	Sep 21 2020	Under reporting of C19 in the workplace/ difficulty monitoring work place transmission	Opinion using review of UK reported cases in workplace
Dennerlein, J.T., Burke, L., Sabbath, E.L., Williams, J.A., Peters, S.E., Wallace, L., Karapanos, M. and Sorensen, G., 2020. An integrative total worker health framework for keeping workers safe and healthy during the COVID-19 pandemic. Human factors, 62(5), pp.689-696.	June 2020	Recommending an integrated Total Worker Health (TWH) approach which embraces core human factors and ergonomic principles, supporting worker safety, health, and well-being	Review of emerging workplace recommendations
ECDC. COVID-19 clusters and outbreaks in occupational settings in the EU/EEA and the UK 2020 https://www.ecdc.europa.eu/en/publications-data/COVID-19 - clusters-and-outbreaks-occupational-settings-eueea-and-uk.	Aug 11 2020	Describing C19 clusters/outbreaks linked to occupational settings in EU/UK	Review of national data sets
HIQA https://www.hiqa.ie/sites/default/files/2020-11/Evidence-summary-activities-and-settings-at-higher-risk.pdf	Nov 18 2020	Lists transmission factors from 19 studies	Evidence summary

HM Government Guidance COVID-19 secure guidance for employers, employees and the self-employed5 November 2020Working safely during COVID-19 in construction and other outdoor work	Nov 5 2020	Guidance for employers, employees and the self-employed in the UK understand how to work safely during this pandemic	Government guidance (UK)
Hollingsworth, J., 2020. Construction safety practices for COVID-19. Professional Safety, 65(6), pp.32-34.	June 2020	Construction safety practices	Des Plaines: American Society of Safety Engineers article
i-news https://inews.co.uk/news/construction-workers-at-risk-unsafe-practise-COVID-19-transmission-spike-768176	Nov 22 2020	Construction as unexpected risk	Journalist report of interview with UK government adviser
Institution of Civil Engineers (2020). COVID-19: an engineering approach to protecting workers during the pandemic. https://www.ice.org.uk/knowledge-and-resources/best-practice/COVID-19-an-engineering-approach	July 2020	Guidance on worker protection during the pandemic	Institution of Civil Engineers Guidance
Jones, Chow, Gibb COVID-19 and construction: early lessons for a new normal? Loughborough University https://www.balfourbeatty.com/media/318555/COVID19-and-construction-early-lessons-for-a-new-normal.pdf	24 Aug 2020	Rapid and effective response on six sites	Qualitative interviews; no peer review
Leclerc, Q.J., Fuller, N.M., Knight, L.E., Funk, S., Knight, G.M. and CMMID COVID-19 Working Group, 2020. What settings	June 5 2020	Informing C19 measures exit strategies by exploring the types of indoor and outdoor settings where transmission of	Systematic review of journals and media reports

have been linked to SARS-CoV-2 transmission clusters?. Wellcome open research, 5.		SARS-CoV-2 has been reported to occur and result in clusters of cases.	
Office for National Statistics Coronavirus (COVID-19) related deaths by occupation, England and wales: deaths registered between 9 March and 28 December 2020 https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/causesofdeath/bulletins/coronavirusCOVID19relateddeathsbyoccupationenglandandwales/deathsregisteredbetween9marchand28december2020	December 2020	Provisional analysis of deaths involving the coronavirus (COVID-19), by different occupational groups, among men and women aged 20 to 64 years in England and Wales	Summary of deaths by occupations
Pasco, D., Du, Z., Wang, X., Petty, M., Fox, S.J. and Meyers, L.A., COVID-19 in Austin, Texas: Epidemiological Assessment of Construction Work. University of Texas at Austin.	Apr 2020	Modelling to project impact of construction workers returning to work using modified US COVID-19 Pandemic Model	Modelling
Ramazzini C. 24th COLLEGIUM RAMAZZINI STATEMENT - PREVENTION OF WORK-RELATED INFECTION IN THE COVID-19 PANDEMIC. Eur J Oncol Environ Health [Internet]. 2020May22 [cited 2021Jan.25];:No.1. Available from:	May 22 2020	Urgent calls for preventative measures particularly in the workplace	International society of physicians and scientists

https://mattioli1885journals.com/index.php/EJOEH/article/view/9890			
Raoufi, M. and Fayek, A.R., 2020. Identifying Actions to Control and Mitigate the Effects of the COVID-19 Pandemic on Construction Organizations: Preliminary Findings. Public Works Management & Policy, pp. 47-55	Oct 2020	Identifying Actions to Control and Mitigate the Effects of the COVID-19 Pandemic on Construction Organizations: Preliminary Findings	Review of actions, policies and evidence. Survey of 43 construction organisations representatives (Canada, USA, North America)
Sim, M.R., 2020. The COVID-19 pandemic: major risks to healthcare and other workers on the front line. https://oem.bmj.com/content/oemed/77/5/281.full.pdf	May 2020	Urging more research on workplace transmission beyond healthcare workers	Opinion
Stiles, S, Golightly, D, Ryan, B. Impact of COVID-19 on health and safety in the construction sector. Hum Factors Man. 2021; 1– 13. https://doi.org/10.1002/hfm.20882	Dec 2020	Issue of implementing safety measures across complex organisation structures	Opinion
The Lancet COVID-19 transmission - up in the air https://www.thelancet.com/journals/lanres/article/PIIS2213-2600(20)30514-2/fulltext	Oct 29 2020	Calls for guidance to be updated to manage airborne transmission indoors	Editorial
Unite the Union https://unitetheunion.org/news-events/news/2020/november/stricter-rules-urgently-needed-to-combat-construction-COVID-transmissions-warns-unite/	Nov 22 2020	Construction Union raising concerns about COVID transmission	Commentary on UK Gov. advice

Wales online The 'worst' job sectors for COVID-19 transmission, according to a Government scientific adviserhttps://www.walesonline.co.uk/news/uk-news/worst-job-sectors-COVID-19-19325254	Nov 22 2020	Highlights construction as high-risk sector for transmission	Journalist report of interview with UK government adviser

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Appendix 12: Pre-interview survey summary

Eight stakeholder responses from four large construction companies			
Collected evidence on transmission of COVID-19 in the workplace	*All organisations collected:* ▪ Positive COVID-19 tests ▪ COVID-19 sickness absence *3/4 organisations collected:* ▪ Data on job role/ demographics/ vulnerable groups	*Additional data in individual organisations:* • Temperature data • Close contact information • Site risk assessments • Productivity/ programme impact • Labour levels	*Data management systems:* • Existing incident databases/ workforce management platforms • Track sheets • HR database • New reporting system (COVID-19 portal)
Transmission risk data management	*All organisations analysed data to inform transmission management* Data used to manage transmission risk to (e.g.): • track cases onsite • manage and localise outbreaks • look for transmission trends and pathways (e.g., cohorts of staff, locations) • review SOP inspection data and effectiveness of control measures • track impact of C19 on productivity and programme - for processing contractual claims • inform C19 controls and forward plan (e.g. car	*All organisations were aware of requirements for subcontracting companies in order to reduce transmission risk on site.* *Organisations reported having evidence from:* ▪ Tests (4/4 organisations) ▪ Number of vaccinated people (0/ 4 organisations) ▪ How vulnerable groups are managed (1/4 organisations)	

	parking and canteen/welfare capacity) • compare data business wide and plan labour resources		
Technology use for COVID-19 transmission management	*3/4 organisations used technology for COVID transmission management, including:* • Air purifiers • Access cards • Thermal imaging • Wearables • Hot desking booking app • Virtual team apps • Tablets	*2/4 organisations used new technology for COVID transmission management, including:* • Thermal imaging cameras • Proximity sensors (trial)	
Employee voice in transmission risk management	*All organisations have set up ways to gather employee feedback, including:* • Employee feedback forums • Near miss reporting schemes • COVID committees • Central portal communication • Daily informal engagement onsite • Tier 1 forums, meetings • Local union meetings • Steering group meetings		
COVID-19 related work practice changes	*All organisations have taken actions to create COVID-19 safe workplace, including:* • Social distancing measures:	*Reported special consideration for vulnerable groups:* ▪ Age (1/4 organisations)	*All organisations measured compliance; ways of measuring compliance included:*

	○ Spacing of work areas ○ Individual seating areas ○ Outdoor briefing areas ○ Single occupancy vehicles where possible ○ App to book hot desks ○ Change in fit-out cycles ○ Introduction of Close Working Permits ○ Change of work gang sizes • Transmission mitigation measures: ○ Use of PPE (i.e., face coverings etc.) ○ Signage ○ Hygiene stations ○ Cleaning regimes (including vehicle cleaning) ○ Screens in dining rooms/offices ○ Thermal imaging ○ Wearables (e.g., proximity sensors) • Other adjustments: ○ Implementing COVID portal to manage staff and planning activities ○ Change in travel policies and local arrangements	▪ Pre-existing health conditions (2/4 organisations) ▪ Ethnicity (1/4 organisations)	• SHE assurance system • SOP site inspections • Daily walk arounds and checks • Safety reviews • Risk management software • Line management inspections of social distancing compliance

	○ Work from home policy if possible ○ Restriction of visitors ○ Roll-out of virtual meeting platforms ○ Increased communication with teams (informal/formal meetings) ○ Timing of work (Changing area timings; staggered start times; sitting times) ○ Shift work adjustments		
Impact of COVID-related work practices on Health & Safety	*3/4 organisations reported impact on traditional health and safety, including:* • Return to pre-COVID small incident levels • Increasing fatigue and isolation • Fewer SC visits • Use of PPE • Access and egress management • Site monitoring • Access to OH • First Aid responses • Close monitoring of near misses and sickness		

COVID-related messaging	*All organisations reported messaging being important in changing work practices, including:* • Providing context and information specific to work scenarios • Reinforcement through behavioural management • Simple, consistent messaging • Continuous reminders via COVID stewards, safe starts etc. • Daily communication • Sharing experiences within the workforce	*3/4 organisations reported positive employee response to messaging, 1 organisation reported positive and negative employee responses, such as:* • Individual response to social distancing and restrictions • Attitude towards COVID-19 management	

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PROTECT
A COVID-19 National Core Study

TAI Thomas Ashton Institute

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'.

Construction workers across the UK have played a vital role in keeping the country running during the COVID-19 pandemic. This research report describes a scoping study aimed at improving understanding of the construction sector's efforts to build a 'COVID-secure' workplace. The study was carried out by researchers from the Thomas Ashton Institute and was completed in July 2021. The researchers carried out: a rapid review of previous studies investigating transmission; a survey and interviews with four principal contractor organisations; and interviews with representatives from the Health and Safety Executive (HSE)'s Construction Division and the Unite Union. The researchers identify six key themes in the industry's response to reducing COVID-19 transmission: contractual partnerships; organisational culture; communication; multi-level challenges; context of the sector; and best safety practice and technology use. The report includes two case studies of construction sites with some of the measures used to reduce COVID-19 transmission.

Published by the PROTECT COVID-19 National Core Study 09/2021