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SURVEYING THE EXTENT AND USE OF 4D BIM IN THE UK

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EDITOR: Amor R.

Barry J. Gledson
Faculty of Engineering and Environment, Northumbria University
barry.gledson@northumbria.ac.uk

David J. Greenwood
Faculty of Engineering and Environment, Northumbria University
david.greenwood@northumbria.ac.uk

SUMMARY: *More than half of construction projects exceed their agreed time schedules. Attempts to remedy this have been monitored over a number of years in the UK using standard industry KPI measurement data. The aim of this research was to investigate how contracting organisations have adapted their existing construction planning practices by using 4D BIM to improve project delivery and time predictability. In the light of the current lack of robust case-based evidence in support of this premise, a survey of 136 construction practitioners was conducted to measure the extent and use of 4D BIM in the UK and the perceptions of its value. Results indicated a high level of general BIM awareness, and some experience of 4D BIM for work winning, methods planning, and the visualisation and validation of construction processes. The study revealed the perceived value of 4D BIM, the extent of its use, and those elements of planning which were its principal targets. It also provided a view of the drivers and barriers for 4D BIM adoption. Several associations were found between the characteristics of user organisations and the extent and use of 4D BIM (and BIM more generally). The study uncovers the areas in which 4D BIM is believed by practitioners to be more effective than traditional means of construction planning. The conclusion is that the benefits of 4D BIM are considered to be less concerned with creating, validating and controlling project timescales (all of which still require the skills of experienced practitioners) but are more related to handling and communicating information. Given that these aspects are, using traditional 2D methods, considered to be a primary cause of 'poor predictability', the study supports the value of 4D BIM in improving project delivery.*

KEYWORDS: *4D, Building Information Modelling (BIM), Construction planning, Innovation, Diffusion, process modelling.*

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1. INTRODUCTION

In reviewing long term concerns over construction industry inefficiencies Egan (1998) highlighted construction innovations including lean processes and new technologies (including 3D object orientated modelling) as possible solutions to many of the industry's problems. Innovations can be described as a not-insignificant enhancement in products, processes, or systems, new to the company applying such advances (Slaughter, 2000). Building Information Modelling (BIM) has been classified as an innovation (Davies and Harty, 2013) and proposed as a solution for tackling construction industry production problems (Eastman et al., 2011). Cain (2003) emphasized that any industry innovations would fail to have a significant impact unless the industry continually measured its own performance and acted upon the results of these measurements. Of the Key Performance Indicators (KPI's) collected from 1999 onwards, some (notable those that are 'people focussed') have shown improvements. However, project Cost and Time Predictability have not: analysis of UK construction project 'time predictability' KPI data shows that more than 50% of all projects are delivered later than original advised completion dates. The problem of UK construction industry time performance was documented in a 2013 report 'Industrial Strategy: government and industry in partnership' (HM Government, 2013). Here a 'Vision for 2025' was communicated with targets of 50% quicker project delivery and reductions in the overall time, from inception to completion, for new build and refurbished assets targets, being benchmarked against 2013 UK industry performance.

The functionality of the planning process may be improved in a number of ways by using 4D. These include: the ability to import information from a design model or a common data environment; 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 schedules that are more accurate 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 more easily recognised and emphasised. The following literature review will highlight poor construction project time predictability, the drive for the implementation of BIM within the AEC industry, the benefits of 4D planning identified in research and an apparent stagnation in construction planning practice. There is then, a need to assess whether contracting organisations have adapted their existing practices by using 4D BIM to improve project delivery; if so, how these methods are being used in practice; and, whether, at this relatively early stage in the Industry's adoption of such methods, there is a prospect that their use may contribute to an improvement in the poor record of construction time and cost predictability.

This article presents the results of a study of the current use of 4D BIM by those involved in the planning and control of construction work in the UK. It examines the uptake of BIM in general, and of 4D in particular. An exploration is made, through the opinions of practitioners, of how contracting organisations have adapted their existing practices, and of the perceived benefits of the use of 4D BIM in different elements and stages of the project planning and control function. The aim is to address the premise that use of 4D BIM can assist in improving project delivery and time predictability.

2. LITERATURE REVIEW

Crotty (2012) considered the poor quality of production information generated by using traditional 2D methods to be a primary cause of 'poor predictability'. The drive for all centrally procured UK construction projects to be working at BIM Level 2 by 2016 is seen as an important step in improving predictability. Much research has already been done around the implementation of BIM within the AEC industry (Gu and London, 2010; Khosrowshahi and Arayici, 2012). The aim of the present study is to investigate the extent to which contractors are using methods of planning and control of construction work based on BIM technology (commonly referred to as 4D BIM) in order to improve the time predictability of construction projects. The following literature considers key aspects of conventional construction planning then focuses on 4D BIM as an innovation before identifying suitable questions for research in this area.

2.1 Traditional construction planning

Construction planning is necessary to establish the duration against which project performance can be measured. Cooke and Williams (2009) see the planning process as comprising the following elements: 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. Planning practitioners have been encouraged to challenge these standard planning solutions (Greenwood and Gledson, 2012) however, despite incremental developments in commercially available project management software, actual construction planning methods and output have largely remained static since the late 1990's (Li et al., 2015). Criticisms of conventional methods of presentation include their failure to take necessary account of spatial and location-related aspects when activities are sequenced; that the formats used to communicate the plan are independent from the building design; and that addressing the spatial aspects is left to the experience and intuition of the individual planner (Winch and North, 2006). Others have criticised the fact that project control frequently overshadows action planning, and scheduling is overemphasised at the expense of methods planning (Faniran et al., 1994; Laufer and Tucker, 1987).

2.2 4D BIM

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 (Heesom and Mahdjoubi, 2004; Koo and Fischer, 2000); 4D-Modeling (Buchmann-Slorup and Andersson, 2010); 4D Planning and Scheduling (Allen and Smallwood, 2007; Rischmoller and Alarcón, 2002); 4D Simulation (Heesom and Mahdjoubi, 2002; Tulke and Hanff, 2007); 4D site management model or 4DSMM, (Chau, Anson and De Saram, 2005; Chau, Anson and Zhang, 2005) and 4D Technology (Hu et al., 2008; Wang et al., 2004). 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 (Buchmann-Slorup and Andersson, 2010; Heesom and Mahdjoubi, 2002; Liston et al., 2001);
- 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 4D BIM tools now enable the incorporation of multiple models and schedule data to link intelligent objects to individual resource-loaded and logic-linked activities. Researchers (Chau et al., 2003; Koo and Fischer, 2000; Mahalingam et al., 2010) have identified the requirements for a 4D model as: (i) a 3D geometric model with building components; (ii) a construction programme (with activity data, durations, logical relationships); and (iii) a 4D simulation tool that allows the linking of elements of the 3D model with those of the programme. 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.

3. RESEARCH METHODOLOGY

There are still very few empirical studies of the benefits of BIM to the management of construction projects and those that exist are tentative: an example being the study of Bryde et al., 2013. Even in the United States, where BIM has a longer history of application, Barlish and Sullivan (2012) have cited the lack of 'a relevant and accepted calculation methodology and baseline to properly evaluate BIM's benefits…' which has led to 'mixed perspectives and opinions of the benefits of BIM, creating a general misunderstanding of the expected outcomes'. As a consequence, the approach adopted for this study was to solicit of expert opinion using a survey method of data collection. The target population was those involved in planning and controlling the delivery of construction projects. A structured questionnaire was developed and distributed direct to an accessible sample of the population, that is, 335 construction professionals attending courses to update their planning skills. Full responses were received from 136 subjects, which represented a response rate of 41%. A further 39 partially-completed responses were excluded from analysis.

The first section of the questionnaire contained thirteen questions which required the respondents to provide information about their own and their company's industry profiles; consisting of general demographic questions regarding age, job function, job level, experience, company size in terms of number of employees and annual turnover. This section also included questions asking respondents to provide detail of the total number and value of any projects they had been associated with that had incorporated any form of BIM. The second section contained thirteen questions that focused upon issues around BIM implementation. Respondents were invited to select from ready-made statements that most closely matched their views on: BIM maturity and planned adoption timescales (of their own company and the wider industry) and the implementation strategies demonstrated by their own company. This section also required respondents to rank various factors that influenced BIM implementation, including the benefits of, and barriers to adoption. The third section contained eight questions that focussing specifically upon aspects of 4D BIM, requiring respondents to identify how their companies had used elements of 4D and to compare the planning undertaken with these newer methods of working against conventional planning. This article presents summary results of the entire study but places a greater emphasis on the third section of the questionnaire, namely the current use of 4D BIM by respondents' companies and its perceived benefits in different elements and stages of the project planning and control function. Use has been made of descriptive and inferential statistical analyses and a short account is given of the more indicative results.

4. RESULTS OF THE STUDY

4.1 Descriptive analysis

Responses to the general demographic-type questions revealed the profile of respondents. Responses to Q3 showed that the highest proportion (47.1%; n = 64) of respondents held the job function 'Planner'. For Q5, the most frequent management level was identified as 'middle management' (44.1%; n = 60), with 'senior management' recorded as the next highest (28.7%; n = 39). For Q6, participants provided detail of their construction industry working experience, with '11 to 20 years' being the most frequent response (28.7%, n = 39) and a mean of 13.7 years. For Q8, 55.9% (n = 76) of the respondents identified themselves as working for large companies, (250+ employees) with 24.3% (n = 33) working for a small company (1-49 employees) and 19.9% (n = 27) for medium-size enterprises. For Q9, the largest percentage (25%; n = 34) gave their firm's turnover as 'over £500 million per year'. Responses to Q12 indicated that 54.4% (n = 74) of respondents had been involved in 1-5 projects that used some form of BIM and 8.1% (n = 11) in 6 to 10. Only 2.9% (n = 4) of respondents reported an involvement with 50+ BIM projects. For Q13, 16.9% (n = 23) of respondents indicated that the approximate total value of the BIM projects that they had been involved in was over £100 million. In contrast, 27.2% (n = 37) reported that they had not worked on any project using BIM 'in any capacity'.

Section 2 revealed details about whether the respondent's organisation was implementing BIM and if so, how. Against Q15, a majority (63.2%; n = 86) confirmed that their company had started implementing BIM, and 23.5% (n = 32) stated that they were 'planning to'. For Q16, most respondents (57.4%; n = 78) thought the government 2016 target to be 'realistic'. In Q17, 52.9% (n = 72) assessed their companies' BIM maturity at Level 1, and 27.9% (n = 38) at Level 2. For Q19, 62.5% (n = 85) predicted that by 2016 their company would meet the Level 2 requirements with an equal number (16.9%; n = 23) believing that they would be in either the Level 1 or Level 3 category by the 2016 target date.

In Q20, respondents were provided with a list of eight 'external barriers' to BIM implementation identified from the literature, and were asked to place these in order. A weighted calculation was used with items ranked first being valued higher than following ranks. Result show 'the fragmented nature of the industry' itself (725) was the most important issue, with 'time and commercial pressures' (712), 'culture and human issues' (699), a 'lack of adequate BIM awareness and understanding' (696) and 'the structure of procurements and contracts' (657) grouped closely as the next most important reasons. Respondents ranked 'lack of leadership' (525) and issues around education and training (448) as less important with 'lack of proof of performance from measurement systems' (434) ranked as the lowest external barrier.

In Q22 respondents were asked to rank, in order of importance, the three aspects of organizational infrastructure (people, process, and technology) 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' (302) as being the most significant internal challenge followed by 'process issues' (281), then 'technology issues' (233).

Using the same method, Q23 asked respondents to rank the broad order of BIM benefits. 'Improvements in communication and collaboration' scored highest (344) with 'improvements in product (asset) modelling' scoring (239) and 'process modelling and analysis' scoring almost equally (233).

Section 3 of the survey specifically focused on the use of 4D BIM. In Q27, respondents were asked to report on any use of 4D within their company. It was confirmed by 52.9% of respondents that their company had used elements of 4D on live projects, with a further 13.2% reporting that their company had investigated its use but not yet used any elements on live projects. A further 22.1% answered that the company had not used it before and 11.8% were unsure. Q28 asked respondents to confirm use of 4D BIM within the categories shown in Figure 1.

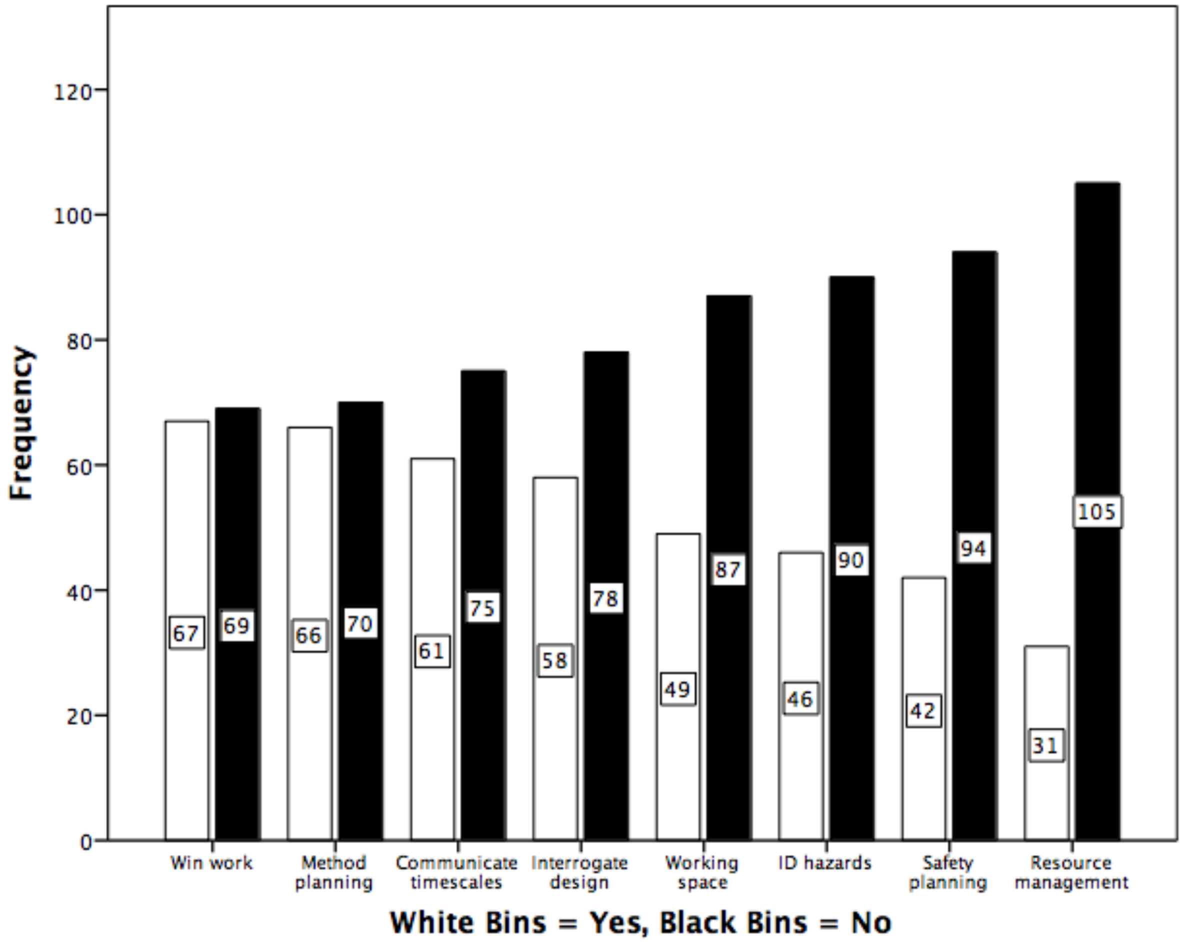

Figure 1: Use of 4D BIM for construction planning

These data show that whilst all categories scored higher in terms of negative responses, nearly half of all respondents are aware that 4D BIM had been used in their organisation to help work winning activities (49.3%; n = 67) and to assist in the planning of construction methods (48.5%; n = 66).

There was a greater ‘negative majority’ (i.e. respondents reporting non-use by their companies) for the extended range of potential uses that was suggested to them. Thus, a clear majority of respondents were not aware of their organisation using 4D BIM for *hazard identification* (66.2%; n = 90), *safety planning* (69.1%; n = 94) and *resource management planning* (77.2%; n = 105).

In Q29, respondents were asked to confirm any use of 4D BIM for site layout planning within the categories shown in Figure 2.

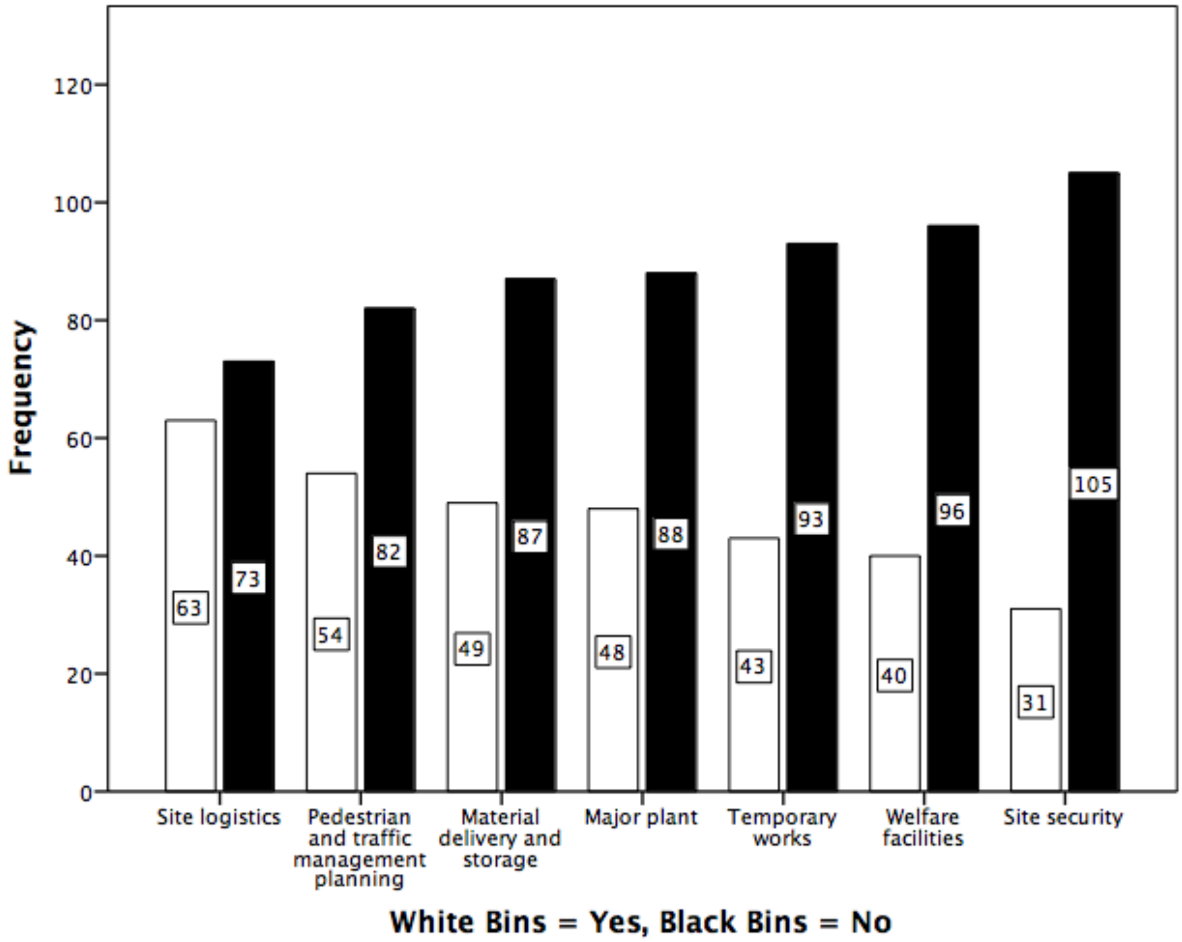

Figure 2: Use of 4D BIM for site layout planning

As previously, all the proposed uses of 4D BIM for site layout planning had higher negative counts, although a significant minority (nearly half) of respondents reported that a 4D BIM had been used in their organisation to plan ‘site logistics’ (46.3%; n = 63).

In Q30 respondents were asked about the value that 4D planning would add to their business using a 5 point Likert scale to establish ordinal measurement (1 being very low value, and 5 being very high value). In response 67.7% (n = 92) agreed that 4D planning would add value to their business, with the mean and median scores being 3.79 and 4.00 respectively.

Qualitative comments were sought regarding the impact of the value of 4D planning and responses focused on project complexities, construction sector inefficiencies, and work winning/schedule validation aspects. Examples included:

"There is value, for sufficiently complex projects, with sufficiently ambitious goals".

"In the UK and worldwide, the only economic sector which has not improved in efficiency & productivity is the construction industry, whereas it has been slow at adopting digital tools that allowed others (manufacturing, services, banking, etc.) to progress"

"The purpose of this is to provide more visibility on schedule validation rather than visualise and plan the construction process itself (where the real savings are to made)"

"Schedule validation before construction starts can help to reduce to reduce exposure to risk, avoid unforeseen costs such as those associated with having to dismantle plant, help with crane planning etc., and helps improve the quality of 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 number of prescribed aspects, or elements of the planning process. The possible responses were *'traditional planning processes are better than 4D planning'*; *'traditional processes and 4D planning processes are equal in this respect'; '4D planning processes offer a small improvement in this respect'* and *'4D planning processes offer a significant improvement in this respect'*.

Table 1: Comparing traditional and 4D planning against aspects of the planning process.

Aspect of planning process	**Traditional better than 4D**		**Traditional and 4D equal**		**4D small improvement**		**4D significant improvement**		**Totals**	
	%	*Frequency*	*%*	*Frequency*	*%*	*Frequency*	*%*	*Frequency*	*%*	*Frequency*
Work winning	5.9	8	9.6	13	26.5	36	58.1	79	100.0	136
Planning construction process	5.1	7	9.6	13	33.8	46	51.5	70	100.0	136
Visualising construction process	2.9	4	6.6	9	5.9	8	84.6	115	100.0	136
Understanding construction processes	5.1	7	4.4	6	22.8	31	67.6	92	100.0	136
Validating the time schedule	10.3	14	17.6	24	36.8	50	35.3	48	100.0	136
Location based planning	8.1	11	11.0	15	43.4	59	37.5	51	100.0	136
Progress reporting	11.0	15	11.0	15	39.7	54	38.2	52	100.0	136

In contrast to the high negative responses received for Q28 and Q29 regarding its current exploitation, the responses for this question (Q31) show a majority expectation of the ‘significant improvement’ of 4D planning over traditional in four of the seven planning elements, with the majority expecting a ‘small improvement’ in the remaining three elements.

The elements where 4D was expected to offer ‘significant improvement’ were ‘visualising construction processes’ (84.6%; n = 115), ‘understanding construction processes’ (67.6%; n = 92), and ‘work winning’ (58.1%; n = 79). The three planning elements where the majority of respondents believed that 4D planning offered only ‘small improvements’ over traditional were ‘validating the time schedule’ (36.7%; n=50), ‘location based planning’ (43.4%; n = 59) and ‘progress reporting’ (39.7%; n = 54). Over all seven planning elements, very few respondents reported their preference for traditional planning processes (*mean* 6.9%; *mean* n=9.4) and of the particular planning elements the highest example of a preference for traditional processes was ‘progress reporting’ (11%; n=15).

In Q32, respondents reported, using the same available response options, on how they considered 4D planning might offer improvements over traditional methods at different stages of the planning process (see Table 2).

Table 2: Comparing traditional and 4D planning against each stage of the planning process.

Stages of the planning process	**Traditional better than 4D**		**Traditional and 4D equal**		**4D small improvement**		**4D significant improvement**		**Totals**	
	%	*Frequency*	*%*	*Frequency*	*%*	*Frequency*	*%*	*Frequency*	*%*	*Frequency*
Gathering Information	5.9	8	17.6	24	35.3	48	41.2	56	100.0	136
Identifying activities	4.4	6	19.9	27	42.6	58	33.1	45	100.0	136
Assessing durations	6.6	9	27.9	38	44.9	61	20.6	28	100.0	136
Logical relationships	8.8	12	15.4	21	41.2	56	34.6	47	100.0	136
Sequence	4.4	6	11.8	16	38.2	52	45.6	62	100.0	136
Project timescale	7.4	10	20.6	28	47.8	65	24.3	33	100.0	136
Communicating the plan	2.2	3	1.5	2	16.9	23	79.4	108	100.0	136

The three highest-scoring areas where 4D was seen to offer ‘significant improvement’ were in ‘communicating the plan’ (79.4%; n = 108), ‘gathering information’ (41.2%; n = 56) and ‘sequence’ (45.6%; n = 62). Respondents thought that 4D planning would bring a ‘small improvement’ over traditional working in the stages of ‘identifying activities’ (42.6%’ n=58), ‘assessing durations’ (44.8%; n=61), ’logical relationships’ (41%; n=56), and ‘project timescale’ (47.8%; n=65). Examining these stages more closely, it can be seen that the stages that attracted the least positivity (based on a summation of the scores for the categories ‘traditional better than 4D’, ‘traditional and 4D equal’ and ‘4D small improvement’) were ‘assessing durations’ and ‘project timescale’.

The final two questions were intended to determine the extent to which the respondents' companies have used 4D BIM in both method planning (Q33) and time scheduling (Q34). The available response categories for each question were whether 4D BIM was 'used to identify …’, ‘used to assess…’, ‘used to plan…’, ‘used to communicate…’ and ‘used to manage…’ construction methods (in Q33) and construction timescales (in Q34). The responses - 50.7% (n = 69) in the case of method planning, and 61.0% (n = 83) for time scheduling of construction work – indicated that companies had not yet used 4D BIM extensively for either purpose. Companies that have used 4D BIM have used it primarily to *communicate* their methods (36.8%; n = 50) and timescales (26.5%; n = 36). Additional qualitative comments were sought at the end of section 3, and the salient responses have been reproduced here:

4D Planning will only be successful if planners/contractors understand BIM technology and have suitable experience of construction practices e.g. BIM won't solve lack of experience or bad planning"

4D Planning is only useful where there is an expressed need to understand a sequence of works in more depth. For simple elements, this can be a wasteful practice and the question "why are we doing this?" should always be asked.

Virtual construction and 4D modeling for us involve much more than mapping a model to a sequence. It involves the integration of project controls, costing, resourcing, design and fabrication, warehousing procurement and other functions with outputs in many different formats".

4.2 Inferential Analysis

Several associations between the extent and use of BIM and 4D BIM, and the characteristics of the user organisations were explored. The research instrument was designed to make use of categorical variables in order to facilitate Chi-Square (Pearson, 1990; Yates, 1934) and Fisher Exact tests (Fisher, 1922) to investigate association between the variables (the latter being more appropriate for smaller samples). The tests were for associations between:

1. *Company size* and *company plans to implement BIM*.
2. *Company size* and *organisational BIM Maturity*.
3. *Company size* and *company use of 4D BIM*.
4. *Company size* and *perceived value of 4D BIM*.
5. *Organisational BIM maturity* and *company use of 4D BIM.*
6. *Organisational BIM maturity* and *perceived value of 4D BIM*.

In each test competing null (H_0) and alternative (H_A) hypotheses were formulated and all 136 cases could be used. No statistical significance was found in test 3 (regardless of company size, the most frequent response from respondents of all organisations is that the company has used 4D BIM in some capacity) and test 4 (regardless of size all companies perceived there to be high value in the use 4D BIM). Consequently, these tests are not expanded upon in any further detail. Statistical significance was found in the results of tests 1, 5 and 6 and this is expanded upon below. The results of test 2 provided a statistic so close to significance that it has also been expanded upon.

4.2.1 Test 1

- **H_0:** There is no relationship between company size and those companies that plan to implement BIM.
- **H_A:** There is a relationship between company size and those companies that plan to implement BIM.

Conditions for Chi-Square (X^2) were not met as two cells had expected counts of less than 5, therefore a Fisher's Exact Test was used, which gives a test statistic of .029 indicating that that H_0 could be rejected in favour of H_A: *There is a relationship between company size and those companies that plan to implement BIM.* Interrogation of the largest proportion (41.2%) of data produced in the cross-tabulation about this relationship appears to suggest that the larger companies have already commenced implementing BIM (See Figure 3).

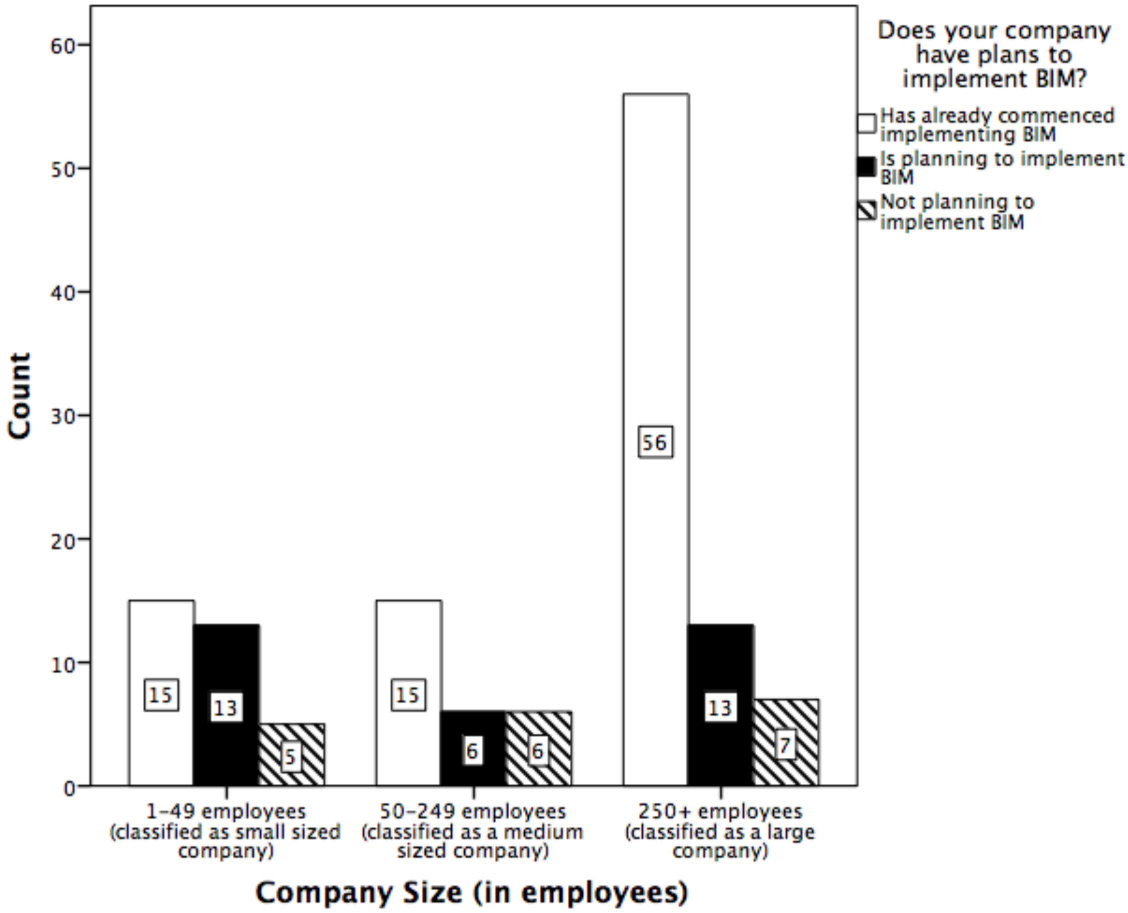

Figure 3: Tests of association: Company size against BIM implementation plans

4.2.2 Test 2

- **H_0:** There is no relationship between company size and organisational BIM Maturity.
- **H_A:** There is a relationship between company size and organisational BIM Maturity.

Conditions for X^2 were not met as one cell had an expected count of less than 5, therefore a Fisher's Exact Test was used, which give a close to significant association in a test statistic of .051. Strictly this mean that H_0 could not be rejected in favour of H_A, indicating that: *There is no relationship between company size and organisational BIM Maturity.*

4.2.3 Test 5

- **H_0:** There is no relationship between organisational BIM maturity and company use of 4D BIM.
- **H_A:** There is a relationship between organisational BIM maturity and company use of 4D BIM.

Conditions for X^2 were met and a test statistics of .000 and was given, which meant that H_0 could be rejected in favour of H_A: *There is a relationship between organisational BIM maturity and use of 4D BIM.* Interrogation of the data produced in the cross-tabulation about this relationship appears to suggest that as organisational BIM maturity increases so does the company use of 4D BIM (see Figure 4).

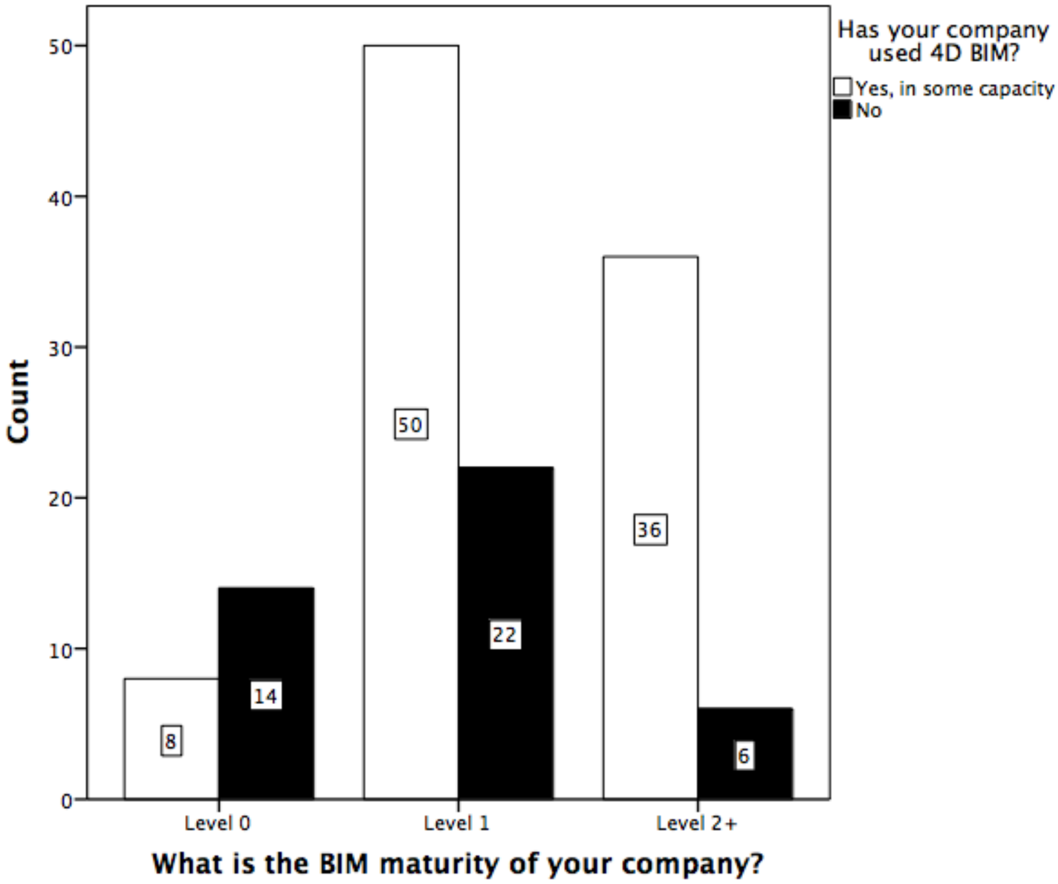

Figure 4: Tests of association: Organisational BIM Maturity against company use of 4D BIM

4.2.4 Test 6

- $\mathbf{H_0}$: There is no relationship between organisational BIM maturity and the perceived value of 4D BIM.
- $\mathbf{H_A}$: There is a relationship between organisational BIM maturity and the perceived value of 4D BIM.

Conditions for X^2 were not met as six cells had expected counts of less than 5, therefore a Fisher's Exact Test was used, which gives a test statistic of .017 indicating that that H_0 could be rejected in favour of H_A: *There is a relationship between organisational BIM maturity and the perceived value of 4D BIM.* Interrogation of the data produced in the cross-tabulation about this relationship appears to suggest that as organisational BIM maturity increases so does the perception of the value of 4D BIM.

5. DISCUSSION, CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

This study was conducted in the lead-up to the start date of UK Government's 'Level 2 BIM mandate' and aimed to gauge current industry attitudes to, and adoption of 4D BIM amongst construction planners and project managers, who are arguably amongst the main potential beneficiaries. The demographical data they returned demonstrate that in terms of their job descriptions and level of experience the respondents were well placed to offer informed opinions on the extent and use of 4D BIM in the UK. Just over half had been involved in between one and five projects that used some form of BIM, while just over a quarter had no such experience. However, the preponderance of those working for large companies is certainly not representative of the Industry, and any conclusions must be viewed accordingly.

The subjects produced few surprises in their responses on the adoption of BIM by their companies. Most had seen a start, or recognised an intention to do so. There was a significant positive relationship between company size and BIM adoption, and also between organisational BIM maturity and company use of 4D BIM (together with its perceived benefits). In general terms, almost 70% of the sample thought that 4D planning would ‘add value to their business’. Respondents’ perceptions of their organisations’ Level 2-readiness must be tempered by the recognition that the UK Government’s mandate relates not to organisations but to projects. Thus, 'the fragmented nature of the industry' was seen to be the greatest barrier to BIM adoption. Why this should be the case was not established, and is open to question, but it may be conjectured that on projects this ‘fragmentation’ manifests itself in long and intricate supply chains, presenting difficulties for information exchange between the organisations involved (see, for example, Stewart et al., 2004). It may be that a Tier 1 contractor is capable of working at Level 2 (or even Level 3, as some respondents -possibly optimistically - thought) but for the project as a whole to be at that level would require at least some basic BIM capability throughout its supply chain.

Just over half the respondents reported the use of 4D BIM in some form by their companies: current use appears to be focused predominantly on winning work, and there was little evidence of exploitation of its full potential. There were, however, distinct opinions on where this potential lay, and this proved to be of particular interest in the context of the study. The problem highlighted at the start of this article concerned the cost- and time-predictability of construction projects. These are clearly related and the UK construction industry’s record on both has been identified as unacceptable. Predictions and early assessments of the beneficial impact of 4D BIM have held out the prospect of improvement through better visualisation of the time and space relationships of construction activities, better construction schedules, and enhanced communication between project team members, and indeed, all stakeholders. In the absence, so far, of supporting evidence, the main focus of the present study was to solicit expert opinion on where such improvements could realistically be expected.

Questions 31 and 32 of the survey broke down the planning process by elements/aspects (Q31) and by stages (Q32), in each case enquiring whether respondents considered 4D planning to offer significant or marginal improvements, to offer no change, or actually to be inferior to traditional planning methods.

In responses to Q31, significant improvement was expected in ‘visualising construction processes’, ‘understanding construction processes’ and ‘work winning’ (as per Table 1). The consensus in Q32 of the survey (see Table 2) that ‘communicating the plan’ offered most significant improvement accords with this view of the importance of 4D for better communication. Equally interesting, at the opposite end of the scale, is the general agreement, that the least improvement from 4D was expected in ‘assessing durations’ and ‘project timescale’. This accords with the results of Q31 where the three elements where 4D was least likely to offer improvements were ‘validating the time schedule’, ‘location based planning’ and ‘progress reporting’. A possible explanation for these patterns can be found in the following comment by one respondent:

“4D Planning will only be successful if planners/contractors understand BIM technology and have suitable experience of construction practices e.g. ***BIM won't solve lack of experience or bad planning"*** [emphasis added]

The conclusion that may be drawn from this is that the benefits of 4D BIM are those related to understanding and communication, rather than the technical aspects of assessing, creating, validating and controlling project timescales. Indeed, there was evidence of a degree of suspicion that over-reliance on accessible 4D technology could mask a lack of planning skill and experience, arousing fears similar to those aired in other disciplines, such as education (see Bennett, et al., 2008) and medicine (Goodwin, 1995).

For the purposes of this investigation, the planning and control function has been divided into sub-elements on the basis that an overall improvement in the delivery of construction projects will require an improvement in each, or at least, some of these elements. Whether 4D BIM has yet provided, or in the opinion of planners, has the potential to provide such improvements was also a major focus of the study.

5.1 Limitations and implications

A number of limitations should be noted regarding the sampling strategy adopted. Firstly, the sample, although of a reasonable size (136 ‘clean’ responses) was not random, and therefore some caution must be adopted over generalisation to the population. On a similar note, the relative proportions of respondents working for large (56%), medium (20%) and small (24%) companies is far from representative of the state of the industry at large, which has a high proportion of small or very small firms, The results of this survey should be qualified accordingly. Nevertheless, the research can be replicated, particularly since the measures used for the concepts are stable. Should this be done, it may be possible to adopt a longitudinal perspective – given the nature of the government BIM Mandate, the likely changes to future project requirements and expectations. For these purposes an 'innovation diffusion' standpoint, such as that advocated by Rogers (2010) and its applications, may be useful.

6. REFERENCES

Allen, C.J. and Smallwood, J. (2007), "Improving Construction Planning Through 4D Planning", *Journal of Engineering, Design and Technology*, Nelson Mandela University.

Barlish, K., and Sullivan, K. (2012), "How to measure the benefits of BIM: A case study approach", *Automation in Construction*, 24 (July) 2012, pp. 149–159.

Bennett, S., Maton, K., and Kervin, L. (2008), " The 'digital natives' debate: A critical review of the evidence", British Journal of Educational Technology, **39** (5), pp. 775-786.

Bryde, D., Broquetas, M., and Volm, M. (2013), "The project benefits of Building Information Modelling (BIM)", *International Journal of Project Management*, **31** (7), pp. 971–980.

Buchmann-Slorup, R. and Andersson, N. (2010), "BIM-based scheduling of construction–a comparative analysis of prevailing and BIM-based scheduling processes", *Proceedings of the CIB W78 2010: 27th International Conference*, Cairo, pp. 16–18.

Cain, C.T. (2003), *Building down barriers : a guide to construction best practice*, Spon, London.

Chau, K.., Anson, M. and De Saram, D.D. (2005), "4D dynamic construction management and visualization software: 2. Site trial", *Automation in Construction*, **14** (4), pp. 525–536.

Chau, K.., Anson, M. and Zhang, J. (2003), "Implementation of visualization as planning and scheduling tool in construction", *Building and Environment*, **38** (5), pp. 713–719.

Chau, K.., Anson, M. and Zhang, J. (2005), "4D dynamic construction management and visualization software: 1. Development", *Automation in Construction*, **14** (4), pp. 512–524.

Cooke, B. and Williams, P. (2009), *Construction planning, programming and control*, Wiley-Blackwell, West Sussex, 3rd ed.

Crotty, R. (2012), *The Impact of Building Information Modelling: Transforming Construction*, Spon Press, Oxon.

Davies, R. and Harty, C. (2013), "Implementing 'Site BIM': A case study of ICT innovation on a large hospital project", *Automation in Construction*, **30**, pp. 15–24.

Dawood, N. (2010), "Development of 4D-based performance indicators in construction industry", *Engineering, Construction and Architectural Management*, **17** (2), pp. 210–230.

Dawood, N. and Mallasi, Z. (2006), "Construction Workspace Planning: Assignment and Analysis Utilizing 4D Visualization Technologies", *Computer-Aided Civil and Infrastructure Engineering*, **21** (7), pp. 498–513.

Eastman, C., Teicholz, P., Sacks, R. and Liston, K. (2011), *BIM handbook, A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers, and Contractors*, Wiley, New Jersey, 2nd ed.

Egan, J. (1998), *Rethinking Construction. Report of the Construction Task Force.* London: HMSO

Faniran, O.O., Oluwoye, J.O. and Lenard, D. (1994), “Effective construction planning”, *Construction Management and Economics*, **12** (6), pp. 485–499.

Fisher, R. A. (1922). "On the interpretation of $\chi2$ from contingency tables, and the calculation of P". *Journal of the Royal Statistical Society* **85** (1): pp. 87–94.

Goodwin, J. (1995) " The importance of clinical skills", British Medical Journal, **310** (May), pp. 1281-2.

Greenwood, D. and Gledson, B.J. (2012), “The efficient scheduling of resources in engineering construction projects : reflections on a case study from Iran”, *Construction Management and Economics*, **30** (8), pp. 687–695.

Gu, N. and London, K. (2010), “Understanding and facilitating BIM adoption in the AEC industry”, *Automation in Construction*, Elsevier B.V., **19** (8), pp. 988–999.

Heesom, D. and Mahdjoubi, L. (2002), “A dynamic 4D simulation system for construction space planning”, in Khosrowshahi, F. (Ed.),*Proceedings of the Third International Conference on Decision Making in Urban and Civil Engineering,* pp. 1–6.

Heesom, D. and Mahdjoubi, L. (2004), “Trends of 4D CAD applications for construction planning”, *Construction Management and Economics*, **22** (2), pp. 171–182.

HM Government. (2013), *Construction 2025. Industrial Strategy: government and industry in partnership*, London, available at: http://www.bis.gov.uk/assets/biscore/innovation/docs/b/12-1327-building-information-modelling.pdf.

Hu, Z., Zhang, J. and Deng, Z. (2008), “Construction Process Simulation and Safety Analysis Based on Building Information Model and 4D Technology”, *Tsinghua Science Technology*, Tsinghua University Press, **13** (October), pp. 266–272.

Khosrowshahi, F. and Arayici, Y. (2012), “Roadmap for implementation of BIM in the UK construction industry”, *Engineering, Construction and Architectural Management*, **19** (6), pp. 610–635.

Koo, B. and Fischer, M. (2000), “Feasibility Study of 4D CAD in Commercial Construction”, *Journal of Construction Engineering and Management*, **126** (4), pp. 251–260.

Laufer, A. and Tucker, R. (1987), “Is construction project planning really doing its job? A critical examination of focus, role and process”, *Construction Management and Economics*, **5** (3), pp. 243–246.

Li, H., Chan, G., Skitmore, M. and Huang, T. (2015), “A 4D automatic simulation tool for construction resource planning: a case study”, *Engineering, Construction and Architectural Management*, **22** (1), pp. 91–107.

Liston, K., Fischer, M. and Winograd, T. (2001), “Focused sharing of information for multidisciplinary decision making by project teams”, *ITCon*, **6**, pp. 69–82.

Mahalingam, A., Kashyap, R. and Mahajan, C. (2010), “An evaluation of the applicability of 4D CAD on construction projects”, *Automation in Construction*, Elsevier B.V., **19** (2), pp. 148–159.

Pearson, K. (1900). "On the criterion that a given system of deviations from the probable in the case of a correlated system of variables is such that it can be reasonably supposed to have arisen from random sampling". Philosophical Magazine, Series 5 50 (302): pp. 157–175.

Rischmoller, L. and Alarcón, L.F. (2002), “4D-PS : Putting an IT new work process into effect”, *CIB w78 conference*, Aarhus, pp. 1–6.

Rogers, E.M. (2010) *Diffusion of Innovations* (4th Ed.) The Free Press, New York

Sacks, R., Koskela, L., Dave, B.A., Owen, R. (2010) ' Interaction of lean and building information modeling in construction'. American Society of Civil Engineers. *Journal of Construction Engineering and Management.* **136** (9), pp. 968-980

Slaughter, E. (2000), “Implementation of construction innovations”, *Building Research & Information*, **28** (1), pp. 2–17.

Stewart, R.A., Mohamed, S., and Marosszeky, M. (2004) "An empirical investigation into the link between information technology implementation barriers and coping strategies in the Australian construction industry", *Construction Innovation*, 4 (3), pp.155 - 171

Tulke, J. and Hanff, J. (2007), “4D construction sequence planning–new process and data model”, *Proceedings of CIB-W78 24th International Conference on Information Technology in Construction, Maribor, Slovenia*, Citeseer, pp. 79–84.

Wang, H.., Zhang, J., Chau, K.. and Anson, M. (2004), “4D dynamic management for construction planning and resource utilization”, *Automation in Construction*, **13** (5), pp. 575–589.

Winch, G. and North, S. (2006), “Critical Space Analysis”, *Journal of Construction Engineering and Management*, **132** (5), pp. 473–481.

Yates, F (1934). "Contingency table involving small numbers and the $\chi 2$ test". *Supplement to the Journal of the Royal Statistical Society* **1**(2): pp. 217–235