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Lessons from implementation of Key Technological Developments to improve occupational safety and health processes in a complex UK-based construction project

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Lessons from implementation of Key Technological Developments to improve occupational safety and health processes in a complex UK-based construction project

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Abstract. The use of new Key Technological Developments to transform the way Occupational Safety and Health is managed is now becoming a viable option for contractors to consider. These developments can be used to modify the traditional approaches to Occupational Safety and Health to minimize the risks and costs associated with accidents at work and occupational diseases. The research reported in this paper aims to examine the benefits, barriers and challenges associated with the introduction of new digital information technologies in Occupational Safety and Health settings. A longitudinal case study of a complex construction project based in the United Kingdom is reported, which will be used to identify practical solutions and guidelines that can assist organisations in the adoption of these technologies. The lessons learned, both positive and negative, from this project are shared to provide valuable insights to the wider construction industry. The main focus is in the following areas: training; risks identification; site planning. The results of the study can be used to optimise how Health and Safety risks are managed in non-United Kingdom construction projects. The main benefits from this is the resulting productivity gains which can improve project outcomes significantly.

1. Introduction

This paper reports pilot research on the use of new technological developments to transform the way Occupational Safety and Health (OSH) is managed, namely the benefits, barriers and challenges associated. Due to a myriad of terminologies presented for new technological developments through the reviewed literature they will be referred to as Key Technological Developments (KTD). These will include: Building Information Modelling (BIM), Virtual Reality (VR), Augmented Reality (AR), Internet of things (IoT), Wearables, Robotics, Big Data, Artificial Intelligence (AI). The selection of these technologies is based on the Council Directive 92/57/EEC on the implementation of minimum safety and health requirements at temporary construction sites [1] and was carried out in an earlier phase of our research on this topic [2].

The following components apply globally to the Architecture, Engineering, Construction and Operations (AECO) sector and have been selected as the basis of this analysis, from a review of relevant literature:

1) High accident rates - Accidents are persistent, despite several improvements in construction processes. Factors influencing this, include the increasing complexity of site operations and increasing fragmentation in the supply chain and subcontractors. Safety statistics for construction indicate high fatality, injury and illness rates all over the world [3], both in the construction phase and in the maintenance phase, with a considerable financial and logistical impact on companies, and with short, medium and long-term repercussions.

2) OSH approach - Prevention is not always a priority, increasing the risk of accidents at work and occupational diseases. As safety should always be of prime importance, regardless of deadlines and economic interests, a change of mind-set is needed [4]. The correct management of OSH is a critical factor to the success of any construction project and has been widely recognized as one of the most influential aspects in companies' overall performance [5]. OSH needs to be managed throughout the life cycle of the asset, for three main reasons: a) for legal requirements, b) to comply with the hierarchy of controls, c) reducing the number of accidents at work and occupational diseases at work.

3) New technology adoption - The AECO Industry is experiencing changes influenced by the need to improve the methods employed in undertaking ever more complex projects with increasingly strict budgets, faster pace of construction and higher quality. KTD tools have become increasingly important in providing better integration for the development of Architectural, Structural and Mechanical, Electrical and Plumbing (MEP) Project designs, given their proven advantages to respond to a growing need for optimizing processes, procedures and decision-making throughout the entire construction lifecycle [2]. However, when it comes to OSH, KTD are not yet used as often as is the case in other specialties [6].

4) Legal requirements - The hierarchy of controls indicated in ISO 45001:2018 [7] give rise to the urgent need to take into account the latest KTD. This will facilitate timely, easy-to-interpret, and sufficiently efficient management measures and expedite the way to integrate OSH priorities into other design considerations.

The intention of this paper is to analyze the benefits, barriers and challenges associated with implementation of KTD for OSH purposes in real practical cases and retrieve lessons learned from them. Taking in account the technical-scientific gaps identified in the literature review, Research Question (RQ) was established:

- What practical lessons and good practices are there to be shared from Tideway intervention with wider industry and those involved in fields of development and improvement?

Creating a lesson learned register along with identifying their advantages, challenges and barriers will provide a most up-to-date knowledge about the theme which will provide a good instrument for industry and academy evolution.

Answers for this RQ are covered in section 4. The following section outlines the study context and current technical-scientific gaps. It provides an overview of the current status of KTD implementation in OSH management in construction, whilst Section 3 presents the approach to the research methods and methodologies and Section 4 provides the results, demonstrating the concept's feasibility and effectiveness. Section 5 covers the conclusions, explores limitations, and it explains what future studies should focus on.

2. KTD for OSH

AECO sector has witnessed several challenges in last years: low productivity, shortage of qualified staff, insufficient innovation, lack of consistent processes, standardization and automation, need to produce a high and heavy amount of technical documentation, and also the aversion to adopting new technologies [2]. Literature already published indicates that the construction industry, especially larger general contractors and in complex projects, are having a broad increase in the understanding and application of KTD in real cases of design, construction, and facilities management and are starting to adopt KTD for use in OSH management [8] in order to overcome the cited challenges. Applying KTD to OSH management proves very promising and to have the potential to offer innovative and exciting developments in the workplaces, and has some positive impacts on optimization of times and costs (two very important aspects for the financial management of companies), with an increased production efficiency, and a better connection between production and safety [2]. KTD implementation has also some barriers to overcome such as the fact it's use is optional, the lack of training, the cost and so many other social, legal, financial, behavioral factors that need to be investigated. It must be stressed that each project is unique and not all examples of KTD uses for OSH will be universally applicable.

The implementation of OSH management through KTD proves to be a task that implies the efforts of all stakeholders, especially in scenarios characterized by a multidisciplinary nature of the work teams and of multi-organizational scope. There is, therefore, a clear need for researchers to focus more on technology transfer from research into practice to support the entire process of construction site OSH management [2].

Several researchers in the field have identified technical-scientifical gaps in terms of research covering the integration of KTD in OSH management systems and have advocated the need for new studies covering:

- the benefits of using digital technologies to improve OSH outcomes [9];
- the theorical validity of the advantages that have been identified using suitable case studies [10];
- the lack of success in technology transition from construction safety research into practice [11];
- the gap between the theory and realized benefits at the application stage by industry [12];

In a previous phase of the research [2]the authors evaluated the level of applicability of KTD for each OSH area identified from an analysis of the Council Directive 92/57/EEC [1]. Three levels of applicability for each KDT were established: L (Low), M (Medium) and H (High) as presented in Table 1.

Table 1. Level of applicability of KTD vs each area/group [2]

Fields	BIM	VR	AR	IoT	Teleoperation / swarm	AI/BD	Cybersecurity
Contractual / documental management	H	L	L	L	L	M	H
Hazard and risk identification	H	H	H	H	M	H	M
Training	H	H	H	M	M	L	L
Onsite planning and monitoring	H	M	M	M	M	M	H
Emergency planning	H	H	H	L	L	M	M
Accidents investigation	H	M	M	L	L	M	M

In terms of the European Union Council Directive 92/57/EEC on the implementation of minimum safety and health requirements at temporary construction sites which establishes the areas and requirements to be followed. The authors decided to focus this research on the hazard and risk identification, training, and onsite monitoring areas where a number of advantages have been identified from the adoption of KTD for OSH management. These include the following:

2.1. Hazard and risk identification

Simulation of actual working conditions [3]; improved the capacity of stakeholders to identify, anticipate and minimize risks before the onset of problems on the construction site, and enables immediate problem solving [13] (it should be noted that virtual or augmented environments assist in the identification of hazards); robotics and sensors that can detect risks e.g. in human non-accessible zones; the identification of preventive measures can be carried out in a more automated way [14]; visualization provided by simulations can be used to provide predictive and prescriptive analysis [15]; Artificial Intelligence/Big Data (AI/BD) can be used to improve problem solving (namely organizing and interpreting OSH data which is often too large to analyze and interpret) or predicting occupational hazards, using the data obtained from automatic identification and storage of previous records of unsafe behavior as a source [2].

2.2. Training

Using virtual or augmented environments reduces the time it takes for a learner to become competent in their field of work and can produce memorable and lasting experiences for trainees [16], in particular those involving gamification, with outputs easily used for training purposes [14]; it allows users to easily and repeatedly experience different and unlimited scenarios that were previously impossible, dangerous, hard, or expensive to experience (from this they can more rapidly convey information to those who tend to be less able to interpret drawings minimizing the typical gaps in communication [17]).

2.3. Construction site task planning and monitoring

Virtual or augmented environments help to carry out the planning of site construction and tasks (namely by walk-through views) [18]; this facilitates the task of inspecting sites and workplaces [13]; through Internet of Things (IoT) systems (e.g. wearables in clothes or body or sensors) an improved ability to, in real time , identify, track or monitor environments (noise, air quality, dust), people (location, vital signs or posture so that the earliest signs of health or safety issues, such as safety perimeter violation, arising can be detected and corrected), objects (progress, condition of equipment on site, structural conditions of scaffolds) and tasks can be covered in a quick and understandable manner [15] Alternatively Unmanned Aerial or Ground Vehicles equipped with cameras or sensors can be used (note that these unmanned vehicles can move, in a safer way, faster than humans into risky or hard-to-reach areas of jobsites); AI/BD can provide an interpretation or prediction of future scenarios based in data monitored i.e. worker’s risk behavior-based trajectory prediction models, or automated trajectory and path planning [19] .

3. Research methodology

The research described in this paper is based on a case study approach which is where the researcher investigates in depth an activity or process over a period of time using a variety of data collection processes. The research covers an investigation based how one OSH KTD approach was implemented on the Tideway project by FLO JV to improve risk assessment, training and planning during the construction phases.

Initially, the UK was selected as a suitable location to conduct the research for the following reasons [20]:

- The UK has a large history of mega projects and has several ongoing mega projects placing the country in a unique position of global influence [2]. There has been an effort and growing interest in innovation management in megaprojects in UK [21], but there is much to be explored in this area of research [20]. Nevertheless, innovation on megaprojects remains "surprisingly underexplored in the megaproject management literature" [20]. It has also played an active role in driving forward KD adoption perhaps leading to interest from professionals in other countries to follow the UK's progress [2].

- The UK also uses the concept of lessons learned from projects both positive and negative points [2]. Not learning from projects will allow similar errors to occur and miss opportunities to improve performance.
- A process-based open innovation approaches provides an opportunity to explore innovation and learning legacy as a way of transforming the infrastructure industry over time [20].

The case study organization used for the research is the Thames Tideway Tunnel Project (Tideway). It was selected for the following reasons : a) the authors have carried out previous research into the use of OSH on the project which allows them to have a uniquely rich understanding of the topic; b) this is the biggest infrastructure project (4.2 billion pounds) ever undertaken by UK water industry and one of largest in Europe; c) there are some excellent examples of management of the issues being analysed and Tideway management have put an emphasis on lessons learned from previous projects; d) the project has a key objective to pursue innovative technology as a way of improving cost-effectiveness, productivity and quality of work delivered.

The Tideway project is being undertaken to renew the Victorian sewerage systems designed by Sir Joseph Bazalgette. Even though the sewer structure is still in good condition, despite its age, it has a shortcoming – due to the increase of people, it spills millions of tonnes of sewage into the tidal section of the river Thames every year, polluting the river. Tideway intends to help to solve this problem providing a new super sewer infrastructure for London that will reduce the current high number of discharges of effluent into the river. This will, dramatically improve the water quality of the river and give the city a wastewater system that it can rely on for the next 100 years. The scheme is designed to intercept existing Combined Sewer Outfalls (CSO's) located along or adjacent to the river with the construction of new interception chambers and shaft structures built into the foreshore sites of the existing river wall CSO's. The CSO's were designed at peak rainfall to mix rainwater and sewerage outflows to deal with the increased volumes which would otherwise overwhelm the sewerage system. The new interception chambers formed will include connection to these outfalls and the integration of a new sewer using gravity to transfer waste effluent eastwards towards the treatment works at Abbey Mills. The main transfer tunnel is 25km long and 7.2m internal diameter located predominantly beneath the central section of the Thames and will connect to 34 of the most polluting CSOs. The shafts are mainly located within river foreshore locations and are connected at high level to sprayed concrete lining connection culverts from the CSO structures and at low level are directed to the main transfer tunnel. It is being built under London's existing underground infrastructure, deep beneath the London Underground tube lines and utilities, and will pass through a variety of ground conditions. It has commenced construction in 2017 with completion scheduled for 2023. The Tideway project has been let as three distinct contracts for three Main Work Contractors comprising Central, East and West. Ferrovial Agroman UK and Laing O' Rourke Construction (FLO JV) will be undertaking the central section of the Tideway scheme as Principal Contractor and Designer. This section measures 12.7 kilometers in length, it is the largest of the tunnel's three sections and it is worth 746 million pounds, equivalent to 1,050 million euros. The Central Section of the Thames Tideway Tunnel project has 24 construction sites and is illustrated in Figure 1.

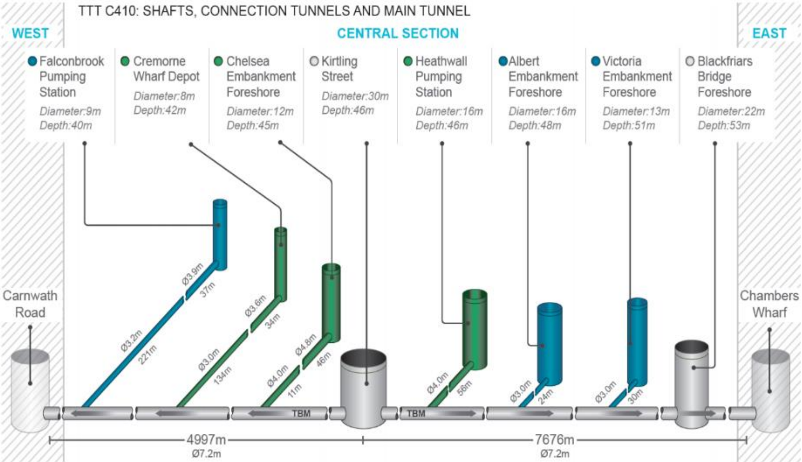

Figure 1 – Tideway Central Section Map

The central section has nine construction sites which have a total of 26 shafts with depths varying between 10 and 70 meters.

Occupational risks related to these works include:

- Structural hazards (ground settlements from temporary or definitive structures fragilities or collapse); lifting operations; confined space ; working at height; flooding; migration of toxic/ explosive ground gases into the tunnel; dealing with services: water, electricity, gas; contact with unexploded ordinance; derailment, roll over and crush of vehicles; fall of blocks and sprayed concrete fragments; trench collapse; risks related to lifting or moving operations (e.g. Tunnel Boring Machine (TBM) parts, segments, cofferdams); rupture of pipes or temporary structures; fall of person on the same level/to a lower level; fire and explosion onshore or offshore; electrocution; overturning of vessels; hypothermia, drowning; musculoskeletal problems; rock mass and sprayed concrete dust inhalation; fumes, diesel gas or fire smoke inhalation; biological risks: leptospirosis and water borne diseases, biological pathogens, live sewers, contaminated land; asbestos; chemical risks: shotcrete, concrete, sprays, petrol, cement, gases from live sewers, gases from soils; terrorist attacks due to site location near and adjacent to government buildings; noise; vibration;; hyperbaric interventions; extreme temperatures; Radiations; psychosocial risks e.g. stress and fatigue.

Tideway, as the Project Owner, has an aspiration to deliver a transformational approach to OSH which enables the sharing of best practice to deliver OSH performance better than any else currently experienced in construction [22]. It intends to achieve this through better: leadership; organizational processes and procedures; communications; collaboration; and engagement. These factors have been the key to the successful delivery of the activities carried out in the project in a safe and healthy manner. The improved processes are embedded in everything the project does, from Project Manager's to the workers, subcontractors, and suppliers. What makes Tideway Central different from other construction projects is the solid focus on people, and on what is done well on site. FLO, as a contractor, is taking steps in order that to workers leave the project with a good understanding of OSH management and how transformational approaches can be adopted.

In next section, it will be described the FLO approach to OSH using Virtual Reality to improve the three areas of focus for this study as described in section 2 e.g. the risk assessment, training and planning areas.

4. Results and discussion

FLO decided to create a Virtual Reality (VR) model that could be used as part of task planning meetings with the workforce. A key objective was to improve the logistical understanding of the works normally covered during inductions. The VR model was created using a visual support tool using Reality Capture Platform (RCP) software supplied by Unity. This software allows the user to visualize 360-degree images of the construction site similar to street view on Google Maps. The process to create a RCP inductions was initiated with a working group from the site teams, digital team and the OSH team to create an accurate 3D model. The 3D model was then reviewed by the site team to ensure all high-risk areas were captured within the model and the key areas highlighted that need to be reached within the final virtual model. The 3D virtual model was then created using the virtual model using the Unity software. The model is viewed using a virtual reality headset (Figure 2). This is followed by a discussion of the content of the induction and key areas and routes of the site that they would like to follow in the eventual 360-degree image tour. Digital team then takes the 360-degree camera and follow the agreed upon route and takes the 360-degree photographs at the before specified locations.

Figure 2 – VR usage

Each 360-degree image takes roughly 2 seconds to capture using the camera which means that on average, each site would take 30 min to capture. Once all the 360 images had been captured, they were uploaded onto the RCP software along with the induction content, which would be supplied by OSH team. This process took from 30min – 60min. After this process, it was obtained a completed induction including a 360-degree image tour of the site, ready to be used in future inductions. The camera itself is relatively cheap at £300 and the software was developed at cost of less than £1,000.

The Albert shaft construction sequence was a perfect opportunity to investigate the advantages of using this approach.

The construction sequence was complex in terms of the many activities that were occurring in the shaft concurrently and also highlighting to the users the risk of these concurrent works happening at different levels within the shaft. These activities included concrete pour of internal walls and vortex generator while simultaneously pouring 3m secondary lining sections of the shaft using jump form several meters above. Originally, this would have been shown using 3D models and section views in order to try and demonstrate the scale of works and spatial constraints. A 3D virtual model of the Albert Embankment shaft construction sequence was created which included all the permanent and temporary works. It was compiled in a format that allowed users with a VR headset to visualize task specific information i.e. constraints and then enabled risks to be highlighted and solutions or improvements to be identified based on their experiences using the VR headset.

Resulting from this experience, it was observed that the use of VR brought the following advantages:
- gives better visualization, greater accuracy, understanding and information retention of construction site, tasks (and its feasibility) and risks namely in congested areas and with space constraints;
- reduces the time spent looking at drawings to ascertain whether there is space for a certain activity as the VR model gives users an instant appreciation of the actual space available;

- provides the operatives a collective insight of the construction sequence and a chance to familiarize themselves with the future surroundings and allow them an opportunity to plan how the task will be carried out avoiding mistakes and the possibility of rework;
- prepares the site teams and operatives for what they might expect on site throughout the construction sequence which in turn highlights spatial constraints that might not have been seen or appreciated in the 3D model or 2D sections;
- improves how construction is sequenced;
- provides the ability to rotate and move around the site using the 360-degree imaging from the comfort of a meeting room, allows the inductor to highlight high risk areas, dangerous equipment, pedestrian walkways, fire points, first aid points, emergency exits, areas of work and more, exactly how they would see it on site, without having to go on site;
- improves the health and safety planning of the works creating a reduction in risks;
- generates time and cost savings in the form of reduced abortive work and/or wasted time and an increase in production and smart plant selection.

Since the introduction of this new technology has been used for other functions than just improving the induction e.g., by reducing the need for site visits when there are a lot of works going on and a site visit with several stakeholders could have been a risk.

The implementation of this VR based approach to risk assessment, training and planning was recognized by Tideway when it was awarded a ‘Right Way’ Occupational Health and Safety award in the ‘Delivery Performance and Improvement’ category for facilitating constructive communication between teams even during lockdown.

5. Conclusions and further research

It has been shown in the literature that there is need in understanding how to improve OSH management through the implementation of KTD based tools. Improving OSH Management OSH activities such as risk assessment, training and planning, through the use of KTD is shown to be desirable with positive impacts on the optimization of task planning, times and costs. This will lead to increased production efficiency and a better connection between production and safety.

Implementing KTD for OSH requires a solid collaborative culture between people with the right skills and training. The transition of OSH management into a KTD based approach is a task that requires the efforts of all stakeholders especially in scenarios characterized by a multidisciplinary nature of the work teams and a multi-organizational scope.

The learning from this work contributes not only to improving practice but also to the study of related theory and will provide a legacy for the wider industry helping to raise standards for future similar projects. It also has the potential to influence the policy makers in the AECO sector globally e.g. regulatory bodies, standards institutions, etc.

This will enable the AECO industry to act in a more targeted way to improve risk management through the use of the new Information and Communication Technologies. This will enable an active and efficient sharing of information among all participants of the project. As a result, there will be quicker and better prevention planning resulting in more efficient OSH processes and increased productivity which will provide a stronger link between production and safety. Future studies should focus on continue exploring KTD for OSH implementation in real practical cases which could include the development of a technical scientific instrument using an ‘observatory’ approach. The latter could provide a convenient means for sharing lessons learned and the national and European trends covering the levels of use of KTD for OSH purposes.

REFERENCES

1. European Comission 1992 *Council Directive 92/57/EEC of 24 June on the implementation of minimum safety and health requirements at temporary or mobile construction sites*
2. Tender M, et al. 2021 *Emerging technologies for health, safety and well-being in construction industry*, in *Industry 4.0 for the built environment - methodologies, technologies and skills*, B.e. al, Editor. Springer Nature: Switzerland. p. 369-90.
3. Azhar S and Behringer A 2013 *A BIM-based approach for communicating and implementing a construction site safety plan*. in *49th ASC Annual International Conference Proceedings*. Califórnia, EUA: Associated Schools of Construction,.
4. Tender M, Couto J, and Ferreira T 2015 *Prevention in underground construction with Sequential Excavation Method*, in *Occupation Safety and Hygiene III*, Arezes et al, Editor. Taylor & Francis: London, United Kingdom. p. 421-24.
5. Tender M and Couto J 2014 *Factors affecting the safety in Portuguese architectural heritage works*, in *Occupational Safety and Hygiene II*, Arezes et al, Editor. Taylor&Francis: London, United Kingdom.
6. Tender M, et al. 2018 *O BIM como instrumento de prevenção em fase de projeto e de obras de reabilitação*. in *2º Congresso Português de Building Information Modelling*. Lisboa, Portugal: Instituto Superior Técnico.
7. International Organization for Standardization 2018 *ISO 45001:2018 - Occupational health and safety management systems*. International Organization for Standardization,: Geneve, Switzerland.
8. Nnaji C and Karakhan A 2020 Technologies for safety and health management in construction: Current use, implementation benefits and limitations, and adoption barriers. *Journal of Building Engineering*.
9. Tender M, Couto J, and Fuller P 2022 *Improving occupational health and safety data integration using Building Information Modelling - an initial literature review*, in *Occupational and Environmental Safety and Health III*, A.e. al, Editor. Springer Nature: Switzerland. p.
75-84.
10. Tender M, Couto J, and Fuller P 2022 *Integrating occupational health and safety data digitally using Building Information Modelling - uses of BIM for OHS management*, in *Occupational and Environmental Safety and Health III*, A.e. al, Editor. , Springer Nature: Switzerland.
p. 85-96.
11. Mordue S and Finch R 2021 *BIM for construction health and safety*. 2019: Routledge.
12. Pidgeon A and Dawood N 2021 BIM adoption issues in infrastructure construction projects: analysis and solutions *Journal of Information Technology in Construction*. **26**: p. 263-85.
13. New York County Buildings, *Building Information Modeling Site Safety Submission Guidelines and Standards*. 2013, New York: New York City Department of Buildings.
14. Martínez-Aires M, López-Alonso M, and Martínez-Rojas M 2018 Building information modeling and safety management: A systematic review. *Safety Science*, 2018. **101**: p. 11-18.
15. Delgado J, et al. 2020 A research agenda for augmented and virtual reality in architecture, engineering and construction. *Advanced Engineering Informatics*, 2020. **45**: p. August 2020.
16. Kassem M, Benomran L and Teizer J 2017 Virtual environments for safety learning in construction and engineering: seeking evidence and identifying gaps for future research. *Visualization in Engineering*. **5**(1).
17. Tender M, et al. 2018 *BIM as a 3D, 4D and 5D management tool in a construction site*. in *2nd Portuguese BIM Congress*. Lisbon, Portugal: Technical Superior University.

18. Tender M, Couto J P, and Fernandes J, *Using BIM for risk management on a construction site.*, in *Occupational Safety and Hygiene V*, Arezes et al, Editor. 2017, CRC Press/Balkema: Londres, Inglaterra. p. 269-72.
19. Soltanmohammadlou N, et al. 2019 Real-time locating systems and safety in construction sites: A literature review. *Safety Science*, 2019. **117**: p. 229-42.
20. Sergeeva N and Zanello C 2018 Championing and promoting innovation in UK megaprojects. *International Journal of Project Management*, 2018. **36**(8): p. 1068-81.
21. Dodgson M, et al. 2015 Innovation strategy in new transportation systems: The case of Crossrail. *Transportation Research*, 2015. **77**: p. 261-75.
22. Fuller P, et al. 2017 Is the longbow better than the crossbow? Emerging issues from mobilising a longitudinal study on a megaproject. *Journal of Construction Project Management and Innovation*, 2017. **7**(2): p. 2054-65.