

Defining the Key Considerations for Initiating and Implementing 4D BIM Workflows

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Abstract

During recent years, there has been a growing interest in the use of 4D Building Information Models (BIM) to help assist with planning construction projects. The integration of a 3D construction model with the element of time to create 4D models allows the construction process to be visualized, thereby highlighting conflicts and constraints before on site activities commence. Many researchers have evaluated the potential benefits and uses of 4D technologies, yet the process of planning with 4D technologies has not been accepted within the industry on a wide scale. It has been suggested that the use of 4D models is being restricted to the pre-construction phase at the expense of wider integration in projects.

This paper seeks to identify the key considerations for initiating and implementing 4D BIM workflows on a range of projects. To meet this aim, the research adopts a Modified Grounded Theory methodology incorporating long-term participant observations. The research found that 4D is currently used in practice for work winning, communication, validation and to a lesser extent, monitoring progress. Barriers to adopting 4D include a lack of understanding amongst practitioners, training, time and resistance to change.

Keywords

Building Information Modelling (BIM), 4D Technology, Planning, Visualization, Construction Management

1. Introduction

The construction industry – defined by the Department of Business, Innovation and Skills as contracting, services and products - is a key sector for the UK economy (BIS, 2013). The 2013 economic analysis of the construction sector highlighted the importance of the industry to the economy contributing almost £90 billion and providing almost 2.93 million jobs in the UK (BIS, 2013). The UK construction industry is often criticised for its lack of efficiency and ability to deliver to cost, quality and programme; criticisms often believed to stem from its ‘adversarial’ and ‘fragmented’ nature and evidenced in the numerous UK Government commissioned reports intended to address this perceived shortfall (see for example Simon, 1944; Banwell, 1964; Latham, 1994; Egan, 1998). Building Information Modelling (BIM) is considered by many to offer the potential to help change and improve the way the industry works. An example of this belief is provided by the UK government, which has mandated compulsory Level 2 BIM comprising of all project and asset information, documentation and data is electronic, on all UK public sector projects by 2016. The government initially began pushing the BIM initiative due to a need for better information to

give them the ability to make informed decisions. This need for ‘better’ information formed the basis of their drive towards BIM adoption.

The Government’s Industrial Strategy suggests that 30% of the construction process is rework, with 60% of labour and 10% of materials being wasted (Smith, 2013). Ultimately the aim of the Strategy is to find ways to reduce the cost of public sector construction by 20% by the end of this parliament. The strategy does not rely on BIM alone and introduces a number of changes, recognising that they, as a client, need to become ‘more informed and better coordinated’ (Cabinet Office, 2011).

2. 4D BIM

4D BIM was therefore born out of a need to overcome these issues and improve the way in which the industry works. 4D BIM introduces planning data into the model taking visualisation one step further to produce a simulation of the construction phase. The most basic definition has been provided by Eastman *et al* ‘3D models that also contain time associations’, showing that 4D is effectively the construction programme linked to a 3D model, allowing for a visualisation of the construction sequence (p.282).

Traditional Planning

Typically, construction planners interpret drawings and specifications to produce a construction schedule with task activities and sequential relationships (McKinney and Fischer, 1998). This not only requires the sequencing of activities in terms of space and time, but also considers procurement, resources and spatial constraints. McKinney and Fischer (1998) suggest that although the schedule of construction activities provides time and sequencing details, the project team will still mentally associate this information with the physical building, hence creating a ‘mental 4D model’ to visualise the construction sequence as well as any changes in the schedule or design. A 4D model removes this ‘abstraction’ as the construction sequence is represented visually through the use of 3D models.

Benefits of 4D Planning

Eastman *et al* (2011) point out that 4D construction planning requires the linking of a 3D design model to a construction programme to effectively simulate the construction process. This form of planning provides ‘considerable insight’ into how the building will be constructed (p.24). According to Fischer *et al* ‘more project stakeholders can understand a construction schedule more quickly and completely with 4D visualisations than with traditional construction management tools’ (2003, p.2). McGraw Hill (2009), in their Smart Market report, included a case study from a main contractor in the US who credited the use of 4D for helping improve their schedule in a project. They estimated a 50% reduction in labour and in their schedule highlighting tangible benefits of 4D as a planning tool.

Barriers to 4D Planning

Johansen and Wilson’s (2006) findings stressed that whilst 4D BIM was a potentially useful tool, its use was limited to marketing exercises rather than for explicit planning. Issues such as cost, set-up time and the levels of detail needed for the model are seen as barriers (Johansen and Wilson 2006). In contrast, Halpin (2005) sees inefficiency within the development of the 4D models as the factor preventing more widespread usage. Similarly, Boton *et al* (2013) have proposed that the one of the key barriers is that too many users of 4D appear to identify it as a ‘one size fits all’ type of tool without recognising that each project is unique so an element of tailoring will always be required. Another question that quite often arises is ‘who is responsible for producing and updating the model?’. De Vries and Harink (2007) emphasise that the planning expert still plays a ‘crucial role’ in the whole process, suggesting that the 4D responsibility *could* lie with the Planner.

Although there is a significant amount of research in the 4D field focusing on the potential uses and benefits of 4D, application of 4D models within the industry is still uncommon (Fischer *et al* 2003). Eastman *et al* (2011) provide some guidelines to help create a 4D model: 1. Model scope; 2. Level of detail; 3. Reorganization; 4. Temporary components; 5. Decomposition and aggregation; 6. Schedule Properties. These factors provide a starting point for the 4D process, which can then be developed according to project requirements.

3. Methodology

The modified Grounded Theory approach adopted in this research draws on the work of Glaser and Strauss' (1967). The 'grounded' aspect allows the theory to emerge from the data whilst also taking account of existing knowledge. One of the research team worked in a number of 4D active environments during the work taking a participant observer role (see table 1). In the early stages of the work, she worked at a 4D consultancy interacting with a number of Main Contractors who were in the process of implementing, or starting to implement 4D within their organisations. The work involved, '...the systematic observation, recording, description, analysis and interpretation of people's behaviour' (Saunders *et al* 2012, p.288); this therefore allowed a considerable amount of 'richness' to be developed. The four observations that were carried out were in a number of different formats (see Table 1):

	Description	Organisation Type	Contact	Role of Researcher
1	Meeting between 4D consultant and contractor to determine initial implementation of 4D	Small privately owned construction firm	Director of Pre-Construction	4D Consultant – advise on the implementation of 4D in relation to Synchro Pro software
2	4D Conference organised by a 4D software provider	N/A	Planners, CAD Techs, PMs, etc.	Conference Attendee
3	4D consultancy periodically	Main contractor (national design, construction & infrastructure services to public & private clients)	Senior Planner	4D Consultant – produce a 4D model for tender submission-update periodically as on-site progress monitoring tool
4	4D consultancy	National Main Contractor	Senior Planner	4D Consultant – produce a 4D model for presentation purposes

Table 1: Descriptions of Participant Observations

To supplement the participant observation work, six formal semi-structured interviews were also carried out. Different iterations of interview guide developed contemporaneously with the literature review to support the emerging theory. The data was coded using a manual coding technique; as data became available, it was reviewed, analysed and interpreted. The constant comparative method then allowed the analysis process to follow a cyclical manner allowing the researcher to constantly return to the data. Living with the data and experience is important in participant observation and regular journal entries and analytical memos helped develop the work.

4. Themes

Four broad themes or categories were developed, with these further distilled into sub-categories, as shown in Figure 1:

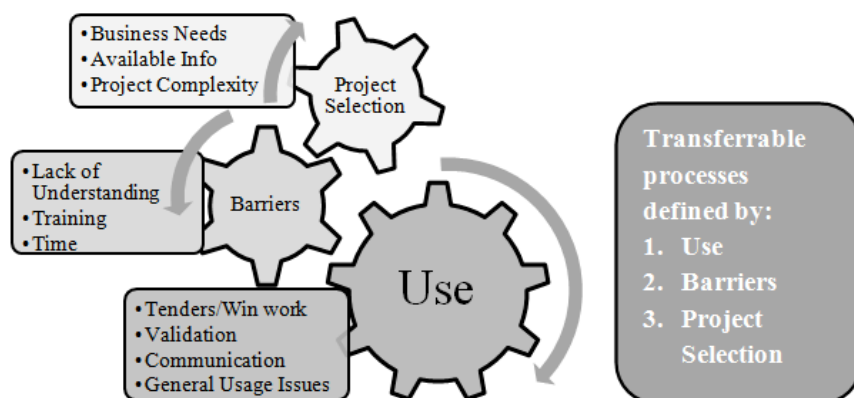


Figure 1: Key Themes

Use

Tenders/Win Work

The study found that 4D models were either being used, or considered for use, overwhelmingly as a communication and sales technique in tender submissions. One participant at a private contractor looking

to bring 4D onto their projects stated that they felt the key benefits of 4D for them would be purely from a presentation and work winning point of view. A similar viewpoint was also demonstrated by a participant from a much larger contracting firm. Although they were very familiar with 4D, it was only used in tender submissions:

'Up until very recently we have only really implemented 4D at the tender stage...It works well for us as a means of presentation – whether it is the annotated stills for the document or the animation we send off on a CD.'

These sentiments were also echoed by a Senior Project Manager who identified that the use of 4D 'provides consistent bid returns'.

Validation

A phrase that was also used quite often by the participants during the interviews was 'validation' – the 4D model was used to validate their project programme. One interview with the 4D lead at a large, worldwide construction company showed that the main use of 4D in their case was for validation, stating that:

'A progressed model allows for a visual representation of the construction sequence at any given point in time so you can show this to the clients as a means of validating your programme. I can easily compare a time slice from the 4D model to the image on the webcam out on site'.

Communication

One participant, a senior planner for a large UK based contractor, also shared a similar viewpoint. Here the model was put together to show the planned vs. actual programme to the client at progress meetings. Again it shows there are some cases where 4D is being used for planning as well as presentation and communication. This finding concurs with the work of Azhar *et al* who stated that 4D was 'a great tool for educating workers in quick time about the site hazards' (2012, p.6). This is not dissimilar to a case study featured in McGraw Hill's Smart Market Report (2010). Here the project was a crown court in the UK, and the 4D model was used both as a visualisation tool but also to assist with the tender presentation (McGraw Hill 2010). Azhar *et al* (2012), on the other hand, noted that 4D had been used in one US case study as a progress monitoring tool; this shows that is a real mixture of usage of 4D and highlights the difference between the UK and foreign construction industries.

General Usage Findings

Initial analysis appeared to show that there was a divide between the larger and smaller contractors prompting further exploration. The BIM Manager at one of the UK's largest contractors was interviewed as part of the research and it became evident very quickly that there was not really any structured implementation of 4D in general. When questioned further on why this was the case, the BIM Manager went on to explain that they had only recently put a BIM Strategy in place to meet the Government's 2016 Level 2 BIM requirements, and were still outlining protocols for 3D modelling and the sharing of data. As a result, any structured procedures for the use of 4D had not been explored. The BIM Manager did note that various endeavours had been made to look into 4D technologies on a general evaluative basis to allow them to make an informed decision in the future.

These use cases clearly highlight that there is a greater potential for the use of 4D, however with many contractors focussing on meeting the Government's 2016 Level 2 BIM requirements, 4D is not seen as a priority yet. This being said, those who are using 4D to some extent, whether it be for work winning or communication, are finding that there is more they could be doing with their 4D model, highlighting that perhaps there may be certain barriers that need to be overcome first before the next step can be made in terms of using 4D as a planning tool.

Barriers

It quickly became evident that there were four key barriers to the implementation of 4D, although they were very closely linked; lack of understanding, training, time and resistance to change.

Lack of Understanding

For a small privately owned construction company that was still new to 4D, it quickly became evident that the key issue they faced in this case was a lack of knowledge about 4D in general. Whilst discussing the initial use of 4D as part of tender submissions and presenting to clients, the Head of the Bid Team became quite confused on how this 4D model could benefit them beyond the tender stage. The company were aware of 4D, however they had not been using it on any projects. Another area of confusion was the composition of the 4D model including how the initial 3D models should be arranged and whether there were any specific requirements and decisions that needed to be addressed early on in the process. Interestingly enough, there were very few questions with regards to technology and software choice, indicating that technology may not be as big a barrier as many perceive.

The 4D conference offered a rich research experience and indicated that the majority – if not all – of those present had sufficient knowledge of 4D to want to move past the ‘why?’ and focus more on the ‘how?’ questions. This is in line with the findings of the National BIM Report 2013 (NBS, 2013), but appeared to contradict the first observation in this study where lack of knowledge was experienced as a major barrier evidencing the developing state of maturity in the industry. With this in mind however, it is important to note that there are now an increasing number of organisations who are providing training in 4D, indicating that perhaps this issue of lack of knowledge may be overcome sooner rather than later.

Training

The majority of contractors spoken to both during interviews and participant observations, indicated that on the majority of projects, the 4D aspect was subcontracted out to a third party organisation. As a result, the planner is used to dealing with 4D consultants who produce the models to match the project programme and then assign the models to tasks in the 4D software. The planner therefore has never really required any in depth understanding into the software and the process involved. Where organisations are looking to bring this in-house, there will also be a training requirement to allow the planner to reach a stage where he is able to produce the model. Khatib (2007) noted a similar viewpoint, identifying that due to a lack of knowledge many contractors are using external 4D consultants to produce these models for them to allow them to receive the benefits of 4D.

It is interesting to note that the interviews to date had indicated that it tended to be the Planners who were most likely to be using the 4D software rather than CAD technicians or Project Managers. When questioned, the 4D Lead was adamant that it must be the planner who puts the 4D model together: *‘The planner! They understand their programme – they will be the one to validate it.’* When looking at 4D as a planning tool it would seem sensible for the main user to be the planner; this therefore highlights the potential barriers that can be faced by the planner, and where training is required there is also a time issue to consider.

Time

The conference also provided an insight into another barrier that contractors are facing when implementing 4D; lack of time. Those present at the conference were all aware of the potential uses and benefits of 4D; however, many of them were still using it for tenders and presentations, and in some cases there were no immediate plans for further implementation. It became evident very quickly that this was due to time constraints more than anything else; this corresponds with previous interviews that were conducted. Interestingly enough, the questions at the conference that did not relate to the technology were related to 4D as a planning tool suggesting that the industry is heading towards the adoption of 4D as a planning tool, it may just be a slow process. The 4D Lead involved in the study emphasised that this was the biggest barrier they face:

‘The biggest kickback is that it is very timely. The process of linking takes a lot of time particularly where the model does not match the programme.’

A Senior Project Manager agreed stating that their biggest issue was ‘the time frame it takes to put a 4D programme together’. This appears to be one of the main issues with implementing 4D at present. With so many contractors placing an emphasis on meeting the Governments Level 2 BIM mandate for 2016, 4D is

far from their key focus. Many perceive that setting up a 4D environment with the correct procedures and workflows is a time consuming process, and with planners already playing a vital role on a construction project, the addition of 4D to their scope of works is currently not a priority.

Project Selection

Business Goals

The most obvious method of selecting projects for 4D would be according to business need. This ultimately means that projects that have a specific 4D requirement would be prioritised. The level of implementation would of course differ. This is quite similar to the findings in the fourth observation where the 4D and the 5D elements were effectively implemented on a project to ‘tick boxes’. Although the model was progressed to be used as planned vs. actual, there was also an indication that it was more of an exercise to ‘tick boxes’. Therefore although this is a good start, it raises the question on whether this level of implementation will be followed through in the future and whether the full benefits of 4D will be realised. This also corresponds with the literature; Peter Rumpf (see Deutsch, 2011, p.142) stated that ‘Those that view BIM or VDC as just another contractual requirement to be ‘dealt’ with miss the true value of VDC’.

These sentiments were echoed in the first interview, with the 4D Lead suggesting that there are some cases where 4D may not be being used effectively. He found that: *‘Quite often, it (4D) is still being used on a one-off basis, to say they are doing it. I think the key here is to upskill staff so that everyone is on a common level.’* However, the participant did emphasise that the industry is still in the process of understanding BIM in general and working to make better use of the 3D element and sharing of data on a common level before venturing into 4D. Similar observations were made by the Project Manger who explained:

‘4D is like one stepping stone on the road to BIM. At this point, there are still many contractors focussing on getting the 3D right, and until there are processes and protocols in place to make the sharing of data more efficient, focussing on the 4D may not take priority.’

Available Information

The 4D lead also discussed how projects were chosen to adopt the 4D approach and stated that quite often projects that have 3D models available tend to be prioritised. However, the question then arises, that if the models were prepared without 4D in mind, how suitable would they be, and how easily could they be used to set up a 4D model? This drives at the heart of the initiation of the model – where consultants do not develop the models from first principles, contractors are less likely to develop their own 4D model unless they see definitive benefits from doing so. From this it would appear that the availability of models is restricting its usage. Perhaps there is a more efficient method of making use of models that are supplied. For example, some 4D technologies allow for elements in the model to be split down once the model has been imported into the software. This could potentially remove some of the restrictions placed in terms of model quality. However, with the advent of BIM, 3D models will be produced as standard on many projects, indicating that this barrier could potentially be overcome with regards to the selection process. There was a similar response from the second interview, however, here the BIM Manager went one step further to say that if the supply chain was involved earlier, these specific modelling protocols could be set up sooner therefore projects could be chosen on merit rather than on suitable models.

Project Complexity

One participant, a senior planner, explained that 4D was chosen for projects based on value and complexity. This aligns with the research carried out by Kassem (2012, p.6) where he noted that ‘use may be based on project size and/or complexity rather than a widespread blanket use’. The Senior Planner then went on to explain further, that another example was where there were two build options that needed to be demonstrated to the client so 4D was the ‘perfect way’ to get this across to the client, rather than by two separate Gantt charts with different dates. This seems to correspond with the findings from the interview with the 4D Lead, and also Eastman et al.’s (2009, p. 285) findings that 4D can communicate a schedule ‘more effectively than a traditional Gantt chart’. At this point it appears that the majority of

projects are chosen based on where information is made available and the complex nature of the projects. This highlights that although 4D is being used and this is a step in the right direction, it would appear that there could and should be a more efficient way of selecting and working on 4D projects.

5. Transferable Processes

This section yielded mixed results. Ultimately there was no definitive yes or no answer on whether processes are transferrable between projects, predominantly because there was a lack of documented workflows within organisations. In terms of the output, according to the 4D Lead, these will generally take one of three formats: a live 4D model file, screenshots or an animation. The actual output would in many cases differ due to the purpose of the 4D model; if the purposes of the models were similar then perhaps a basic process chart could be determined in terms of information that is required to put the model together and the relationships between the different elements. A Senior Project Manager explained that some processes and workflows are transferrable regardless of the project:

'...we try not to reinvent the wheel and try to use existing work flows and processes'

From the participant observations, a basic example can be taken: the third and fourth observations focus on 4D models that were initially put together for tenders; a similar workflow between the projects can be seen. This could potentially be translated into a very broad procedure that corresponds to the model development and can be used as a starting point to ensure the correct information is available at the correct time. Following this, additional detail could be added to allow it to encompass a range of 4D requirements. Based on Eastman et al.'s (2011) model and the data gathered in this study, an attempt has been made to provide a starting point of key considerations. Based on the workflows and processes that were identified in the observations and interviews, the researcher was able to determine a generic process in Figure 2 that indicates the main headings and questions to be considered when developing a 4D model based on current working practices.

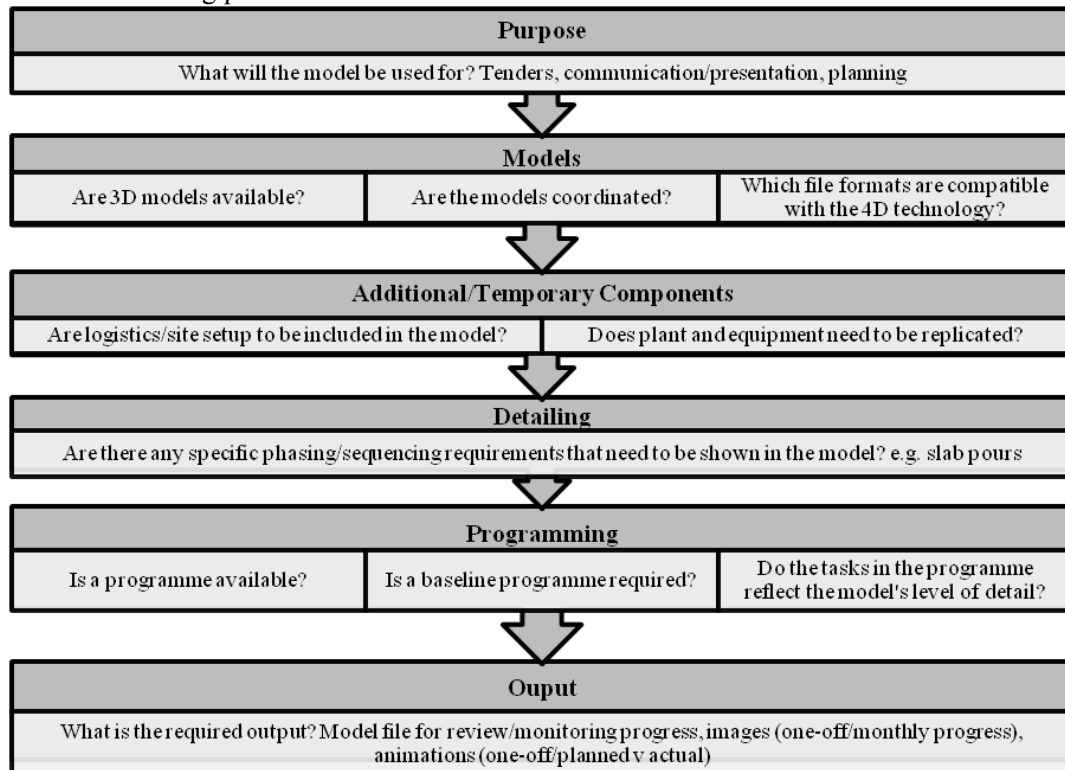


Figure 2: Key considerations when developing 4D models

It is evident that for the process of putting a 4D model together to run smoothly, it would be most efficient if the planner and the design team were on board early enough to be able to collaborate on the production of the model. It is important to note however that all these headings may not be relevant on all

projects as highlighted in the first interview due to the unique nature of projects. As noted, with more complex uses, for example models to monitor progress and create planned v actual, this type of process chart would have to be much more detailed in terms of the headings as the content would be more difficult to envelope under a single heading. The requirements for such projects would be more complex and as such – at this stage – would need to be almost bespoke in nature according to each project requirement. This aligns with the views of Boton et al. (2013) who found that ‘one size’ does not fit all. This being said however, the researcher has been able to use the data to determine the questions that would need to be asked when 4D is being used beyond the work winning stage and as such has begun to incorporate these into the process.

6. Recommendations

It is recommended that to be able to advance the work presented on the efficient use of 4D to date, a more in-depth study with a greater number of participants over a longer period of time be carried out. It is envisaged that such a study would yield results that could assist in forming what could be used as a basis of a more formalised protocol for the use of 4D as a planning tool, similar to how BIM Execution Plans and BIM Protocols are being put in place amongst the various contractors to meet the Level 2 requirements for 2016. Primarily, having some formal workflow in place could assist in eliminating the issues that arise due to a lack of knowledge and understanding. Not only this, but the additional guidance will then allow for contractors to manage the 4D element of projects more proficiently as the guide should allow them to overcome the ‘time’ element; potentially they would not be required to start completely unaided, allowing them to implement a more efficient use of 4D.

Ultimately, the industry is heading in such a direction that 4D planning will become the norm on construction projects. Once this becomes evident, there will then be potential for 4D to be integrated with Lean methods of working to take 4D planning one step further into the realms of location based scheduling and flow line scheduling to allow for resources and production rates to drive the schedule rather than the dates. This will allow for a truly integrated workflow and will not only maximise the efficiencies of 4D but also BIM in general.

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