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

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Abstract

In the UK, construction remains to be a high-risk sector. The dynamic nature of construction is fraught with risk, which can often be difficult to predict and mitigate. The adoption of 4D modelling has been included within the BIM level 2 framework document PAS1192-6:2018, to support the management of health and safety. This paper focuses on the perception of industry professionals in regards to the benefits and barriers of 4D, when used for health and safety management. A focus group comprising of 10 professionals within a selection of industry related sectors were interviewed, and qualitative data collected. The data indicated an 80% awareness of 4D, with 40% of those interviewed currently adopting 4D. However, in most cases the software was not specifically used for health and safety management, although safety risks can be identified in the process. The responses indicated that the key perceived benefits of 4D were in the visualisation and planning of site activities, mainly in the location and movement of plant, working at height and logistics management. Key barriers in the adoption of 4D for health and safety were also identified, including cost, time and a culture within the industry, in which individuals and organisations find it difficult to adapt and except new ways of working.

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

1. Introduction

As digital technologies and processes become further integrated within every day work activates, the way to approach project delivery changes. The construction industry, unlike many others, is a dynamic (Getuli, Giusti, Capone, Sorbi, & Bruttini, 2018; Whitlock, Abanda, Manjia, Pettang, & Nkeng, 2018) and high-risk industry (Li et al., 2018). This high risk could be seen as both commercial risk and also health and safety risk, both areas of which require careful planning and management. The way that information flows through an organisation and a project is key to successful outcomes, ensuring that the correct information is with the correct people, at a sufficient time to enable the most effective decisions to be made. The construction industry is however, known for having complex information flows (Kumar, 2015) and in addition, deep concerns regarding health and safety management (Dawood, Miller, Patacas, & Kassem, 2014; Lacey, 2015). These factors could be traced to the nature of construction, an industry which has previously been criticised for underachieving (Egan, 1998) in addition to this an historic adversarial culture and poor health and safety performance (Egan, 1998; K; Sulankivi, Tauriainen, & Kiviniemi, 2014). Following the release of the government strategy in 2011 and the BIM level 2 mandate in 2016, Bew (2018) believes the industry has progressed, although this is still early stages of its digital transformation. Although the industry has been historically criticised for its lack of innovation (Gledson, 2016) and its adoption of new processes and technologies (Chevin, 2018), the adoption of BIM is shown to be increasing year on year (NBS, 2018) as well as new technologies now being integrated within projects becoming more common place.

The use of innovative technologies can be seen within industry, from modelling software and collaborative common data environments to robotics (Ardiny, Witwicki, & Mondada, 2015; Kuenzel, Teizer, Muller, & Bickle, 2016) and immersive technology (Barnes, 2019; Behzadi, 2016; Yi & Leung, 2019). Although a number of these are still within the testing and feasibility stages of development, 4D modelling has been an area of research, with successful case study applications over recent years.

According to Wang *et al.* (2014), a four-dimensional (4D) model is created by linking the three-dimensional components with the project schedule, this synchronisation of the graphical model components with the schedule data (Dawood et al., 2014; Zhang & Li, 2010) can therefore create a visual construction sequencing models (Gledson, 2016; Hardin & McCool, 2015). These 4D models are used for a number of proposes, including project co-ordination (Gledson, 2016), communication (Azhar & Bahringer, 2013; Ganah & John, 2015; Gledson, 2016; Kassem, Brogden, & Dawood, 2013; Romigh, Kim, & Sattineni, 2017; Kristiina; Sulankivi et al., 2013), logistical planning (Azhar & Bahringer, 2013; Whitlock et al., 2018), and visualisation (Azhar & Bahringer, 2013; Azhar, Behringer, Khalfan, Sattineni, & Maqsood, 2012; Swallow & Zulu, 2019).

As the construction industry continues to develop its adoption of building information modelling (BIM) level 2 processes and digital software, the BSI published PAS1192-6:2018, a BIM level 2 framework document focusing on collaborative sharing and use of health and safety information using BIM. Mordue and Finch (2014) suggests that BIM has been recognised and acknowledged by the HSE, suggesting that its importance is been further elevated, as a way to truly drive health and safety management. PAS1192-6:2018 indicates a clear push for the adoption of modelling software in design development and to improve health and safety (BSI, 2018), stating

> *Each participant shall adopt the use of 3D or 4D construction sequencing model(s) to the support the development and visualisation of safe methods of access and working* (BSI, 2018, p. 11).

The inclusion of 4D modelling within the PAS1192-6:2018 documentation demonstrates its acceptance within the field of information management, project delivery and health and safety. However, with the historically poor adoption of new processes and technology being an identified issue within the industry, how ready is the industry to adopt 4D modelling as standard practice for health and safety management? This paper therefore, is to document industry perceptions of 4D modelling as a tool to manage health and safety, focusing on its perceived impact, benefits and barriers within the construction industry.

2. Materials and Methods

2.1 Background of Health and Safety in the Construction Industry

The very nature of construction often poses pressure on the project team to deliver complex assets on time, to budget and without risk to health and safety. Even with simple projects, the logistics, co-ordination and quality of plant, materials and labour often pose high risk to operatives and those accessing in around the site. For this reason, a high level of health and safety management is required to manage this risk, often involving proactive control measures, which can be costly and timely to plan and execute. Phoya (2017) highlighted that although various control measures are often in place, operatives are still often exposed to risk when carrying out site activities, this is reflected by the 38 fatal injuries reported to the HSE in 2017/2018 (HSE, 2018a). A total of 2.4 million lost working days were recorded each year between 2015/16 and 2017/18 and although non-fatal injuries are on a downward trend, 50,000 are reported each year (HSE, 2018a). With these statistics, the construction industry remains to be one of the highest risk industries in the UK.

The industry is familiar with its historically poor reputation; many infamous reports have highlighted the industries shortcomings including Latham (1994), Egan (1998) and Farmer (2016). Although there has been significant improvement in health and safety and industry image, there are still further improvements to be made. The importance of company culture and personal behaviours towards health and safety has been an area of research for many years. Many methods have been used to improve this factor and in turn, aim to reduce fatality and accident statistics, although is it often these factors which are most difficult to change (Swallow & Zulu, 2019). With key legislation enforced on the industry (such as the Construction Design and Management Regulations 2015) and ethnises on training and education within the sector, further improvements in safety are a clear focus.

Project health and safety management requires planning and co-ordination of the construction team as well as understanding of the project in a holistic view. This could be a wide scope, and should include a clear understanding of the project deliverables, methodology, logistical issues and the specific personal factors of those involved with the activities. As construction projects are dynamic and assets often bespoke, this is a task, which requires precise planning and clear communication (Azhar et al., 2012). This communication is often hindered by poor information creation and exchange, adopting 'traditional' methods, resulting in miscommunication of project outputs, in particular health and safety requirements.

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

Zhang et al. (2011) suggests that planning is a fundamental step in managing health and safety in the construction industry. Traditionally, project planning and scheduling would be carried out as an isolated task from the design and modelling aspects, typically in the form of a Gantt chart. Linking the 3D project with the construction schedule can allow the construction process to be graphically visualised and simulated (Ganah & John, 2015). According to Zhou (2009) collaborative 4D should take into account the needs of various members of the project team in order to produce a robust plan, this in turn requires those creating such documents to have knowledge and experience of the construction process.

The key benefits and barriers of BIM and 4D modelling in regards to health and safety management has been an active area for research over recent years and although the culture of the industry cannot be altered by technology alone (Rowlinson, Collins, Tuuli, & Jia, 2010), the collaborative processes, changes of culture and behaviour could be effected by the adoption of use technology. Azhar & Bahringer (2013) recommend the utilization of BIM technologies in improving occupational safety, this can be achieved by allowing designers and constructors to visualise and assess project specific environments and conditions, in turn identify potential hazards. The use of digital technology, including the creation of models and simulations can further influence the ability of the project team to communicate and implement the desired work activities safety (HSE, 2018b). This view is echoed by Azhar et al. (2012) who highlights the benefits of BIM technology, in improving safety by clear collaboration and communications of project situations, linking accurate planning within detailed visualisation of proposed construction methodologies. Mahalingam et al. (2010) concur, identifying 4D as clear benefits including increased stakeholder collaboration, having further visualisation for design and constructability methods as well as being able to identify clashes within the construction process.

Whitlock et al. (2018) also described the benefits of 4D modelling, however mainly in regards to its impact on logistics management. The use of 4D modelling offers a clearer understanding and visualisation of the site layout, and allows for simulations of the construction sequences to be produced during the pre-construction stages allowing for analysis of the proposed schedule. As construction sites are dynamic, the importance of co-ordinating site activates is key. The understanding and communication of temporary site works, which facilitates the construction processes, could also be included within the 4D model. This process offers clearer co-ordination of site plant, fencing and pedestrian walkways. As opposed to a using 2D information which can be often misinterpreted or difficult to communicate, a 4D environment can provide clearer understanding amongst all of the project team of the proposed site plans and methodology. This in turn can allow for more precise logistics management, increasing the ability to foresee hazards, optimise locations of temporary works, reduce time / space clashes and to minimise health and safety risk.

Sidani et al. (2018) concluded that BIM processes and 4D modelling software can be effective in improving health and safety within the construction industry. Prevention planning methods, such as the use of 4D for visualisation of site actives in order to access potential schedule conflicts, identifying optimised sequences and to identify safety risks both during design and construction stages can be key benefits. In addition, safety training and accident investigation data can also be advantages of such methods. In an empirical study, Swallow & Zulu (2019) collected and analysed quantitative data to identify adoption and perceptions of 4D when used as a safety management tool, in light of the publication of PAS1192-6:2018. Findings indicated a 35% adoption of 4D within the construction sector and concluded that the primary purpose for its use was not in health and safety management. Key benefits being in the adding of value through visualisation and clearer communication of project outputs and scheduling co-ordination, which in turn can have a positive impact on safety. Whilst barriers included culture, resistance to change, costs and time to implement the processes and software, Kassem et al. (2013) also added by concluding that barriers include a lack of experience, universal use and contract type.

Whitlock et al. (2018) identified barriers to the adoption of 4D, with limited involvement of the supply chain and minimum levels of site training in 4D software being present. The accuracy of the 4D model once works commences was also an aspect in which could cause barriers to its use, due to the dynamic nature of construction it was highlighted that although the models where useful in identify hazards and optimising sequencing, the same processes are not necessarily utilised on site, Whitlock et al. (2018) stated

> *4D BIM logistics models produced at the outset of the project are infrequently utilised to coordinate logistics processes following commencement of the scheduled works, instead reverting back to management of construction logistics via 2D information* (Whitlock et al., 2018, p. 52)

Kassem et al. (2013) suggests barriers to implementation of 4D planning within the industry, highlighting consults limited knowledge of the benefits of 4D being a key aspect, with 34% of surveyed consultants aware of 4D. Other key barriers to the wide spread use of 4D modelling included and lack of understanding of the business value and experience amongst the workforce, in addition to this a resistance to change in working methods and software adoption in addition to the additional up front cost and time factors. Romigh et al. (2017) concluded that 4D has potential within the industry to allow clear visualisation of work processes and allows the creation of virtual alternatives which can be simulated and communicated effectively. The key issues identified being in the "cumbersome nature of the software" in addition to the training and learning curves required to operate such systems.

3. Methodology

Further to the publication of PAS1192-6:2016, promoting and advocating the use of this software to improve safety in construction, the paper sets out to investigate current perception of BIM and 4D modelling with specific regards to its uses, impact, benefits and barriers for health and safety management. A qualitative study approach was adopted and data was collected through interviews with construction industry professionals. Such an approach was deemed appropriate as the study sort to draw on the experiences and perceptions (O.Nyumba, Wilson, Derrick, & Mukherjee, 2018) of the participants who were chosen using selective sampling technique. Structured interviews, enabled the collection of data in a consistent format which could also be further explored (Farrell, 2011; Naoum, 2013), using a combination of open and closed questions. This gave the participants the opportunity to expand the response from their experience and understanding, careful considerations were given to reduce prompting of responses (Bryman & Bell, 2007). The industry professionals were selected through selective sampling (Naoum, 2013) and ranged from national contractors and designers to local contractors and subcontractors, ensuring that varied sectors were chosen to show a fair overview.

4. Results

4.1 Sample Demography

Ten interviews were conducted in order to collect qualitative data, the interviewees comprised of a selection of the industry sector professionals each holding management positions, as indicated in table 1 and 2. The data shows interviewees being within construction, civil, building services and manufacturing linked with the construction sector.

Table 1 Sample Demography (summary)

Interviewee	Position	Industry	Experience	BIM use
1	BIM manager	Building services engineering	Quantity surveying, BIM information management.	Experience on BIM level 2 projects
2	Contracts manager	Construction	Site management of complex projects, logistics management and H&S	No experience of BIM level 2 projects
3	Company director	Manufacture	Quantity surveying, risk management and procurement strategies. Senior management experience.	Experience of BIM level 2 projects
4	Company director	Manufacture	Site operations and management, product manufacturing risk management and procurement strategies. Senior management experience.	No experience of BIM level 2 projects
5	Company director	Construction	Site operations, logistics, H&S and co-ordination management. Experience in procurement and risk management.	No experience of BIM level 2 projects
6	Logistics manager	Manufacture	Site operations within construction and manufacturing. Logistics, planning and H&S management. Training and educational experience.	No experience of BIM level 2 projects

7	Senior digital manager	Civil infrastructure	Site operations and senior BIM information management. Digital technology and BIM process integration experience	Experience on BIM level 2 projects
8	Site manager	Construction	Site management of complex projects, logistics management and H&S	Experience on BIM level 2 projects
9	Product designer	Manufacture	Digital design and manufacturing. Experience in procurement and quantity surveying	No experience of BIM level 2 projects
10	Project manager	Construction	Site management of complex projects, logistics management and H&S. experience in site technologies and BIM processes	Experience on BIM level 2 projects

Table 2 Sample Demography (sector)

Industry Sector	**Interviewee**	**Total number of interviewees**	**Percentage**
Construction	2, 5, 8, 10	4	40%
Civil infrastructure	7	1	10%
Building services engineering	1	1	10%
Manufacture	3, 4, 6, 9	4	40%
Total		10	100%

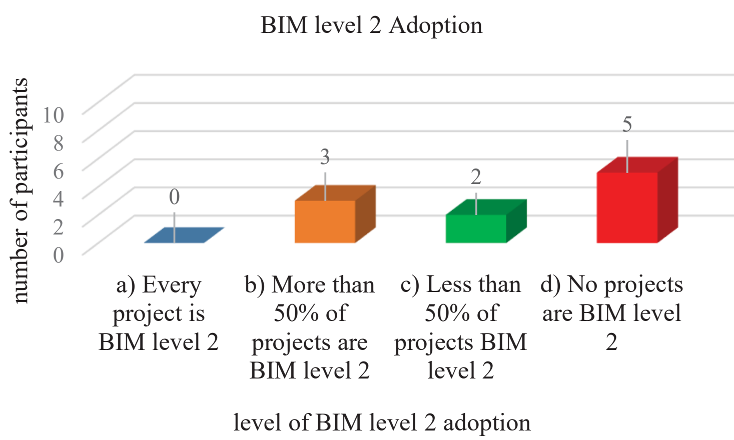
The interviews recorded the company size in which the interviewees were employed; the total employees ranged from 40 to 1000+ employees in a number of companies. This range was important in order to achieve a fair overview, as smaller scale companies may have different needs or perceptions to larger ones. Table 3 illustrates the company sizes, it can be seen that the majority (40%) of interviewees where employed by companies who employ over 1000 people although the spread is not grossly impropriate.

Table 3 Company Sizes (by employee number)

Number of employees within company	Interviewee	Total number of interviewees	Percentage
less 50 employees	4, 5, 9	3	30%
between 50 - 200 employees	2	1	10%
between 200 - 1000 employees	3, 8	2	20%
more than 1000 employees	1, 6, 7, 10	4	40%
Total		10	100%

4.2 BIM level 2 Adoption

The adoption of BIM level 2 is key to this study as the PAS1192-6:2018 document is a framework for this level of maturity. Participants where asked during the interviews to state their companies adoption of BIM level 2. The data, indicated in figure 1 shows an even division, 50% of those interviewed are working on BIM level 2 projects and that 50% are not, the adoption of BIM level 2 on every project was not confirmed by the interviewees.



BIM level 2 Adoption	Interviewee	Number of Participants Agreed	Percentage
Every project is BIM level 2		0	0%
More than 50% of projects are BIM level 2	1, 7, 10	3	30%
Less than 50% of projects BIM level 2	3, 8	2	20%
No projects are BIM level 2	2, 4, 5, 6, 9	5	50%
Total		10	100%

Figure 1 BIM level 2 Adoption

4.3 4D Modelling Awareness and Adoption

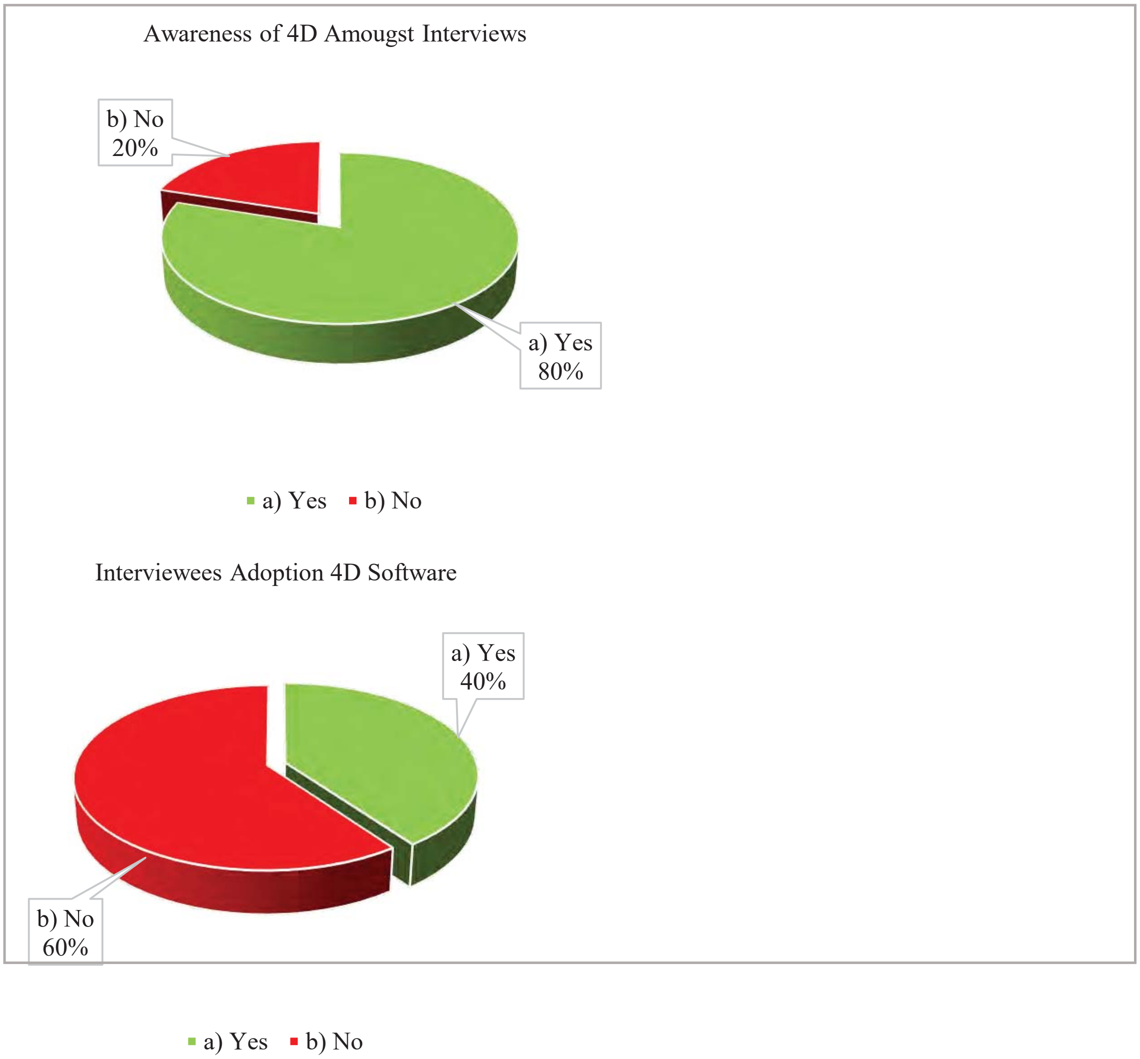
The awareness and adoption of 4D was documented for this study, figure 2 shows the total in both of these areas. The interviewee's responses indicated a high percentage of awareness of 4D at 80%, with total adoption 40% of those interviewed currently adopting 4D. The data also showed that of the interviewees who were employed by companies not working on a BIM level 2 project, 100% were aware of 4D. The interviewees who confirmed the adoption of 4D were ask to identify the software used, the software identified were Navisworks and Synchro pro. The interviewees who used the software gave additional statements in the interviews; most cases the 4D software for a number of reasons, not specifically for health and safety management.

The interviewees were asked *"if you are adopting 4D on your projects, does the software assist in the management of onsite health and safety? If so how?"*

The response to this interview question varied, although many responded stated that 4D was used for visualisation and logistics planning as apposed to a specific health and safety tool.

Interviewee 7: "*yes it does, information can passed between the project team to make informed decisions. Plans are made with a 6 week look ahead, often due to the changes on site. Projects used to be 2D and used to not take many factors into account. We are now in a 3D world, in tight sites this 4D very useful for difficult logistical planning; 4D is confirmation that you are doing things properly*"

Interviewee 9: "*It does, however health and safety is not the full the concern, 4D is more of a management tool and for visualisation"*



Interviewee	Aware of 4D	Adopting 4D
1	yes	yes
2	yes	no
3	no	no
4	yes	no
5	yes	no
6	yes	no
7	yes	yes
8	no	no
9	yes	yes
10	yes	yes

Figure 2 4D Interviewee Awareness and Adoption of 4D

4.4 Benefits to 4D Adoption for Health and Safety Management

During the structured interviews, open questions were asked, *"in regards to using 4D for health and safety management, what would you suggest are the key benefits?"* their responses were recorded and the key benefits identified from each interviewee. The data in figure 4 shows that many of the participants identified similar benefits, with perception of the benefits in the planning for site plant and vehicle movement in addition to clearer visualisation being the highest ranked.

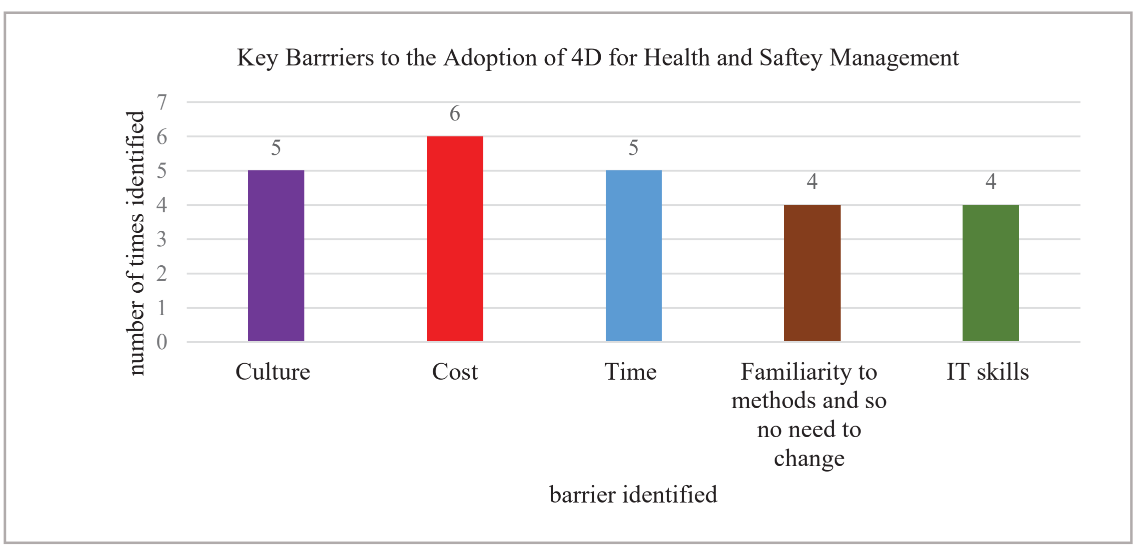
Table 4 Key Benefits to the Adoption of 4D for Health and Safety

Key Benefits to 4D Adoption for Safety Management	**Interviewee**	**Total Number of Participants Highlighted During Interviews (out of 10)**
Planning for plant location and movement	1, 2, 4, 5, 6, 7, 8, 9, 10	9
For operatives to visualise the environment	1, 2, 3, 5, 6, 7, 8, 10	8
Planning working at height	2, 3, 5, 6, 7, 8, 10	7
Planning site logistics	1, 3, 5, 6, 8	5
Planning pedestrian walkways and segregation	3, 4, 6, 9, 10	5
Planning for working in confined spaces	2, 5, 6, 9	4
Planning manual handling	4, 9	2
Planning for welfare locations	8	1

4.5 Barriers to 4D Adoption for Health and Safety Management

The interview participants were asked *"Would you say there are any barriers to using 4D modelling for safety management on site? If so what would these barriers be?"* As figure 3 indicates, a number of barriers to the use of 4D were identified, these factors also corresponded to those identified in key literature sources. The most common barriers identified being in the costs and time to implement 4D on site, inn addition a resistant culture and many unwilling to change familiar processes.

Figure 3 Interviewee Perception of the Benefits of 4D Modelling for Safety Management



key Barriers to 4D adoption Identified	Interviewee	Number Participants Highlighted (out of 10)
Culture	1, 3, 7, 8, 9	5
Cost to implement	1, 2, 4, 5, 8, 10	6
Time to implement	1, 2, 3, 4, 8	5
Familiarity to methods and so no need to change	1, 5, 9, 10	4
Lack of IT skills	4, 5, 6, 10	4

Example statements taken from the industry interviews included:

> **Interviewee 4:** *"Does the increase in time and cost in doing these 3D, 4D models really add value to the project. In theory the principal sounds good however in reality does the savings warrant the time and cost to implement?"*

> **Interviewee 5:** *"The software would need to be easy to operate and require minimal training without the need for extra staff. The software needs to be fast and adaptable"*

> **Interviewee 7:** *"There is a resistance to move people on to a new way of working".*

> **Interviewee 8:** *"Resources and training would be a barrier, the training would take time and resources cost money"*

> **Interviewee 9:** *"People fear of the new and fear of innovation"*

4.6 Influence PAS 1192-6:2018 on 4D Adoption

To conclude the interviews, the participants were asked "*Would you agree that the inclusion of 4D modelling for safety management within PAS1192-6:2018 will influence the adoption of 4D within the industry?"* Table 5 identifies the responses, with 80% agreeing that these standards will have a positive impact on the adoption of 4D for health and safety.

Table 5 Perception of PAS1192-6:2018 Having Influence on 4D Adoption

Perception of PAS1192-6:2018 in Regards to Influence on 4D adoption	Interviewee	Total (out of 10)
Yes	1, 2, 3, 6, 7, 8, 9, 10	8
No	4, 5	2

During this discussion with the interviewees, one participant noted

Interviewee 4: *4D would be useful and would help identify health and safety risks on a construction site but until the use of this becomes law, it will only be the larger company who adopt it.*

5. Discussion and Conclusion

The industry interviews confirmed a number of key aspects in regards to awareness, adoption, benefits and barriers of 4D within the construction industry. The findings indicated a high awareness of 4D amongst participants, with interviews highlighting that although 4D is used, the software is not used exclusively for health and safety. The use of 4D can have impact on health and safety by highlight hazards thoughts its visualised planning environment. The interviews identified many perceived benefits to the use of 4D for health and safety, including the increased visualisation and planning of site plant, logistics and high risk works such as working at heights. Through rehearsing of site activities and planning the project in a virtual 4D environment, the clearer visual communications can allow the optimum locations and work processes to be selected in terms of time and cost saving and site safety. The process and software allow the project team to identify foreseeable hazards allowing for clear visualisation and communication of hazard elimination and control, including the planning of both temporary works and non-temporary works.

The study validated many barriers to the adoption to 4D as standard practice in the construction industry, with the cost and time to implement alongside a culture, which is resistant to change and adopt new ways of working. The impact of PAS1192-6:2018 in regards to the adoption of 4D could be assessed in time, although the perception of its introduction looks to be positive. The adoption of BIM level 2 in the industry, as well as the awareness and education of these industry standards and benefits could also have an influence on the adoption of 4D. The industry may continue to have a slow adoption of new technologies and processes however, it is clear that in order to reduce risk during the construction stages and reduce industry fatalities, accurate planning is key. 4D allows these often-unforeseen issues to be identified, planned and managed ahead of time; with hazards removed or more effectively controlled, the reduction of risk to operatives can inevitably be achieved.

Ethics Statement

We can confirm that appropriate ethics approval was obtained for this research and that participants to the study were made aware of the purpose and nature of the study. All interview participants were advised of the voluntary nature of their participation and consented using the institution approved documents, following approved procedures.

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