THE IMPLEMENTATION AND USE OF 4D BIM AND VIRTUAL CONSTRUCTION

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The 2013 UK Government construction strategy, presented at its 'Construction Summit' set targets for 50% faster project delivery and reductions in the overall delivery time for new build and refurbished assets. Despite the best efforts of constructors, who have considerable in house experience, skills and knowledge in project delivery, more than half of all UK construction projects exceed their agreed time schedules; with current data revealing the worst performance for 12 years. The concurrent drive for all centrally procured public construction projects to be working at BIM Level 2 by 2016 is seen as an important step in improving the quality of project information, which, in turn, should result in improvements in project predictability, including predictability of both time and cost. The current research investigates how contracting organisations have adapted their existing practices to utilize BIM and improve project delivery. As part of the work a quantitative survey was undertaken that focused upon the current use of virtual construction. Results show a high level of BIM awareness and a more limited degree of experience of using virtual construction practices to improve construction planning. There was, however, a generally high level of recognition of the potential value of 4D planning. With additional data, the study will investigate whether potential benefits of 4D planning are being actualised, as well as exploring associations between the extent and nature of its use and characteristics of the user organisations.

Keywords: 4D planning, building information modelling (BIM), construction planning, construction scheduling, virtual construction.

INTRODUCTION

Lean processes and new technologies including Building Information Modelling (BIM) have regularly been proposed for tackling the construction industry's production problems. In order for such initiatives to succeed, the industry must continually measure its own performance and act upon the results, something it has, in part, achieved by the widespread adoption of Key Performance Indicators (KPIs). Currently, however, more than half of UK construction projects exceed their agreed time schedules; 'time predictability' KPIs for 2102 are the worst in 12 years (see Table 1, below) with only 34% of projects being delivered on time overall and only 42% of construction phases completing on time (Constructing Excellence 2012).

Crotty (2012) has highlighted 'poor predictability' to be one of the 'first order issues' facing the construction industry; poor quality project information to be its primary cause; and the use of BIM, mandated for all centrally procured public construction projects by 2016, to be an important step in improving this situation.

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Table 1: Construction time predictability for years 2007 - 2012 -percentage of projects and phases delivered on time or better. Table adapted from Constructing Excellence (2012)

KPI	2007	2008	2009	2010	2011	2012
Predictability Time: Project	58	45	45	43	45	34
Predictability Time : Design	58	58	53	69	51	48
Predictability Time: Construction	65	58	59	57	60	42

Since the announcement of the 'BIM mandate' in its 2011 Construction Strategy (HM Government, 2011) there has been a large volume of work published on aspects of BIM implementation. The specific aim of the present study is to investigate the extent to which contractors are using 'alternative' BIM-based methods of planning construction work. The following discussion briefly considers key aspects of conventional construction planning then focuses on 4D BIM.

Conventional construction planning

Cooke and Williams (2009) see the planning process as involving: gathering information (including establishing key dates and constraints); identifying key activities and events; assessing of durations; establishing logic and sequence; and presenting the plan in a suitable medium.

Historically, the key elements of the construction plan were activities, durations, sequence and timescale, communicated on the earliest (circa 1910) hand drawn programmes. The introduction of networks in the 1950's allowed logic links to be established, and use of the critical path method (CPM) allowed critical tasks and float to be determined. From the 1980s, the use of construction planning and scheduling software enabled the planner to use the bar chart format - preferable to many over the network view - to make explicit logical relationships, float and task criticality. Using CPM software also enabled project progress to be recorded, delays to be identified, and the impact of resources and costs to be clearly communicated. Criticisms of these conventional methods of presentation included their failure to take necessary account of spatial and location-based aspects when activities are sequenced: the formats used to communicate the plan are independent from the building design and addressing the spatial aspects is left to the experience and intuition of the individual planner (Winch and North 2006). Others criticise the fact that project control frequently overshadows action planning, and scheduling is overemphasised at the expense of methods planning (Laufer and Tucker 1987; Faniran *et al*. 1994).

Building Information Modelling and 4D virtual construction

Koo and Fischer (2000) have argued that the addition of a 'fourth dimension' (i.e. time) to a 3D-model could be useful for project and construction management. Subsequent work has employed a range of terminology, including: 4D CAD (Koo and Fischer 2000; Heesom and Mahdjoubi 2004); 4D-Modeling (Buchmann-Slorup and Andersson 2010); 4D Planning and Scheduling (Rischmoller and Alarcón 2002); 4D Simulation (Heesom and Mahdjoubi 2002; Tulke and Hanff 2007); 4D site management model or 4DSMM, (Chau *et al*. 2005a; Chau *et al*. 2005b) and 4D Technology (Wang *et al*. 2004; Hu *et al*. 2008). Amidst this terminological variety it is clear that 4D planning involves linking a time schedule to a 3D-model to improve construction planning techniques through:

- visualisation of the time and space relationships of construction activities (Liston *et al*. 2001; Heesom and Mahdjoubi 2002; Buchmann-Slorup and Andersson 2010);
- analysing the construction schedule to assess its implementation (Koo and Fischer, 2000);
- reducing errors through plan interrogation/validation, simultaneously improving communication between project team members (Dawood, 2010).

The origins of 4D can be traced back to the late 1980s in a collaboration between Bechtel and Hitachi Ltd (Rischmoller and Alarcón 2002) and to the work of Fischer and associates from Stanford University who created the original technique for producing visual 4D models (Dawood and Mallasi, 2006). Over time, technology has advanced. Whereas earlier versions simply made use of 3D 'dumb' design in design software and allowed for the incorporation of time associations, dedicated virtual construction (VC) tools now enable the incorporation of multiple models and schedule data to link intelligent objects to individual resource-loaded and logic-linked activities.

The functionality of the planning process may be improved in a number of ways through the use of 4D. These include: the ability to gather information from a coordinated project information repository; improved ability to identify activities through model interrogation; and calculation of durations using automated quantity extraction processes. These enhancements should enable the planner to produce more accurate schedules and more effectively communicate aspects of the plan (including construction methods and sequence, directing the plan recipient toward the exact location of work content, and the impacts of resource movement and site logistics). Hazardous activities can also be emphasised.

Chau *et al*. (2003) have identified the inputs necessary for a 4D model as follows:

29. a 3D geometric model with building components and operational objects;
30. a construction programme (with activity data, durations, logical relationships) ;
31. a central processor in the form of a 4D simulation tool that allows the linking of the 3D model and the programme data.

Tulke and Hanff (2007) provide a detailed description of the process (and the challenges) of importing and linking the separate 3D model and programme data before defining the visual parameters of how and when objects appear in a 4D simulation.

The interaction of BIM and Lean

Along with performance measurement and prior to BIM, one of the more prominent process improvement efforts championed within the construction research community was that of lean principles and concepts applied to project delivery. There have been several significant successes in improving the time predictability of construction projects using approaches such as the 'Last Planner System' and 'Lean Project Delivery System' as promoted by the Lean Construction Institute. Furthermore, Sacks *et al*. (2010) have recognised potential synergies between Lean and BIM and proposed 56 distinct interactions as opportunities for further research. Seven of these interactions were incorporated into the design of the current research (see Table 2, below).

Table 2: Lean/BIM interactions and current research questions

Interaction description (adapted from Sacks et al., 2010)	Interaction	Question
Building complexity - BIM simplifies the task of understanding designs, helping construction planners deal with complex products	3	23, 28, 32
Automated task generation for planning helps avoid human errors such as omission of tasks or work stages.	14	32
Discrete event simulation used to test and improve production processes and to run virtual first-run studies which are often impractical	15	31, 33
Animations of production or installation sequences can be prepared. These guide workers in how to perform work ensuring standardized procedures	17	31, 32
Discrete event simulation can reveal uneven work allocations and support assessment of work assignments to level production	37	38
4D sequences provide opportunities to visualize construction processes, identify resource time & space conflicts for optimization	40	28, 29
Visualization of proposed schedules and visualization of ongoing processes verify and validate process information	47	31, 32

RESEARCH METHODOLOGY AND FINDINGS

The target population of the study were those involved in the delivery of construction projects, including those who provide professional design and management services. A questionnaire survey was considered to be an appropriate means of data collection for this study. A structured questionnaire was developed and distributed direct to 321 randomly selected construction professionals between July 2013 and March 2014. A total of 122 full responses were received, giving a response rate of 38%. An additional 39 partial responses were received although these were excluded from analysis due to their incompleteness.

The first section of the questionnaire required the respondents to provide information about their industry profile, and consisted of general demographic questions over company size in terms of number of employees and annual turnover. The respondents were to provide detail as to the total number and value of any projects they had been associated with that had incorporated BIM in any capacity. Section 2 focused upon issues around BIM implementation including adoption timescale and maturity of their own company and wider industry, along with any implementation strategies demonstrated by their own company. This section required respondents to rank external barriers to BIM adoption, internal factors that influenced implementation, and its benefits. The third section focused upon 4D planning, virtual construction (VC) and the virtual construction environment (VCE). This section required respondents to identify how their companies had used any elements of VC and VCE and compare 4D planning and new methods of working afforded by BIM with conventional planning. Only a selection of the findings is presented in this paper due to space constraints.

Findings

In terms of job function (Q3), the highest proportion (46%) of respondents was, appropriately, 'Planners'. In Q8, 55% of the respondents identified themselves as working for large companies, (250+ employees) with 25% working for a small company (1-49 employees) and the remaining 20% for medium-size enterprises. In Q9 the largest percentage (25%) gave their firm's turnover as 'over £500 million per year'. In Q12, 55% of the respondents indicated that they had been involved in 1-5 BIM projects and 7% that they had been involved in 6 to 10 projects. Interestingly 3% of respondents reported an involvement with 50+ BIM projects, and in response to a separate question (Q13), 16% indicated that the approximate total value of the BIM projects that they had been involved in was over £100 million(s); though 26% reported that they had not worked on any project using BIM 'in any capacity'.

Section 2 revealed details about if and how the respondent's organisation was implementing BIM. A majority (64%) confirmed that their company had started implementing BIM (Q15), and 22% they were 'planning to'. Most respondents (61%) thought the government 2016 target to be 'realistic' (Q16). In Q17, 50% assessed their companies' BIM maturity at Level I, and 30% at Level II. A majority of respondents (62%) predicted that by 2016 their company would meet the Level II requirements (Q19) with 19% believing that they would be in the Level III category.

A concern the industry faces in the implementation of any new initiative is overcoming cultural barriers to its acceptance. For Q18, which addressed this, Alarcon and Conte's list of 'critical organisational elements' (Alarcon and Conte, 2003, cited in Johansen *et al*, 2004) was used (see Figure 1, below).

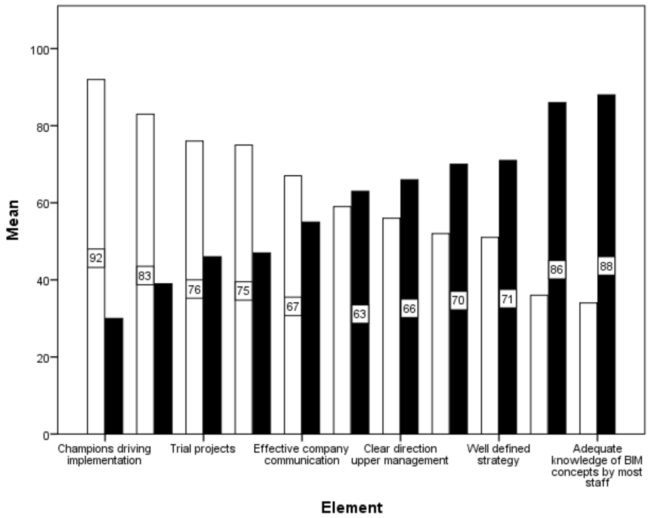

Figure 1: In terms of BIM implementation would you agree (white bins) or disagree (black bins) that your company has the following elements. Highest counts only shown

Highest scoring 'agreement' categories include 'key personnel or champions driving implementation' (75%; n = 92), 'high commitment from upper management' (68%; n = 83), and 'special task force driving implementation' (62%; n = 75). Highest scoring 'disagreement' categories were 'a lack of adequate knowledge of BIM concepts' (72%; n=88) or 'BIM implementation efforts' (71%; n = 86) from staff at the same level as the respondent. Despite high levels of management commitment indicated, there are many who believe their company does not have 'well-defined implementation strategy' (58%; n = 71); that there is 'no clear direction from upper management' (54%; n = 66); the company 'does not have a clear methodology' (54%; n = 66) and does not 'effectively communicate lessons learned throughout the company' (57%; n = 70).

In Q20 respondents were provided with a list of 8 'external barriers' to BIM implementation identified from the literature, and were asked to place these barriers in order. Using a weighted calculation (items ranked first valued higher than following ranks), the result show 'the fragmented nature of the industry' itself (649) as the most important issue, with 'time and commercial pressures' (625), 'culture and human issues' (623), a 'lack of adequate BIM awareness and understanding' (619) and 'the structure of procurements and contracts' (601) grouped closely as the next most important reasons. Respondents ranked 'lack of leadership' (474) and issues around education and training (404) as less important with 'lack of proof of performance from measurement systems' (397) ranked as the lowest external barrier. Qualitative comments were also sought regarding further external barriers, and responses demonstrated a preoccupation with client issues. These included,

"Unclear benefits for Client, the majority of the benefit lie with the contractor."

"Clients not understanding that they need to define what they want from BIM and how they want it using on a project."

"Feel that generally, projects that will implement BIM will be driven by Clients who want to be market leaders and not by contractors or design teams."

"There is still a lack of client demand for principal contractors to implement BIM..."

"Lack of client awareness ... and mentality that a traditional BOQ project is cheapest"

In Q22 respondents were asked to rank, in order of importance, the three aspects of organizational infrastructure as identified by Sacks *et al.* (2010). The intention was to determine the real internal challenges to BIM implementation. Using the weighted calculation the respondents scored 'people issues' (272) as being the most significant internal challenge followed by 'process issues' (251), then 'technology issues' (209). Using the same method, Q23 asked respondents to rank the broad order of BIM benefits. 'Improvements in communication and collaboration' scored highest (305) with 'improvements in product (asset) modelling' scoring (214) and 'process modelling and analysis' scoring almost equally (213).

Section 3 of the survey specifically focused on the use of 4D and VC techniques. In Q27, respondents were asked to confirm any use of VC within their company. It was confirmed by 53% of respondents that their company had used elements of VC on live projects, with a further 14% reporting that their company had investigated its use but not yet used any elements on live projects. A further 21% answered that the company had not used it before and 12% were unsure. Q28 asked respondents to confirm use of VC within the categories shown in Figure 2 (below).

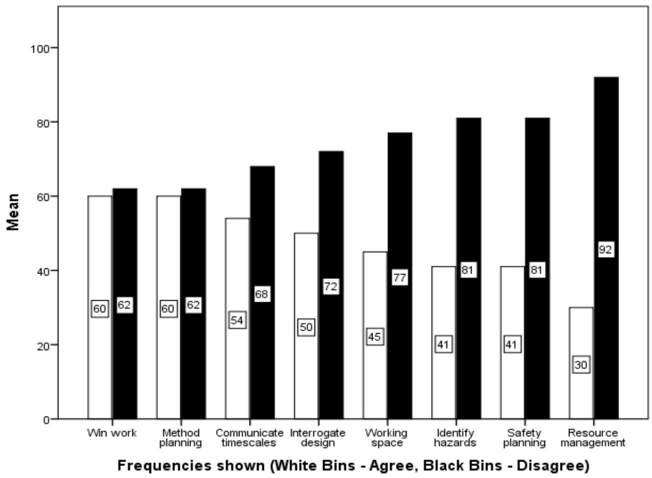

Figure 2: Categories of VC use.

Figure 2 shows that whilst all categories score higher in terms of negative responses nearly half of all respondents are aware that VC had been used in their organisation to help work winning activities and to assist in the planning of construction methods.

Both categories showed 49% (n = 60) as 'agree'. In Q29, respondents were asked to confirm any use of a Virtual Construction Environment (VCE) for site layout planning within the categories shown in Figure 3 (below).

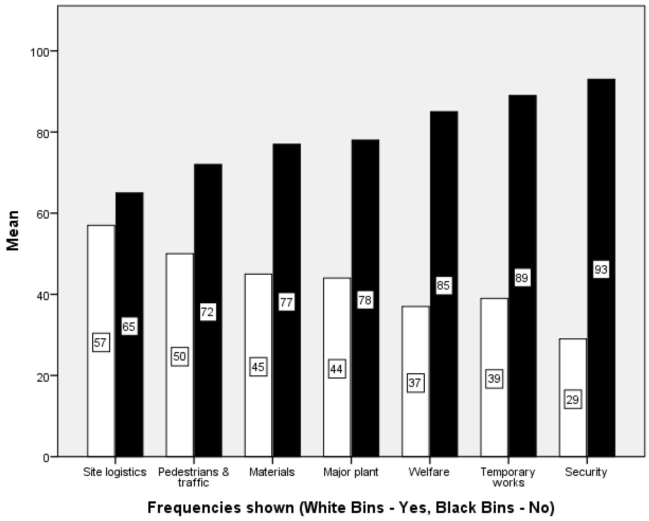

Figure 3: Categories of Virtual Construction Environment (VCE) for site layout planning

As previously, all categories scored higher negative counts for 'use of the virtual construction environment', but nearly half of all respondents were aware that the VCE had been used in their organisation to plan site logistics (47%; n = 57), and in 'pedestrian and traffic management planning' (41%; n = 50).

In Q30 respondents were asked the value that 4D planning would add to their business. As shown in Figure 4 (below), most respondents agreed that 4D planning would add value to their business: as indicated in Figure 4, the mean and median scores were 3.79 and 4.00 respectively.

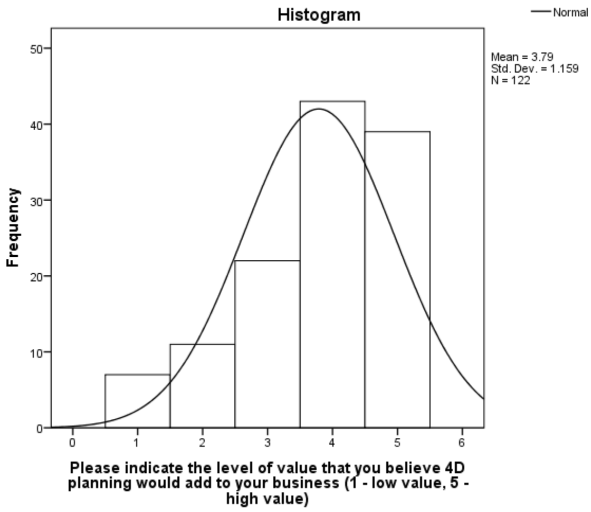

Figure 4: Value of 4D planning

Further comments were on project complexities, sector inefficiencies, and work winning/schedule validation; examples being:

"... [it's] for sufficiently complex projects, with sufficiently ambitious goals"

"Only…sector which has not improved in efficiency and productivity is the construction industry…slow at adopting digital tools that allowed others…to progress"

"… schedule validation before construction starts can help to reduce … risk, avoid unforeseen costs such as those associated with having to dismantle plant, help with crane planning etc., and helps improve … decisions made early in the design phase"

"There isn't a big difference between selling/convincing mode and testing/validating mode. Just the audience"

In Q31 respondents were asked to rate how 4D planning may offer improvements over traditional planning processes in a prescribed number of aspects of the planning process. The responses, graded between '4D can offer significant improvement' and 'Traditional planning [is] better' are shown in Figure 5, below.

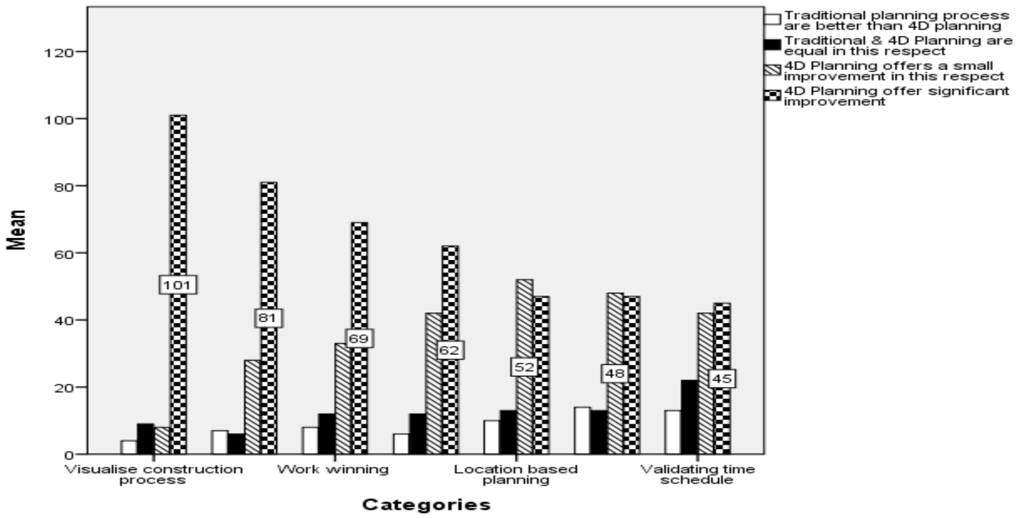

Figure 5: Traditional planning process versus 4D planning processes, highest counts shown.

Despite high negative responses received for questions 28 and 29, this question clearly shows that in nearly every category, respondents thought that 4D planning offered significant improvements over traditional planning processes.

The highest-scoring category was visualising construction processes (83%; n = 101), and understanding construction processes (66%; n = 81). The two categories where respondents believed that 4D planning processes offered small improvements against traditional planning processes were in location based planning (43%; n = 52) and progress reporting (39%; n = 48). Traditional planning processes scored low across each category.

In Q32, respondents reported how new methods of working may offer improvements over traditional methods at each stage of the planning process, using the same available response options and the results of this question are shown in Figure 6 below.

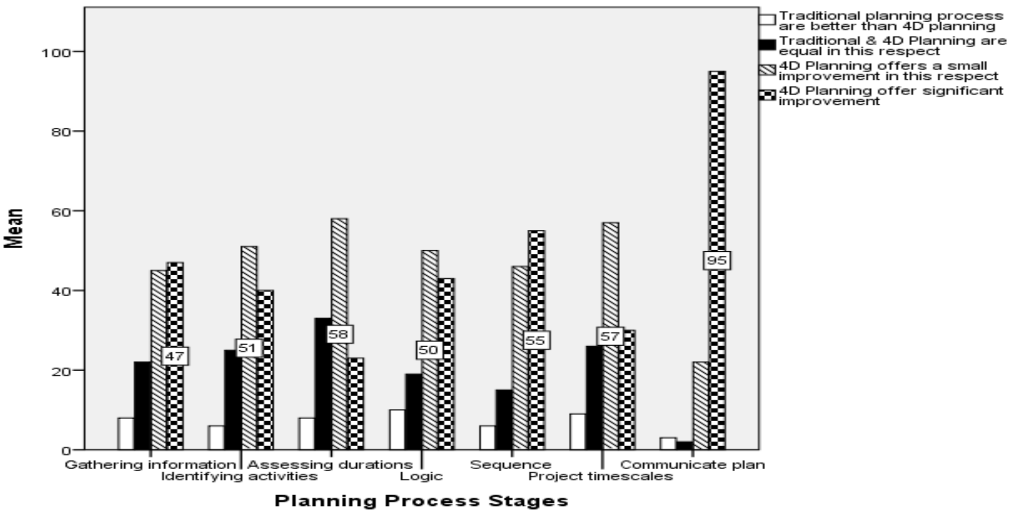

Figure 6: Traditional methods versus new methods of working: stages of the planning process

The highest-scoring area of benefit that new methods of working were seen to offer was in 'communicating the plan' (78%; n = 95). Two areas where new methods did not seem to score particularly well were in 'assessing durations' and 'communicating project timescales'. The final two questions (33 and 34) were to determine the extent to which the respondents' company has used VC in both the method planning and time scheduling. Although the most frequent response was that companies had not used VC for these elements, companies that have used VC have used it primarily to communicate methods (36%) and timescales (25%).

CONCLUSIONS

Results indicate a high level of BIM awareness and some experience of use of VC, particularly for work winning, methods planning, and the visualisation and validation of construction processes. The study as it stands shows a general recognition of the value of 4D planning, the extent of its use, and what elements of planning are its principal targets. It provides an up-to-date and informed view of drivers and barriers.

With additional data, analysis will be extended in a number of directions. Firstly, the likely response rate would permit inferential statistical analysis to explore the associations between the extent and nature of 4D planning use and the characteristics of the user organisations. Secondly, the suggestion by Dawood and Mallasi (2006) and Dawood (2010) that 4D planning can help reduce scheduling errors and improve communication between project team members, can be tested, as can other assertions from the literature regarding its greater efficiency and effectiveness over traditional methods. Ultimately, the work will consider whether the potential benefits of 4D planning are being actualised, as well as exploring their extent.

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