Real world lessons that can assist construction organisations in implementing BIM to improve the OSH processes

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Abstract

Changing the way OSH management is performed with BIM is relevant. Several authors propose that real world cases need to be studied as there are few examples of studies covering BIM implementation for OSH. The UK PAS1192:6 introductory standard indicated some of the requisites and approaches to implementing BIM for OSH. Lessons from projects that have already implemented PAS 1192:6 will provide valuable inputs. This paper explores the stakeholders' perceptions about benefits and barriers of adoption of BIM for OSH purposes using examples from a complex large project (Thames Tideway Tunnel). The methodology adopted was a survey of 39 project participants. The study focused on the following areas: collaboration, risk assessment, training and awareness, inspection of workplaces, work accidents, budget control, error detection, liaison between logistics and productivity. The implementation of the new BIM based approach to construction OSH management in this project

shows that there is a very positive vision, namely in areas of risk assessment and training, in terms of the improvement of OSH management as well as of optimization of times and costs, better liaison between OSH and production, with increased production efficiency. This can potentially lead to a paradigm shift in OSH management in large projects.

1. Introduction

1.1. Background and justification

Research into BIM for OSH is justified by key technical and scientific factors and gaps, witnessed by the authors in their day-to-day professional activities, and which are shown below:

1) **Underground works –** although underground works have been carried out for several thousands of years, the scope and scale has increased exponentially in recent years. They have been critical to development of the central infrastructure of cities and urbanized areas [1]. There is an undeniable link between population growth and the development of underground infrastructures. Underground infrastructure can improve mobility, quality of life and ultimately social sustainability of the city's inhabitants; concomitantly, as a city's population grows it presents an opportunity to install infrastructure systems which are more economically feasible and environmentally sustainable [2].

2) **High accident rates on construction sites –** These continue to persist despite several evolutions in the improvement of construction processes. Factors contributing to high accident rates 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 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.

3) **Risks in tunnelling –** Tunnelling risks are as extensive as those involving works above the surface, or even more [3]. Tunnelling works are prone to several types of emergency situations, particularly collapse, electrification/electrocution, being hit by a vehicle, roadway accidents, intoxication and lack of oxygen.

4) **Lack of BIM adoption in OSH settings**: Architecture, Engineering, Construction and Operation (AECO) Industry is experiencing changes influenced by the need for improving methods to complete ever more complex projects with increasingly strict budgets, faster pace of construction and higher quality. However, although there has been a broad increase in the area of OSH, BIM does not yet have the prominence it has in other disciplines. Additionally, there are no published cases of a practical application of BIM in OSH at a real-life, complex construction project (note that NBS Digital Construction Report 2021 focus, in a global approach, that "there isn't clarity

among all professionals in terms of what they need to do in order to play their part in creating the golden thread of information" [4]).

5) **Past research points to the need to explore practical cases** – tests should address and clarify the various perspectives that are still existing internationally, namely in PAS1192:6 [5]; further research is needed to explore the advantages of using BIM for OSH using suitable case studies [6]; there should be a focus on detecting barriers, in order to try and find solutions for them [7]; there is incomplete technology transition from construction safety research into practice [8]; and there is a gap between the theory and realized benefits at the application stage by industry [9].

1.2. Gaps and objectives

According to the technical gaps which show that there is a need for further studies, based on real cases, that will demonstrate the most adequate way to integrate OSH technical information with modelling software. The main objective of this study is to understand experts perceptions regarding the integration of OSH management with BIM in a large and complex project which takes into account the requirements of PAS1192:6 [10]. Providing construction stakeholders with information to improve OSH management along with identifying key benefits and barriers that will improve knowledge. This in turn will lead to increased adoption of BIM solutions, especially amongst smaller contractors who are typically more likely to be resistant to change [4]. In this way, safety performance throughout the industry should be improved.

The following section outlines a literature review of the theme, whilst Section 3 presents the approach and methodology to the research and Section 4 provides the results, demonstrating the feasibility and effectiveness of the concept. Section 5 covers the conclusions, explores limitations, and explains future trends.

2. Literature review

The attempt to improve OSH working conditions through BIM tools is an increasingly clear trend worldwide [11]. The advantages emerging in the literature are listed below:

- Improved risk detection in design phase [8];
- Faster notification about the risks that could not be avoided in the design phase as well as the corresponding preventive measures and conditions on the site and surrounding area [12];
- 3D tools are more effective for OSH than 2D static drawings, given they adequately simulate actual working conditions, allowing visual assessment of working conditions [13];
- A better identification of hazards and risks namely identification of zones or time periods where there is a higher level of risk [12] has improved risk management;

- Improves the capacity of identifying, anticipating and minimizing risks and conflicts before the onset of problems on the construction site, as facilitator for better identification of hazards and risks and allowing immediate problem solving [14], saving time and costs;
- Improved visualization and early simulation of working conditions [13] which facilitates the identification, anticipation, and minimization of risks before problems appear on the ground;
- The integration of safety planning and project planning which enables safety managers to recognize when, where, and why safety measures on the safety plans must be used [15];
- It corresponds to faster access and dissemination of information [16], with the ability to easily cross the linguistic barrier, improving training actions and communication between participants, the outputs being easily utilized for training purposes [17];
- It can increase the risk recognition capacity of workers, which makes the real-time communication between safety managers and workers more effective and, by so doing, reduce the probability of accidents [18];
- It enables a detailed analysis of the construction site logistics, which can be used to enhance the flows of materials and equipment, optimizing the space available at the construction site, and improve safety conditions [19];
- It allows a spatial and temporal simulation of construction site and tasks in progress, optimizing planning, improving logistics and productivity, and allowing a more efficient analysis of problems and potentially reducing costs and waste of time [16];
- The upfront simulation of the sequence of tasks leads to the early identification of various scenarios, with their opportunities and problems, allowing for the evaluation of advantages and disadvantages of each scenario [8];
- It helps the planning of tasks, in particular regarding constructability – which is typically not considered enough - as well as the necessary resources for each one, reducing the number of possible errors in the project [14];
- It allows for the comparison between what is planned and what is done, within the scope of OSH e.g., setting up of collective protection;
- It allows for a swift translation of planning changes into safety-related changes [11];
- Facilitates the task of inspecting workplaces [14];
- A reduction in the time spent in quantity take-off and estimation from weeks to minutes [20];
- It allows for an easier correction of costs and budgets whenever a change is made in the project in terms of construction solutions, materials, equipment, and labor, among others [21];
- It is possible, at any time and at any stage of the work, to know what material is needed, as well as to foresee the estimated final cost related to each activity [11].

Based in the literature review, next section will explore how these different uses of BIM where understood by stakeholders in a large and complex project.

3. Methodology

3.1. Presentation of case study

The research is based on the FLO JV on the Thames Tideway Tunnel (Tideway) super sewer project based in London, UK. This project was selected because:

a) This is the biggest infrastructure project (£4.2 billion pounds) ever undertaken by UK water industry and one of largest in Europe;
b) There are some excellent examples of management of the issues covered by the research;
c) The project stakeholders' perspective include researching innovative technologies as a way of improving cost-effectiveness, productivity and quality of work delivered.

Underneath London lies a sewerage network, designed in the Victorian Era 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 tons of sewage into the tidal section of the Thames every year, polluting the river. Tideway addresses this problem by providing a new "super sewer" infrastructure for London which aims to reduce the current number of discharges of effluent into the River Thames. This will dramatically improve the water quality of the River Thames and give the city a wastewater system it can rely on for the next 100 years. The scheme is designed to intercept existing sewer outfalls located along or adjacent to the river with the construction of new interception chambers and shaft structures built into the foreshores on or adjacent to the existing river wall combined sewer overflows. The main transfer tunnel is 25km long and 7.2m internal diameter located predominantly beneath the central section of the River Thames and will connect to 34 of the most polluting combined sewer overflows. Construction commenced 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. A Ferrovial Agroman UK and Laing O' Rourke Construction joint venture (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 and is the largest of the tunnel's three sections with a contract value of 746 million pounds (Eur1,050 million). The Central Section of the Thames Tideway Tunnel project has 24 construction sites and is illustrated in Figure 1.

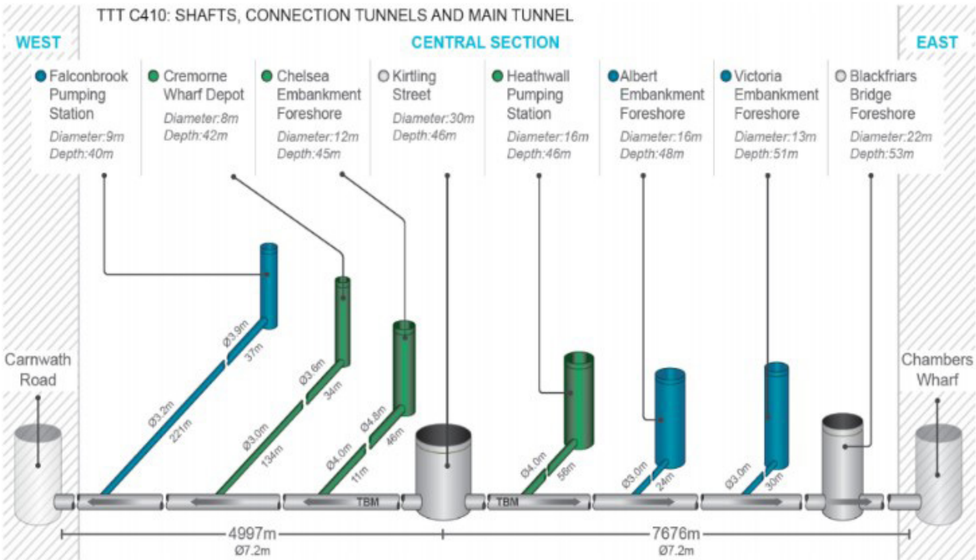

Figure 1
Tideway map.

The central section has eight construction sites which include a total of 26 shafts with depths varying between 10 and 70 meters. Tideway, as Project Owner, has the aspiration to deliver a transformational approach to OSH which enables the sharing of best practice to deliver OSH performance better than anything else that is currently experienced in construction [22]. FLO, as a contractor, is taking steps to ensure that workers leave the project with a good understanding of OSH management and an ability to implement some of the transformational approaches they have experienced on other projects. Both Tideway, as a Project Owner, and FLO, as a Main Contractor, adopted BIM as a management tool.

The focus of the research is based on actual OSH BIM approaches that the FLO JV has used on the Tideway project. The research covers the design and construction phases, and it should be noted that their BIM approach was not only applied to H&S issues. In this research an online survey was chosen as the data collection vehicle as it had the capability of reaching a high number of respondents, provided anonymity, gave respondents the choice of when it was competed (within the target timeframe) and did not expose respondents to influences from the questioner. The questions were crafted after analyzing the gaps identified in the literature review in order to obtain data to assess the impact of using BIM on OSH. The questionnaire was reviewed by two highly experienced technicians to provide internal validity and to provide feedback to improve the questionnaire. A survey with closed-answer questions was developed. It was drafted a multiple-choice survey ranging from “1 - strongly disagree” to “5 - strongly agree”. The survey asked respondents to rate their agreement with the following statements: How would you rate your agreement with the phrase: S1-“BIM aids the anticipation and improvement of risk identification”; S2-“BIM facilitates risk assessment”; S3-“BIM helps to identify, implement and monitor preventive measures”; S4-“BIM provides faster access to information and improves dissemination”; S5-“BIM improves the quality of training activities”; S6-“BIM has the ability to easily cross the linguistic barrier”; S7-“BIM facilitates the task of inspecting workplaces”;

S8-"BIM assists in the investigation of accidents"; S9-"BIM helps to control budgets/costs related to risk prevention"; S10-"BIM improves logistics and productivity"; S11-"BIM helps to save time"; S12-"BIM optimizes collaboration"; S13-"BIM enables better management"; S14-"BIM reduces the number of possible conflicts and errors"; S15-"BIM help to integrate production planning and risk prevention"; S16-"The launch of the PAS 1192:6 standard has affected the way Health, Safety and Well-Being was managed"; S17-"BIM tools available for Health, Safety and Well-Being are sufficient and adequate"; S18-"Adopting BIM has increased coordination of OSH documents"; S19-"BIM has reduced occupational risk levels". The panel of respondents of survey (56) was composed by research team with FLO JV and the selection criteria requiring respondents to have at least 2 years of experience in the field of construction and be currently working in Tideway project. Participation in the survey was voluntary and anonymous. The survey was implemented between April and September 2021. It was obtained 39 full and valid answers of a total of 56. All requirements need were verified in order to confirm the validated answers. 30% are Site tunnel/SCL/interface or civil Engineer, 32% are OSH Manager, Head, Director, Leader, Manager or Technician, 26% are BIM Specialist, Coordinator, Manager or Modeller, 7% are Environmental/ Quality Engineers, 5% are Project Owner Representative or Program Director. This split was there to give a general idea of the split in the roles of the respondents in terms of BIM vs OSH. However, all respondents are OSH related.

4. Results and discussion

The results were analyzed in an aggregate method that did not differentiate the work areas of respondents. The results obtained in the survey are presented, analyzed and discussed below.

Figure 2 illustrates the results obtained in survey.

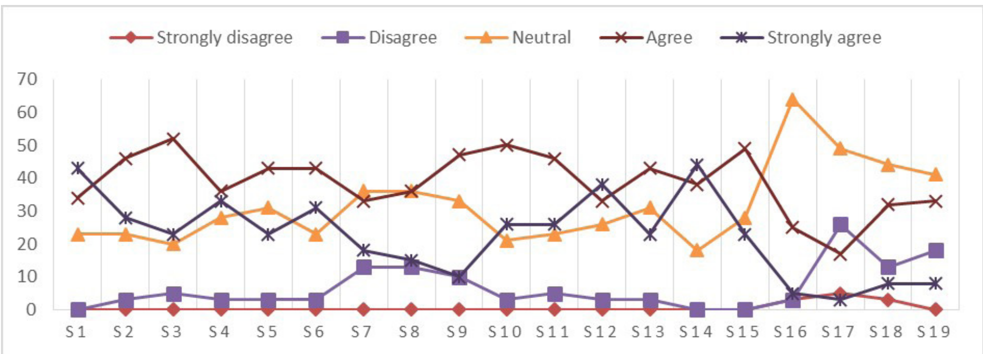

Figure 2
The results obtained in survey (in percentage).

The results are examined by analyzing each answer and discussing the likely reasons for the percentage obtained. In the majority of the questions, most of the respondents agreed with the sentences, confirming that using BIM for OSH purposes is a good option. They, therefore, provide good insights into the validity, feasibility and suitability of the use of BIM for OSH.

S1 – BIM aids the anticipation of risks and therefore improvement in risk identification

Most respondents (77%) agree / strongly agree and 23% are neutral. This result confirms that risk identification is one of the more important features of BIM use in OSH management. The perception of respondents reflects the case that the project was delivered using 3D and 4D models both for permanent works and temporary works (i.e. cofferdams). This enabled the scenario-testing of construction sequences including plant movement and safe working zones. This result can also be a positive sign for the potential of using BIM for OSH in design phase.

S2 – BIM facilitates risk assessment

The majority of respondents (74%) agree/strongly agree and 23% are neutral. From this it may be the case that BIM is seen as a facilitator of the production and dissemination of Construction Phase Risk Assessments and Method Statements. This is enhanced with the use of 4D BIM. This shows that risk management is being carried out differently which supports the use of a BIM based approach.

S3 – BIM helps to identify, implement and monitor preventive measures

Most respondents (75%) agree/strongly agree and 20% are neutral. This result again supports the notion that BIM supports how preventative measures are dealt with.

S4 – BIM provides faster access to information and improves dissemination

Most respondents (69%) strongly/agree or agree and 28% were neutral. This shows that to a slightly lesser extent that BIM enables better access to OSH data and information.

S5 – BIM improves the quality of training activities

A majority of respondents (66%) strongly agree/agree and 31% were neutral. These numbers show that views on BIM's use in facilitating training is not as strong. It should be noted that Tideway is using a new type of induction, EPIC. The fact that EPIC is a novel approach using the latest VR technology rather than a BIM based solution could account for this lower result.

S6 – BIM has the ability to easily cross the language barrier

Most respondents (74%) strongly agree/agree and 23% were neutral. This result shows that BIM is seen as a key enabler in overcoming barriers due to linguistic issues which can arise on UK construction sites due to workers from different nationalities.

S7 – BIM facilitates the task of inspecting workplaces

A relatively smaller majority of respondents (51%) strongly agree/agree and 36% were neutral. This is an indication that the use of BIM for this activity is not very widespread currently.

S8 – BIM assists in the investigation of accidents

Again, a relatively smaller majority 51% of respondents strongly agree/agree, 36% were neutral and 13% disagree. This is an indication that the use of BIM for this activity is also not very widespread currently. This is reflected in the literature that show that his OSH area is not currently being the subject of much research.

S9 – BIM helps to control budgets / costs related to risk prevention

A smaller majority of respondents (57%) strongly agree/agree, 33% were neutral and 10% disagree. This result shows that due to the high proportion of respondents not agreeing there are doubts about the use of BIM to assist OSH budgeting.

S10 – BIM improves logistics and productivity

Most respondents (76%) strongly agree/ agree and 21% were neutral, result that is compatible with 2020 NBS Report which indicates that 71% of respondents see that BIM improves productivity [23]. This is evidence that changes are taking place and that productivity can be enhanced with this.

S11 – BIM helps to save time

A majority of respondents (72%) strongly agree/agree and 23% were neutral which shows that it can be used to improve OSH management responsiveness and productivity.

S12 – BIM optimizes collaboration

Most respondents (71%) strongly agree /agree and 26% were neutral. One of the main reasons for this result was due to many actors were already familiar with the use a Common Data Environment (CDE) in other complex projects (such as Crossrail) to share project information. It also aligns to the 2020 NBS report that indicates that use of CDE's to share project information is becoming increasingly prevalent, and shows how the industry is moving from being predominantly paper-based [23]. In terms of OSH, it means that CDE assisted participants to manage risks and helped improved the flow of information. This high percentage was also likely to be due to many stakeholders working with CDE to manage thousands of different documents. BIM provides good communications between all stakeholders in order to manage design and construction issues e.g. approvals, getting access to appropriate versions of documents, risk transfer, preparation of definitive and temporary works, reviewing constructability, clash detections, risk registers, method statements, investigation of accidents, etc. Creation of 4D models was also used to help plan and disseminate construction site safety activities by providing a weekly look-ahead of construction activities. This provides evidence that major collaboration changes are now taking place in the construction industry.

S13 – BIM enables better management

A large majority of respondents (66%) strongly agree/agree and 31% were neutral. This shows that BIM is viewed as improving the management of projects

S14 – BIM reduces the number of possible conflicts and errors

A clear majority of respondents (82%) strongly agree/agree. This l result confirms the result in the NBS report 2020 that identifies this area as one of the main advantages of BIM [23].

S15 – BIM help to integrate production planning and risk prevention

A majority of respondents (72%) strongly agree/agree and 28% were neutral. These results show that, as noted in the previous literature, BIM can assist with the planning of works and the reduction in risks.

S16 – The launch of the PAS 1192:6 standard has affected the way Health, Safety and Well-Being was managed

Over a quarter of respondents (30%) strongly agree/agree and 64% were neutral. This shows that awareness of PAS1192:6 and its importance is relatively low. This may be due to the fact that PAS1192:6 is written as guidance which gives three very different choices for integrating this kind of information, but it does not say which is the best i.e. graphic marking or. Note that in Tideway adopted graphic marking as one of the most basic and common ways of integrating OSH information into the model's digital data. This consists of introducing a 3D symbol (mark) in the graphic component of the model, giving a visual cue to a risk present in that place or within that object. This mark can have information about the risk and can also be linked, e.g., to a safety procedures sheet.

S17 – BIM tools available for Health, Safety and Well-Being are sufficient and adequate

A minority of respondents (20%) strongly agree/agree, 49% were neutral and 26% disagree. The results show a general disagreement with the statement. This number may be explained by the fact that there are some recent software tools that are being trialed and have not yet fully proved BIM's utility and viability in OSH settings.

S18 – Adopting BIM has increased coordination of OSH documents

A minority of respondents (40%) strongly agree / agree, 44% were neutral and 13% disagree. These results do not align with the 2020 NBS report where the vast majority (85%) of users and non-users say that BIM increases coordination of construction documents speeding up the process and aiding in communication and production of information [23]. The figures may reflect the level of maturity in the use of BIM for OSH.

S19 – BIM has reduced occupational risk levels

A minority of respondents (41%) strongly agree / agree, 41 % were neutral and 18% disagree. This result is not compatible with NBS report that affirms that 72% of BIM users agree that it reduces the risk of problems arising [23]. This is obviously an area that needs further research.

5. Conclusions

There has been a broad increase in understanding and interest in applying BIM to the area of prevention of occupational risks. Integrating OSH in digital data through BIM proves to be a task that implies the effort of all stakeholders, especially in scenarios characterized by the multidisciplinary nature of the work teams and a multi-organizational scope. The main output of the research is a practical industry guidance on how large and complex projects can practice OSH management using a BIM approach. This will become a legacy for the wider industry, raising standards for future similar projects. BIM OSH implementation will enable the AECO industry to deal in a more targeted way to improve risks management. This will lead to quicker and better prevention planning resulting in more efficient OSH processes and increased productivity which will provide a stronger link between production and safety.

It can be said that as Tideway project stakeholders have some BIM experience and already realized their advantages, so they probably turn to be more effective in leveraging BIM implementation for OSH purposes. Observing the results obtained, it can be seen that BIM implementation for OSH has been well received by the Tideway technical community, namely in risk assessment and training areas, which reinforces and validates the results of previous studies. It can then be concluded that the implementation of the new BIM based approach to construction OSH management in this large and complex project shows that there is a very positive vison in terms of OSH management as well as of optimization of times and costs, better liaison between OSH and production, with increased production efficiency. This fact can potentially lead to a paradigm shift in OSH management. It also can be noticed that the implementation of BIM for OSH implies that there is a collaborative culture between stakeholders, that people have the appropriate skills and are trained on the importance and usefulness of technology. In this research there was a very positive effect of the joint efforts of the academia and industry which should be stressed, as it enhances and facilitates the implementation of research such as this, taking advantage of the know-how of the parties, respectively scientific and technical.

This is ongoing longitudinal research in progress and so new phases are planned. A focus group will be set up to conduct interviews to improve results and overcome limitations. The following topics should be considered in further studies: practical cases of implementation of OSH information through BIM (namely best practices, difficulties and barriers) must be recorded and published, in the format of "lessons learned", for legacy / future memory to clarify PAS1192:6 perspectives. Dynamics and trends of BIM for OSH at European level and different National levels should be explored and monitorized. Limitations of study: as the study only takes place in one project, it may not provide a complete picture of the whole industry. Unprecedent COVID lockdowns and restriction had a great influence in terms of small sample size of survey and affected on gathering answers and discussing results. On the other hand, COVID had a positive effect in terms of facilitating gathering of the team and growing of partnerships (through periodic online platforms).

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