Benefits and Barriers to the Adoption of 4D Modelling for Site Health and Safety Management

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Abstract

The use of Building Information Modelling processes and supporting technology in the construction industry continues to grow. Its application to various project processes including management of health and safety is acknowledged. The aim of this study was to investigate the current perception of industry professionals of the benefits and barriers of the adoption of 4D modelling for management of construction site safety. This is in light of the BIM level 2 framework document PAS1192-6:2018, which promotes the integration of 4D modelling for safer design and construction.

The paper reports findings from a questionnaire survey of 141 construction industry professionals. The analysis of data took into the level of seniority of the participants. The study indicated that 70% of directors/managers and 74% of professionals are aware of 4D. This awareness, however, is not reflected in the current adoption rate as an average of 31.2% of participants had adopted the 4D modelling at their workplace. The study identifies that the perceived primary purpose of 4D is not for health and safety management, although a need for this purpose is evident. The main perceived benefits of 4D were adding value through visualisation and clearer communication of project outputs, issues which have positive effects on health and safety management including site planning and logistics. The findings also showed that seniority can influence the perception of barriers to 4D modelling adoption. Such barriers include the cost of training, time to implement and underlining cultural issues.

The study recommends an increase in further education and trainingin BIM, health and safety management. Further evidence-based exploratory studies and promotion of 4D modelling to demonstrate the value of 4D modelling for construction site safety would also be useful as a platform to encourage the uptake of 4D modelling for construction site safety.

Keywords: Construction, BIM, 4D modelling, Health and Safety, PAS1192-6:2018

1. Introduction

The construction industry is a fast-paced, project-based industry (Kumar, 2015) involving high-risk activities, (Fung *et al.*, 2010). Health and safety management is, therefore, a key aspect to consider throughout a project (Lacey, 2015) and should begin at the early stages. However, delivery of high-risk activities and complex site logistics during an often strict and rigid timeframe can be difficult to predict, therefore challenging to effectively plan. This unpredictability can lead to extensive co-ordination time, costs (Smith *et al.*, 2009), increased safety risk and result in potential miscommunication of expectations or outcomes between the project teams. Early accurate planning of site activities can allow the team to make the most effective decisions (Abdulkadir and Godfaurd, 2014) for the project, which would assists in the reduction of cost, time, aborted works and increased safety. To achieve these specific project outcomes reduced risk to those carrying out (or affected by) the construction activities, a clear understanding of the outcomes and methodology is required.

The construction industry remains the highest risk industry in the UK, with the Health and Safety Executive (2018) recording 38 fatalities in the construction industry in 2017/18. With an emphasis of legislative requirements (in specific regards to the Construction (Design Management) regulations (2015) as well as the moral and financial impacts of poor safety management (Hughes and Ferrett, 2015), the industry requires improvement. The nature of construction is, however, a continually developing environment which often involves numerous coexisting high-risk physical activities. These activities can often be temporary, with exposure to natural elements, involving major plant and equipment, creating difficult logistical interfaces. With this in mind, the reasons behind these current statistics could be due to its nature or traced to other core issues, linked to a historical poor history and culture towards health and safety (Lacey, 2015).

The construction industry has however made progress in improving standards in managing health and safety. This in part has been influenced by the findings of many reports such as those by Latham (1996) and Egan (1998), who both criticised the industries approach and attitudes towards many aspects, including site safety conditions and workflows. In addition, Egan (1998) identified the slow adoption of digital software to support effective processes and identified these as clear cultural issues.

In recent years, the industry has begun to embrace digital technologies to improve its processes. Although the industry is still criticised for its lack of innovation (Gledson, 2016) a clear push for digital processes is evident, with a UK government mandate for BIM level 2 in place since 2016. The process involves collaborative approaches, structured information and digital software. In addition, with a need to improve safety within the construction industry, the PAS1192-6:2018 document has been published by the British Standards Institution (BSI). This standard forms as part of the BIM level 2 framework and focuses on collaborative sharing and use of structured health and safety information. Within this standard, the encouragement to adopt digital technologies including the use of 4D is clear by stating, "Each participant shall adopt the use of 3D or 4D construction sequencing model(s) to support the development and visualisation of safe methods of access and working" (BSI, 2018, p.11).

Adding the dimension of 'time', 4D has been an area of active research (Tanyer and Aouad, 2005) and is regarded as a useful addition to project management (Koo and Fisher, 2000), resulting in a range of software emerging over recent decades including design and management applications. 4D software has been developed to allow the project team to manage structured schedule data and create a further visualisation of the project throughout its construction. For example, this approach gives the project team opportunities to assess and agree its sequence as confirmation that the plan will execute correctly (Barbrook, 2018).

Whilst there is a significant volume of research into BIM and 4D modelling for safety management, this is a developing and evolving field (Migilinskasa *et al.,* 2013), both in industry and academia with few studies analysing the industries perception of these processes. Due to the incremental nature of BIM adoption (NBS, 2017) and the push to use 4D modelling for safety planning on construction projects, this study aims to contribute to this field by investigating the current perception of industry professionals of the benefits and barriers to the adoption of 4D modelling for management of construction site safety. While most studies have focused on the general application of 4D modelling for H&S management, this study focused on the application of the technology and process at a construction site management level.

2. Materials and Methods

2.1 Background

Health and safety in the Construction Industry

Within any working environment, safety is a factor among many others, which must be considered. The widespread implications of poor safety in the workplace can result in loss of life and or serious damage (Lacey, 2015); thus having various effects on the project, companies and individuals involved. For this reason, the importance of health and safety within the construction industry is extremely high. The construction industry is the largest in the UK employing about 10% of the working population (Hughes and Ferrett, 2016) and is one of the high risk industries. According to Pinto *et al.,* (2011) the construction industry is plagued by risky situations and poor site conditions. With an industry focused on performance outcomes, (particularly cost and time constraints) effective planning to enable the most effective methods is needed to reduce these site risks.

Statistical data from the Health and Safety Executive (HSE) does indicate a gradual decrease in both fatalities and reportable injuries within the construction industry over recent years. However, with a 27% increase in fatalities from 2016/2017 to 2017/2018 this would suggest there are still large improvements to be made within the industry. The main causes of these fatalities are collisions, workers struck by moving vehicles/objects and working at height (HSE, 2018).

The Construction (Design & Management) Regulations (CDM), revised in 2015 have been designed specifically for the construction industry and require duty holders to identify, eliminate or control foreseeable health and safety risk throughout and apply the principles of prevention (HSE, 2015). The planning, preparation and management of health and safety should be considered and executed at all stages of a projects life cycle (Zhou *et al.,* 2013; Lacey, 2015) from strategic definition through to the use and demolition of an asset (RIBA, 2013). The project team's development of the information during the pre-construction phase is driven by key project outcomes, including the health and safety of those constructing the asset and of the end users. This requires detailed planning and coordination (HSE, 2015) during the preparation, design and construction stages of the project (RIBA stages 1-5). The decisions made during these stages are highly influential in how the asset is to be constructed, used and maintained. However, it is those stages leading up to construction and indeed the construction stage itself, which contains the physical risk (Abdulkadir and Godfaurd, 2015). Due to this, the methodology choices should be tested and confirmed to ensure a safe working, operational environment (Mordue and Finch, 2014).

The HSE (2015) suggest it is essential that site activities are effectively pre-planned to enable the works to be carried as far as reasonably practicable without risk. The CDM Regulations (2015) states the requirements for managing all aspects of health and safety during the continually evolving and changing construction phase, requiring the Principal Contractor to

> *'...plan, manage and monitor the construction phase and coordinate matters relating to health and safety during the construction phase to ensure that, so far as is reasonably practicable, construction work is carried out without risks to health or safety'* Health and Safety Executive. (2015, p.36)

The development and enforcement of the CDM regulations 2015 have an influence on the planning process, ensuring that pre-construction and construction information is exchanged collaboratively between the design and construction teams (HSE, 2015).

Challenges of Managing Health and Safety

Due to the importance of health and safety in construction, it is key that this is embedded within the industry (Lingard and Rowlinson, 2004), from definition and design to on-site activities. The management of health and safety can, however, face a number of challenges, including:

- Cultural attitudes towards safety (Lacey, 2015).
- Financial support for training, developed processes and suitable equipment
- Limited resources
- Human behaviour (Dester, 1995)
- Project timescales (Faridi and El-Sayegh, 2007)

Dester (1995) suggests cultural and human behavioural factors are the core reasons for a historically poor record of safety in the construction industry; with cost, timescales and training often having an influence on this behaviour. The construction industry is a competitive industry. Therefore, understanding the project and its methodology is key to ensuring that the correct funds and resources are allocated to provide an adequate working environment. If the project timescales in tender and construction are short and/or limited information is provided, this can reduce the likelihood of correct decisions being made regarding safe methodology. Allowing adequate time to ensure that safety can be fully considered and planned is therefore essential (Faridi and El-Sayegh, 2007).

Lingard & Holmes (2010) proposes that the industry has a challenge in making decisions, which are equitable to all members of the process. According to Hughes and Ferrett (2016), a positive, collaborative safety culture should be embedded within the company ethos, through investment in people, processes and equipment, clear safety policies, communication, leadership and commitment to health and safety. The issues regarding collaboration can be assisted in the use of structured processes, techniques and advanced digital technologies, as stated in PAS1192-6:2018 (BSI, 2018).

Application of 4D to Health and Safety Management

Construction projects often include bespoke structures, regularly involving complex designs, interfaces and logistics, involving numerous team members and project stakeholders. A clear understanding of project deliverables, timescales and methodology is key to safe design and construction projects. In order to achieve these outcomes, with ever increasing project complexities (Abdulkadir and Godfaurd, 2014), planners would design construction schedules linking project activities to timescales and duration. Ahmed *et al.,* (2014) however, suggests that poor interpretation of these schedules often lead to various conflicts and errors throughout the duration of the project. Azhar and Bahringer (2013, pp1) state that "the link between planning for safety and work task execution is often weak" proposing that BIM technologies can further improve safety on site by a collaborative approach to construction planning and in addition, providing advanced visualisation methods to illustrate site safety plans and procedures.

A 4D model involves the synchronisation of graphical model components with schedule data (Zhang and Li, 2010). This creates a visual construction sequencing model (Hardin and McCool, 2015). This process allows the schedule information, once an isolated process to be visualised. This can allow the project team to assess the logic and sequence of the proposed plan and ascertain if this is possible or most effective. This provides opportunities for alternative options to be explored and to select optimum methodologies. The 4D model can also be used for continuous visualisation and management as potential safety risks evolve. Zhou *et al.*, (2013) argue that the proposed approach can be a collaborative tool in which detection of safety risks prior and throughout the construction process can be assessed and preventative measures evaluated in order to avoid accidents.

According to Zhang and Li (2010), a virtual representation of the construction process (virtual construction) can simulate the activities involved during construction using virtual simulation technologies or virtual reality. Virtual construction has a number of key benefits, these include identifying potential issues, risks and problems that may occur with the real construction process ahead of time to allow preventative measures to be planned. 4D simulations can be generated which could be focused on the safety procedures. These simulations can identify methodology, temporary safety elements and can highlight areas of concerns within the project (Azhar *et al.,* 2015). A number of rule-based systems (Zhou *et al.,* 2013) have been developed. For example, Vacharapoom and Sdhabhon (2010) discussed systems designed to automatically detect high-risk site activities and indicates necessary safety measures. The control measures are then incorporated into the schedule and further visualized on the 4D model.

The further potential for 4D modelling has been identified in the literature, from 4D virtual reality to live tracking applications. According to Saeedfar (2017), the further utilisation of the model data and geometry allows for "Live safety tracking". This process involves the live data within the model to be used for tracking objects, activities and operatives within the site. The potential for this includes levels of dust and noise as well as incorporating monitoring using sensors and tag systems.

2.2 Benefits of 4D Modelling for Construction Health and Safety Management

A number of general benefits for use of 4D modelling have been identified in literature. These include increase collaboration (Manalingam *et al*., 2010) reduce risk, error (Dawood, 2010), increase communication (Azhar *et al.,* 2015) and identify issues in sequencing (Zhuo, 2009) by having the ability to rehearse project activities and demonstrate how the plan would play in a 'virtual world'. According to the BSI (2018), digital information modelling software with 4D capability enhances the ability to foresee hazards and risk. Azhar *et al.,* (2012) suggests that a collaboratively created, virtually simulated environment, is to be a "revolutionary development" within the construction industry4D modelling is also seen to be a useful tool to aid safety and project planning on construction projects (Kassem *et al.,* 2012). This view is shared by Barnes and Davis (2015) who suggests that 4D scheduling and simulation provides a platform for improved planning and management of construction activities.

Gledson (2016) proposes that the key benefits of 4D are in the reduction of uncertainty in the planning process. Mordue and Finch (2014) imply that the use of digital software and collaborative approaches enables a further enhancement in forecasting and planning in regards to site safety. As BIM has been acknowledged by the Health and Safety Executive, creating synergy between BIM and health and safety management is the move forward. The value in adopting this process to management of health and safety is widely acknowledged. For example, according to Cousins (2016, pp), the use of 4D to rehearse activities of the proposed build in a virtual environment could be a key to allow accurate planning of site safety as it provides a platform to identify potential hazard, and modalities for trying potential solutions to mitigate the risks in the pre-construction stage.

Further research carried out by Gledson and Greenwood (2016) assessed the adoption of 4D BIM in the UK. The results indicated a significant relationship between the size of a company and the adoption of BIM as well as a link between the use of 4D and the companies' maturity. The research showed that 52.9% of participants surveyed, worked for companies using 4D on current projects and almost 70% of those surveyed believed that 4D could 'add value to their business'. The study identified that key benefits of 4D are related to "handling and communicating information" as opposed to managing timescales.

As stated within PAS1192-6:2018, the use of 4D modelling provides a number of benefits in regards to health and safety management. The BIM level 2 framework standard aims to support the integration of health and safety data within information management processes, stating:

> *'A 4D animation can be used to review, assess and communicate construction options, hazards and risk. A 4D animation of difficult construction sequences is more easily understood by those who have to take responsibility and accountability of risk mitigation, control and management'.* (BSI, 2018, p.V)

According to Sulankivi (2010), 4D should be a central focus in the management of site health and safety. Although the research highlighted the potential for challenges and limitations, key benefits to the process were also identified. These benefits include the integration of safety within the planning process. Utilising 4D BIM supporting software to communicate site layout plans, allowing accurate co-ordination for safety risk analysis. The use of this structured process and technology can be used for accurate visualisation of site safety arrangements including plant, welfare and safe zones and allows for clearer communication between the project team.

Manalingam *et al.*, (2010) proposes that 4D is to be particularly useful in assessing the constructability of work methodology, increasing visualisation, the ability to detect clashes and providing simulations which assist in planning and further analysis of project methodology. Analysis of data from this study concluded

> *'4D CAD is likely to be most beneficial in the project shaping or planning stage and in the construction stage. In the project shaping stage, 4D CAD is likely to be particularly useful in communicating construction plans and processes to clients, while during the construction phase, 4D CAD is likely to be particularly useful in comparing the constructability of work methods visually in order to detect conflicts or clashes, and as*

a visual tool for contractors, clients, subcontractors and vendors to review and plan project progress' (Manalingam et al., 2010, p.148)

Abdulkadir and Godfaurd (2015) linked the use of 4D for specific health and safety purposes, stating that the technology is critical to the success of a project. This can be achieved by effective control of the programme and reducing risk by "time-controlled realistic simulation". The use of this digital construction approach is not only useful as a tool to increasing collaboration and further value in construction (Barnes & Davis, 2015) but also to reduce project risk (Pittard and Sell 2016). Rwamamara *et al.,* (2010) also argue that 4D has potential in regards to detailed visualization and communication of construction information. The identification of health and safety risks (in specific regards to material movement and repetitive manual operations) during the design process can be a key advantage of 4D as well as clash detection and optimisation of work sequences which reduce workspace congestion can be further highlighted.

As demonstrated above, a number of benefits for use of 4D modelling are identified in the literature. Table 1 below provides a summary of these potential benefits.

Table 1 Summary of the benefits of 4D in relation to health and safety management

2.3. Barriers of 4D within the Construction Industry

According to Romigh *et al.,* (2017), the implementation of 4D requires improvement within the construction industry. A qualitative study highlighted the role in which 4D has during the construction phase in regards to visualisation and communication of the schedule data to improve site operations. The study utilised semi-structured interviews to collect data regarding 4D adoption and use, stating that 67% of those interviewed were familiar and a minority of 33% used 4D on their projects. The findings from these interviews also identified common perceptions of the interviewees, suggesting that the use of 4D is limited. The study also stated that some participants believed 4D was mainly used as a marketing tool and that most were not interested in the idea of updating a 4D model as opposed to a 2D schedule during projects which are constantly changing. A concern which Zhou (2009) highlights is that 4D approaches are limited due to lack of a fully collaborative environment. 4D CAD approaches also provide a planning review mechanism as opposed to a platform for a novel integrated approach to construction planning. This called for the development of a virtual reality environment where collaborative working could take place in order to create a fully integrated and coordinated programme and simulated project. Highlighted further were the issues of technological limitations and human behaviour within such a working environment.

The construction industry as a whole has shown to have a history of slow adoption of new processes and technologies in comparison to other major industries. It is also seen as 'having a reputation for a being slow to change' (Chevin, 2018, p23). Latham (1994) highlighted the positive effects of digital information to enhance construction performance and effective decision making, a view also echoed by Egan (1998) who further discussed the need for digital exchanging of data but also emphasized a cultural change before using this technology. Hardin and McCool (2015) also suggested that those who misunderstand the principle that BIM is a "cultural shift in the mind set in the way construction management teams collaborate" would soon be irrelevant in the industry. With this in mind, it is clear that the use of software must be supported by a collaborative and innovative culture.

Within the BIM process, technology is used to enable effective design and collaboration. However, as Hardin and McCool (2015) suggests, BIM requires people, process and technology; with the most difficult to manage to be people as this often requires a cultural and behavioural change. Egan (1998) proposed that this behavioural and cultural change must take place before the technology can fully be utilised. This may suggest that before the technology can truly assist in the management of health and safety, the behaviours of those involved and the process and procedures in which they work need to be in place to accept this technology. The introduction of technology alone without this behavioural / cultural change and effective processes in place would inevitably end in failure, as Egan (1998, p28) stated "to approach change by first sorting out the culture, then defining and improving processes and finally applying technology as a tool to support these cultural and process improvements". The changing of culture can be challenging as those who have worked in the same way may find it difficult to accept and adapt to new ways of work (Eynon, 2016). It is argued thata core challenge of human behaviour "cannot be changed quickly" (Azhar and Bahringer, 2013).

According to Abdulkadir and Godfaurd (2015), the use of 4D may improve safety although the adoption of this technology within the construction industry is currently "partial and fragmented". They suggest that the use of BIM and these technologies are mainly confined within the design and planning stages with "very little of it being used in the construction phase in relation to H&S through hazard perception". Abdulkadir and Godfaurd (2015, pp42)

Further barriers to the process and technology include the current client experience and project team expertise within the industry to implement BIM level 2 and the use of these technologies effectively. As highlighted by Lymath (2014) barriers to the adoption of BIM processes and software include the cost to recruit and train and demand for BIM in the industry, particularly for smaller projects and companies. The issues surrounding the cost of software, training and expertise could be a major challenge for the industry in order to see the true value in its adoption. According to Migilinskasa *et al.*, (2013), knowledge which 4D modelling software to implement and understanding its limitations including data exchange and effective hardware where also potential issues. Zhang and Li (2010) also argued that 4D modelling requires high hardware requirements and that weak 3D outputs result in poor use of this information.

A change in culture may involve education and training in regards to health and safety but also training in the processes and the integration of the company policy and company ethos, all supported by high-level management and suitable financial backing. Once accepted and agreed, the most appropriate technology can be selected to enable the process and assist those working within it, to manage project information effectively (Mordue and Finch, 2014; Hardin and McCool, 2015). As Kassem *et al.,* (2012) identifies, barriers to this process are not just of the use of the software its self but of the business and stakeholder awareness of its value, stating

> *'... non-technical barriers, such as the inefficiency to quantify the tangible benefits of BIM and 4D and lack of awareness by stakeholders, especially the clients, are affecting widespread use of BIM and 4D more than the technical barriers'.* (Kassem *et al.,* 2012, p.9)

The use of 4D as standard practice in the construction industry may face a number of barriers as the value in these new processes must be clear. These processes require a financial investment in software, training and company infrastructure. The decision of these investments is often made by the highest level of management, requiring a collaborative and forwardthinking culture (Eynon, 2016). Understanding the financial risk and cost-effectiveness also needs to be considered with such an investment. The size of the company, resources and risk of individual projects may all be contributing factors in the adoption of these technologies. According to Bowles (2017), the use of 4D modelling software (including immersive VR) is clearly justifiable on many projects due to risks on major sites being much greater than the costs of software and its implementation. For smaller scale projects, the project risk may not be to this magnitude. Carson (2018) suggests that the benefits of BIM processes and software may not be clear, but that the barriers to its use, such as available resources may be evident. However, the use of BIM is to make improvement and the benefits of the collaboration of project data and a clearer understanding of environmental and safety concerns can be achieved.

Ahmed *et al.*, (2014) carried out research into the barriers to 4D adoption using a survey approach to target construction professionals in which 54 responded. The results of the survey identified a number of barriers to its adoption including the availability of professionals who hold relevant skills, knowledge and experience in BIM and 4D as well as a clear resistance to change. Key barriers also included an unclear return on investment from the use of BIM and 4D. According to Azhar and Bahringer (2013), the adoption of BIM technologies including that of 4D for safety management poses a number of barriers and challenges. The challenges include a lack of knowledge and technical issues (mainly linking to safety objects within software libraries) as well as the cost associated with the development of these models and simulations.

Table 2 below provides a summary of potential barriers to adoption of 4D modelling for managing construction site safety.

Table 2 Summary of the barriers of 4D in relation to health and safety management

3. Methodology

The primary focus of this research was to investigate the current perception of industry professionals of the benefits and barriers to the adoption of 4D modelling for management of construction site safety A survey approach using questionnaires was adopted as the method of collecting data for the study. This enabled collection of data from a relatively larger sample than would be the case if other methods such as interviews were used. The use of questionnaires to gather perception data is a common approach used in related studies, such as Gledson and Greenwood (2016) and Kassem *et al.,* (2012). The questionnaire design was informed by issues identified in the literature as provided in the previous section.

In order to collect the data, a mixture of convenience and purposive sampling methods were used to assist in achieving a relatively high response rate (Bryman & Bell, 2007). The sampling approach targeted participants based on accessibility, and willingness but also targeted specific participants with particular characteristics (Etikan, *et al.,* 2016) based on their knowledge and experience (Bernard, 2002) and who are well-informed in the subject (Cresswell and Plano Clark, 2011). In addition, the sampling method was selected in order to target a range of participants who hold either a director/management or a professional position within the industry. The sample for the study consisted of managers and professionals within various sectors of the industry in order to receive data from the wider construction industry. Table 3 shows the sample demographic data including participants sectors, while table 4 identifies participant seniority. A total of 141 participants completed the questionnaire, 20 who held direct/manager positions and 121 who held professional roles within the industry.

Table 3 – Sample demography

Table 4 - Participants level of seniority within their organisation

4. Results

BIM Level 2 adoption

The premise of the arguments in this paper is that as BIM adoption and practices develop further, the use of 4D modelling will be seen as an integral part of digital technology practices for the construction industry as advocated by the PAS1192-6:2018 document. The adoption of BIM level 2 is therefore seen as a key driver in the use of collaborative processes and digital software. Participants were therefore asked to identify their company's current implementation. The data in table 5 indicates a low uptake of BIM level 2 being used in all projects (5.9%). When the level of seniority is considered, the differences between the two groups are evident. For example, none (0%) of the directors/managers indicated that BIM is used on all projects roles responded 0% in the field. The data, however, shows a 64.5% adoption of BIM level 2 (whether this is the on the majority or minority of projects) and 23.4% not currently adopting BIM level 2. The data suggests that the industry is adopting BIM processes. The government mandates and company policy could be potential influences to these statistics. The finding is comparable to other studies reporting BIM adoption rates. For example, The NBS (2017) study found a 62% adoption rate. The disparities in the level of awareness of BIM application between the two groups, Directors/Managers and professionals, is also evident.

Table 5: BIM Level 2 adoption

Awareness of 4D modelling

As with the emergence of any digital technology, the awareness of 4D within the industry is a key consideration. Participants were therefore asked to indicate the extent to which they were aware of 4D modelling applications in the construction sector. The data in table 6 shows an overall participant awareness of 73.8%. The data indicates that those with director/ management roles are less aware of 4D modelling applications than those who held professional roles.

Table 6: Awareness of 4D modelling

Participants' use of 4D modelling

The data displayed in table 7 shows the participant's use of 4D in the construction sector. The data shows that overall 31.2% of the participants had 4D modelling adopted at their workplace. This suggests a low rate of 4D implementation in the construction industry. The data also shows that those holding director/management positions are fully aware as to the organisation's use of 4D, opposed to 4.1% of professionals unsure as to if their company uses 4D software.

Table 7: Use of 4D modelling

Perception of benefits and barriers of 4D modelling

An analysis of the benefits and barriers to 4D may highlight reasons for this low rate of adoption. A number of potential benefits of 4D modelling were identified in the literature. Participants were asked to rate the extent to which these were viewed as benefits of 4D modelling for construction site health and safety. Figure 1 presents the responses. Both the aggregate scores and disaggregated scores are presented. The disaggregate scores differentiate between directors/managers and professionals and also 4D modelling users and none-users. The participants rated each of the factors on a scale of 1 to 5. The results indicate a clear benefit to 4D being in an increased visualisation of the project during the construction process. This factor was scored highest in all four groups with directors/managers who use this software rating this factor a maximum of 5/5. Increased communication with the project team and schedule accuracy also rated highly, with those using 4D being the highest scoring groups for these factors.

Figure 1: Benefits of 4D modelling for construction site safety

The benefit of 4D for health and safety management received an average score of 3.13/5 from all groups. Those with director/management roles rated this factor least within the four groups at 2.50/5, signifying a low perception of its benefit for safety management. Those who hold professional roles (both who use 4D and those who do not) had a higher perception of this benefit, with 3.32/5 scored on by both groups. These responses were however different when compared to a direct question regarding the perception of 4D as a tool to reduce health and safety risk. Table 8 indicates that both positions responded higher than the use of 4D for safety management with director/management scoring 3.40/5 and professionals scoring 3.58/5.

Further analysis of the benefits of 4D with specific regards to safety management identified key areas in which 4D can positively impact site safety. Participants were asked to rate the use of 4D to assist key safety management hazards/activities on site. The significance of these activities was derived from current HSE statistics and literature including aspects of the CDM 2015 regulations. The data in figure 2 indicates that planning site logistics and plant movement where the highest ranked benefits. The professional participants using 4D also rating these benefits higher than the other groups with a score of 4.18/5, suggesting these to be key practical benefits of the 4D. These areas of health and safety, along with pedestrian segregation also rely heavily on the visual aspects of the project, therefore, implying further support to the benefits of visualisation of project sequencing. The data also suggests that those who use 4D in professional roles have a higher perception overall of the benefits of using 4D in health and safety planning as those in these roles ranked each factor higher than director/management roles who also use 4D.

With identified benefits in literature, and the BSI (2018) encouraging this form of planning to support the development for of safe methods of working, this study indicates that 31.2% of organisations currently use 4D within their projects. This minority adoption could be due to barriers preventing its widespread implementation as a tool for safety management.

A number of potential barriers were identified in the literature. Participants were asked to rate the extent to which these potential barriers could affect the adoption and use of 4D for health and safety management at a construction site management level. Figure 3 shows the extent of these key barriers from both director/manager and professional roles, again separated into those who use 4D and those who do not to allow further comparison of perceptions. The data indicates that directors/managers using 4D rated cost in training and time to implement the highest barriers to its adoption. The industry culture is also a consistent high ranked barrier, director/managers both using and not using 4D rated this barrier higher than those in professional roles indicating a cultural attitude is recognised at high levels within organisations as well as operational levels.

Figure 3: Barriers to 4d Adoption for construction site health and safety

All four groups rated 'the progress is not needed' as the lowest barrier suggesting that the process is required within construction. This finding demonstrates the need for the use of this digital technology within health and safety management, however, in adoption rate in this study remains low. This, therefore, would suggest that barriers identified must be the reason for this low adoption of a needed process.

5. Discussion

This study was carried out to assess the industries readiness to deliver 4D in light of the recent publication of BIM standard, PAS1192-6:2018, which includes the application of 4D construction sequencing modelling (BSI, 2018). The inclusion of 4D within the key BIM framework documentation could spark an increase in the use of 4D as these standards become further widespread in delivering BIM level 2 projects. It was, therefore, appropriate ti investigate and evaluate the perception of construction industry professionals, the benefits and barriers for adoption of 4D modelling for construction site safety management.

The data from this study indicates current adoption of 4D statistics at 31.2%; this value could be affected by the 73.8% awareness of 4D and also key barriers and perceived advantages/limitations highlighted in the literature. The study indicates that those who hold director/management positions have less awareness of 4D. Considering that this is the category that holds more influence on the company strategy and adoption of new processes, it may suggest this could have an effect on the adoption of 4D within an organisation.

The study has highlighted a number of benefits to the use of 4D modelling as documented in literature sources. The participants within this study agreed that the key advantage of 4D is in visualisation. This factor ranked highest in all groups, with an average score among all groups of 4.65 (out of 5). In addition to visualisation, the process has been highlighted as an effective tool for communicating aspects of the project and for more effective logistics management during the construction phase. Although these key benefits centred around visualisation as opposed to health and safety specifically, the advantage of clear visualisation can have natural positive effects on planning for health and safety. This is specifically identified in the planning of logistics including optimum safe plant locations, plant movement and safe access/segregation methodology. The data in this study does, however, suggest that those using 4D and who hold director/management positions within the organisation have a viewed 4D modelling as being less beneficial when it comes to safety management. Within the study, the director/managers rated "4D being beneficial for safety" the least of all groups at 2.5 (out of 5) and they rated the use of 4D in planning the least in every factor when compared to professionals who also use 4D.

The study has confirmed a number of barriers to the adoption of BIM and 4D for health and safety management, these including cost, time and culture (including resistance to change). These key barriers follow a common theme within the industry and are similar to those identified, in other literature and influential construction industry reports. . The finding of this study indicates that the top-ranked barriers were in the initial outlay/continuous costs of the software/training, time to implement these processes and general industry culture to adopt new techniques and technology. The perception of cost and time as barriers appeared to be higher among Directors/managers than professionals. This may suggest that the organisation's financial commitment and investment in time to implement such a process and technology across their projects are key issues to overcome.

The cultural barriers have also been highlighted in this study as an underlying factor. This barrier ranked high amongst all groups and featured heavily within literature. This may suggest that resistance to change to new methods of working may be a significant factor to consider when introducing 4D modelling. It is argued that culture, as discussed by Hardin and McCool (2015) and Egan (1998), can be difficult to change and may not be changed simply by the introduction of new software. It is however important that the construction industry changes its culture as the change would allow the industry to adapt to a collaborative environment and the acceptance of using digital technology to improve health and safety practices.

6. Conclusion and Recommendations

The study concludes that the adoption rate of 4D modelling for construction site safety currently remains low and that the minority of organisations are using 4D. While the PAS 1192-6 advocates for the wider adoption of BIM for safety, the data suggests that the industry is not yet at a position for this process to be seen as a 'standard practice' for safety management. With further understanding and awareness of the benefits of 4D, the industry may break down barriers and further adapt in line with technological advances. While the benefits of 4D modelling for site safety are acknowledged, the findings in this study suggest that technology alone is not the answer. A collaborative approach, understanding of the process, the culture of those involved and indeed the industry itself needs to be in place for this to succeed as a tool to manage health and safety. This may take time and will require these cultural barriers to break before full commitment can be shown.

It is recommended a review of company strategy are undertaken, investigating the feasibility for further investment in 4D modelling within projects. Additional industry training is also recommended in order to increase awareness, in order to understand the current requirements, documentation, available technology and benefits of this process. Further academic research into current and developing adoption of 4D is recommended, including further quantitative study across the UK to enrich this data. In addition, it is recommended that further studies are conducted in order to provide empirical evidence of the value of 4D modelling in improving site safety practices on construction projects.

8. Informed Consent

This is to confirm that

1. Participants to the study were made aware of the purpose and nature of the study.
2. Participants for the questionnaire were advised of the voluntary nature of their participation and that by participating, they would be deemed as having consented.
3. Appropriate ethics approval for this study was obtained

9. Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

10. Bibliography

Abdulkadir, G and Godfaurd, J. (2015) Integrating Building information and Health and Safety for Onsite Construction. *Health and Safety at Work*, 6 (1) March, pp. 39-45

Ahmed, S. Emam, H and Farrell, P. Ahmad O ed. (2014) *Barriers to BIM / 4D implementation in Qatar. Smart, sustainable and healthy cities, proceeding of the first international conference of the CIB Middle East and North Africa Research Network, December 14-16, 2014*, CIB Middle East and North Africa Research Network

Azhar, S. Khalfan, M and Maqsood, T (2012) *Building information modelling (BIM): now and beyond. Australasian Journal of Construction Economics and Building*

Azhar, S. Behringer, A. Khalfan, M. Sattineni, A and Maqsood, T. (2012) *BIM for Facilitating Construction Safety Planning and Management at Jobsite. Proceeding of the CIB W099 International Conference on "Modelling and Building Health and Safety",* September 10-11, 2012, Singapore, pp.82-92

Azhar, S and Bahringer, A (2013) *A BIM-based Approach for Communicating and Implementing a Construction Site Safety Plan. Proceedings of the 49th ASC Annual International Conference. 2013* Associated Schools of Construction

Barbrook, I (2017) *Digital construction*. (Interview) (November 3, 2017)

Barnes, P and Davies, N. (2015) *BIM in Principle and in Practice*. 2nd Ed. London: ICE

Baruch, Y (1999) Response Rate in Academic Studies - A Comparative Analysis. *Human Relations*, 52 (4) p 442

Benjaoran, V and Bhokha, S (2010) *An integrated safety management with construction management using 4D CAD model, Safety Science,* 48, pp. 395-403, ScienceDirect, EBSCO*host*

Biner, P.M and Kidd, H. (1994) The interactive effects of monetary incentive justification and questionnaire length on mail survey response rate. *Psychology and Marketing*, 11 (5), pp. 483-492

Bryman, A and Bell, E. (2007) *Business Research Methods*. 3rd Ed. New York: Oxford

Bsi British Standards Institution. (2013) *PAS 1192-2:2013 Incorporating Corrigendum No. 1 Specification for information management for the capital/delivery phase of construction projects using building information modelling*. London: Bsi Standards limited

Bsi British Standards Institution. (2014) *PAS 1192-3:2014 Specification for information management for the operational phase of assets using building information modelling*. London: Bsi Standards limited

Bsi British Standards Institution. (2018) *PAS1192-6:2018 specification for the collaborative sharing and use of structured Health and Safety information using BIM*. London: Bsi Standards limited

Candelario-Garrido, A. Garcia-Sanz-Calcedo, J and Reyes Rodriguez, A (2017) A *Quantitative Analysis of the Feasibility of 4D Planning Graphic Systems versus Convectional Systems in Building Projects*. Elsevier

Cabinet Office. (2013) *Construction 2025*. Cabinet office: London Cabinet office

Cabinet Office. (2011) *Government Construction Strategy*. London: Cabinet Office

Carey, M. (2013) *The social work dissertation using small-scale quantitative methodology.* London: McGraw-Hill

Carson, J. (2018) *Can BIM successfully deliver small construction projects*? [Online] available from: https://www.thenbs.com/knowledge/can-bim-successfully-deliver-small-construction-projects [assessed 21st November 2018]

Chevin, D (2018) BIM level 2 uptake still slow but AR and automation up. *Construction manager insight on BIM,* April, pp. 22-24.

Cousins, S (2016) *BIM spells safety on site* [Online] available from: https://www.healthandsafetyatwork.com/comment/8279 [assessed 24th February 2018]

Creswell, J (2009) *Research Design Qualitative, Quantitative and Mixed methods approaches*. 3rd Edition. London: Sage

Cresswell, J. W., & Plano Clark, V. L. (2011) *Designing and Conducting mixed method research.* 2nd Edition. Thousand Oaks, CA: Sage.

Dawood, N. (2010) Development of 4D based performance indicators in the construction industry. *Engineering, construction and architectural management*, 17 (2) pp 210 - 230

Dester, W and Blockley, D (1995) Safety-behaviour and culture in construction, *Engineering, Construction and Architectural Management*, Vol. 2 Issue: 1, pp.17-26

Eastman, C. Teicholz, P. Sacks and R. Liston K. (2011) *BIM Handbook A Guide to Building Information Modelling For Owners, Managers, Designers, Engineers, and Contractors*. 2nd Edition. Hoboken: Wiley

Egan, Sir J. (1998) *Rethinking Construction the Report of the Construction.* Norwich: Construction Taskforce

Etikan, I. Abubakar S and Alkassim, S. (2016) Comparison of Convenience Sampling and Purposive Sampling. *American Journal of Theoretical and Applied Statistics*. 5, (1) pp. 1-4.

Eynon, J. (2016) *Construction Managers BIM Handbook*. Oxford: Wiley Blackwell

Faridi, A and El-Sayegh, S. (2007) Significant factors causing delay in the UAE construction industry. *Construction Management and Economics* (24) 11 February, pp 1167-1176.

Farrell, P. (2011) *Writing a built environment dissertation practical guidance and examples*. Sussex: Wiley Blackwell

Fung, I. Tam, V. Lo, T and Lu, L. (2010) Developing a Risk Assessment Model for construction safety. *International Journal of Project Management*, 28 (6) August, pp. 593-600.

Gledson, B (2016) *Exploring the Consequences of 4D BIM innovation*. *In* Chan, P W (Ed) and Neilson, C J (Ed), *Proceedings 32nd Annual ARCOM conference, 5-7* September, 2016. Manchester UK. Associaion of Researchers in Construction Management

Gledson, B. Greenwood, D. (2016) Surveying the extent and use of 4D BIM in the UK. *Journal of Information Technology in Construction* (ITcon), 21 pp. 57-71

Guo, H. Yu, Y and Skimore, M (2016) *Visualization technology-based construction **safety** management in Automated construction*. Elsevier

Gunduz, M. Nielsen, P and Ozdemir, M. (2013) Quantification of delay factors using the relative importance index method for construction projects in Turkey. *Journal of management in engineering*. p134

Hardin, B and McCool, D. (2015) *BIM and Construction Management Proven Tools, Methods and Workflows*. 2nd Edition. Indiana: Wiley

Health and Safety Executive (2011) *five steps to risk assessment*. HSE

Health and Safety Executive. (2015) *Managing Health and Safety in Construction, Construction (Design and Management) Regulations 2015.* HSE

HM Government. (2015) *Digital Built Britain Level 3 Building Information Modelling strategic plan*.

HM Government. (2012) *Industrial Strategy: government and industry in Partnership Building Information Technology.*

Holzer, D (2015) *The BIM managers Handbook: Guidance for professionals in architecture, engineering and construction focus on technology part 3*. West Sussex. Wiley

Hu, Z, Zhang, J and Deng, Z (2008) *Construction Process Simulation and Safety Analysis Based on Building Information Modelling and 4D Technology, Tsinghu Science and Technology*. Science direct, EBSCOhost

Hughes, P and Ferrett, Ed. (2016) *Introduction to health and safety in construction*. 5th Edition. Oxon: Routledge

HSE (2017) *Fatal injuries arising from accidents at work in Great Britain 2017*. HSE

Ivankova, N. Creswell, J and Stick, S (2006) Using Mixed-Methods Sequential Explanatory Design: From Theory to Practice, 18 (1) p3-20

Kassem, M. Brogden T and Dawood, N (2012) BIM and 4D planning: a holistic study of the barriers and drivers to widespread adoption. *Journal of Construction Engineering and Project Management*, 5 pp 1- 10

Kenny, J. (2017) *Technology for 2017 and beyond*. 4 January [online] Available from http://www.bimplus.co.uk/technology/tech5nology-2017-an9d-beyo0nd/ [accessed 19 January 2018]

Koo, B and Fisher M. (2000) feasibility study of 4D CAD in commercial construction. *Journal of construction engineering and management*, 126 (4) pp 251-260

Kumar, B. (2015) *A Practical Guide to Adopting BIM in Construction Projects*. Scotland: Whittles Publishing

Latham, Sir M. (1994) *Constructing the team*. London: HMSO

Lacey, J. (2015) *The Management of Construction Health and Safety Risk*. Fourth Edition. Stourbridge: rms

Laylock, E. Howarth, T and Watson, P. (2016) *The Journey to Dissertation Success for construction, property and architecture students*. New York: Routledge

Lock, D. (2013) *Project Management*. 10th Edition. Hampshire: Gower

Lingard, H and Holmes, N. (2010) Understandings of occupational health and safety risk control in small business construction firms: barriers to implementing technological controls. *Construction Management and Economics*, 19 (2) October, pp. 217-226.

Lingard H and Rowlinson, S. (2007) *Occupational Health and Safety in Construction Project Management*. London: Routledge

Lymath, A (2014) *The top five barriers to BIM implementation* [Online] https://www.thenbs.com/knowledge/the-top-five-barriers-to-bim-implementation. NBS [accessed 10th March 2018]

Mahalingam, A. Kashyap, R and Mahajan, C. (2010) An evaluation of the applicability of 4D CAD on construction projects. *Automation in Constructio*n. 19 (2) March, pp 148-159

Migilinskasa, D. Popovb, V. Juoceviciusc, V and Ustinovichiu, L. (2013) The Benefits, Obstacles and Problems of Practical BIM Implementation. In: *Proceedings of the 11th International Conference on Modern Building Materials, Structures and Techniques, 2013, Vilnius, Lithuania*. Elsevier, pp 767 – 774

Mills, F (2017) *Building a Skyscraper in 4D VR* [Online] the B1M. Available from: https://www.theb1m.com/video/building-a-skyscraper-with-4d-vr [assessed 24 February 2018]

Mordue, S. and Finch, R. (2014) *BIM for Construction Health and Safety*. Newcastle: RIBA

Naoum, S.G. (2013) *Dissertation research and writing for construction students*. 3rd Edition. New York: Routledge

NBS. (2017) *National BIM report 2017*. Newcastle upon Tyne. NBS

Nulty, D (1992) Students opinions on students opinions. *In research and development in higher education: academia under pressure: theory and practice for the 21st century*. Higher education research and development society of Australasia. 15 pp.498-502

Nulty, D (2008) The adequacy of response rates to online and paper surveys: what can be done? *Assessment and Evaluation in Higher Education*. 33 (3) June, p. 302

RIBA (2015) *RIBA plan of work 2013 guide Information Exchanges*. Newcastle: RIBA

Pinto, A. Nunes, I and Ribeiro, R (2011) Occupational risk assessment in the construction industry – Overview and reflection. *Safety Science* 49 (5) June, pp. 616-624.

Pittard, S and Sell, P. (2016) *BIM and Quantity Surveying*. Oxon: Routledge

Porwal, A and Hewage, K. (2012) *Building Information Modeling (BIM) partnering framework for public construction projects*. Elsevier ScienceDirect

Prospect (2012) *The Tallest Tower: Building the Shard*. More 4, 3rd February 2018 21:00

Rodriguez, J (2018) *Building Information Modelling (BIM) Benefits Per Profession* [Online] Available from: https://www.the balance .com/building-information-modelling-BIM-benefits [accessed 26th March 2018]

Romigh. A. Kim, J and Sattineni, A (2017) 4D Scheduling: A Visualization Tool for Construction Field Operations. *Proceedings of the 53rd ASC Annual International Conference, April, 2017, Seattle, Washington*. Associated Schools of Construction.

Rwamamara, R. Norberg, H. Olofsson T and Lagerqvist, O. (2010) Using visualization technologies for design and planning of a healthy construction workplace. *Construction Innovation,* 10 (3) pp.248-266

Saeedfar, A. (2017) *Blog: Role of Safety in BIM*. [Online] Assemble Systems. Available from: https://assemblesystems.com/blog/role-of-safety-in-bim/ [Accessed 25 February. 2018].

Saxon, R. (2016) *BIM for Construction Clients*. Newcastle upon Tyne: RIBA

Smith, N. Merna, T and Jobling, P. (2009) *Managing Risk in Construction Projects*. 2nd Edition. Oxford: Blackwell

Sulankivi, K. (2010) *4D-BIM for Construction Safety Planning*. VTT Technical Research Center of Finland

Tanyer, A and Aouad, G. (2005) Moving beyond the fourth dimension with an IFC-based single project database. *Automation In Construction,* 14 (1) January, pp.15-32

Vacharapoom, B and Sdhabhon, B. (2010) An integrated safety management with construction management using 4D CAD model. *Safety Science*. 48 (3) March, pp. 395-403

Wilkingson, D and Birmingham, P. (2003) *Using Research Instruments*. London: Routledge

Zhang, J and Li, D. (2010) *Research on 4D virtual construction and dynamic management system based on BIM. Proceeding of the International Conference on Computing in Civil and Building Engineering*. Nottingham University Press.

Zghari, A (2013) *The cost saving benefits of BIM* [Online] Available from: https://www.thenbs.com/knowledge/the-cost-saving-benefits-of-bim [accessed 10th March 2018]

Zhou, W. (2009) *An investigation into a distributed virtual reality environment for real-time collaborative 4D construction planning and simulation*. University of Wolverhampton Zhou, W, Whyte, J and Sacks, R (2012) Construction Safety and Digital Design: A Review, Automation In Construction, 22, Planning Future Cities-selected papers from the 2010 eCAACe Conference, ScienceDirect EBSCOhost.

Zhou, Y. Ding, L and Chen, L (2013) Application of 4D visualization technology for safety management in metro construction. *Automation in Construction*, 34, September, pp. 25-36

Tables

Table 3 Summary of the benefits of 4D in relation to health and safety management

Benefit	Authors
Reduce safety risk	(Dawood, 2010) (Pittard and Sell, 2016) (Abdulkadir and Godfaurd, 2015) (Mordue and Finch, 2014) (Rwamamara et al., 2010) (Azhar *et al.*, 2015) (Vacharapoom and Sdhabhon, 2010) (Azhar and Bahringer, 2013) (Zhou *et al.*, 2013)
Ability to foresee hazards	(BSI, 2018) (Cousins, 2016) (Zhang and Li, 2010) (Abdulkadir and Godfaurd, 2015) (Zhou *et al.*, 2013) (Azhar and Bahringer, 2013) (Vacharapoom and Sdhabhon, 2010) (Mordue and Finch, 2014) (Azhar *et al.*, 2015) (Rwamamara *et al.*, 2010)
Improved project planning	(Gledson, 2016) (Sulankivi, 2010) (Mordue and Finch, 2014) (Kassem *et al.,* 2012) (Vacharapoom and Sdhabhon, 2010) (Azhar and Bahringer, 2013) (Barnes & Davis, 2015) (Zhou, 2009) (Manalingam *et al.*, 2010) (Zhou *et al.*, 2013) (Abdulkadir and Godfaurd, 2015) (Zhang and Li, 2010) (Azhar *et al.*, 2015)
Improved communication	(Gledson and Greenwood, 2016) (Azhar and Bahringer, 2013) (Manalingam *et al.*, 2010) (Azhar *et al.*, 2015) (Rwamamara *et al.*, 2010)
Increased collaboration	(Barnes & Davis, 2015) (Azhar *et al.*, 2015) (Manalingam *et al.*, 2010) (Mordue and Finch, 2014) (Carson, 2018) (Zhou *et al.*, 2013) (Azhar and Bahringer, 2013)
Increased project visualisation	(Manalingam *et al*, 2010) (Rwamamara *et al.*, 2010) (Azhar *et al.*, 2015) (Zhou *et al.*, 2013) (Zhang and Li, 2010) (Azhar and Bahringer, 2013) (Vacharapoom and Sdhabhon, 2010)

Table 4 Summary of the barriers of 4D in relation to health and safety management

Barrier	Authors
Industry culture and resistance to change	(Mordue and Finch, 2014) (Hardin and McCool, 2015) (Eynon, 2016) (Chevin, 2018) (Egan, 1998) (Azhar and Bahringer, 2013) (Latham 1994) (Ahmed *et al.*, 2014)
Human behaviour	(Azhar and Bahringer, 2013) (Zhou, 2009) (Abdulkadir and Godfaurd, 2015)
Lack of collaboration	(Zhou, 2009) (Egan, 1998)
Lack of awareness of 4D	(Kassem *et al.,* 2012) (Abdulkadir and Godfaurd, 2015) (Ahmed *et al.*, 2014)
Perception of value	(Romigh *et al.*, 2017) (Kassem *et al.,* 2012) (Abdulkadir and Godfaurd, 2015)
Cost of software and resource	(Carson, 2018) (Zhang and Li, 2010) (Azhar and Bahringer, 2013)

Lack of experience	(Ahmed *et al.*, 2014) (Kassem *et al.,* 2012) (Azhar and Bahringer 2013)
Cost of training	(Lymath, 2014) (Azhar and Bahringer, 2013
Demand for 4D	(Lymath, 2014) (Ahmed *et al.*, 2014)
Effective hardware	(Migilinskasa *et al.*, 2013) (Zhang and Li, 2010)

Table 3 – Sample demography (sector)

Industry Sector	**Number of Participants**	**Percentage**
Construction	76	54%
Civil infrastructure	21	15%
Building services	36	26%
Manufacturing	8	5%
Total	141	100%

Table 4 - Participants level of seniority within their organisation

Role	**Number of participants**	**Percentage**
Director / Manager	20	14%
Professional	121	86%
Total participants	141	100%

Table 5 - BIM level 2 adoption

	Every project is BIM level 2	**More than 50%** of projects are BIM level 2	**Less than 50%** of projects BIM level 2	**No** projects are BIM level 2	don't know		total
Director / manager	0%	30%	30%	35%	5%		100%
Professional	7%	28%	31%	21%	13%		100%
Overall	5.7%	28.4%	30.5%	23.4%	12.1%		100%
Adopting BIM level 2		64.5%		35.5%			100%

Table 6 - Awareness of 4D in industry

	Not aware of 4D	Aware of 4D		Total
Director / manager	30.0%	70.0%		100%
Professional	25.6%	74.4%		100%
Overall	26.2%	73.8%		100%

Table 7 - Use of 4D in industry

	Not using 4D	Using 4D	Don't know		Total
Director / manager	70.0%	30.0%	0%		100%
Professional	64.5%	31.4%	4.1%		100%
Overall	65.2%	31.2%	3.5%		100%

Table 8 - Perception of 4D as a tool to reduce safety risk

Position in organisation	To what extent can 4D be used to reduce safety risk (Score out of 5)
Director / manager	3.40
Professional	3.58
Overall average	3.49