
BIM AND 4D PLANNING: AN EMPIRICAL STUDY OF THE INDUSTRY UPTAKE AND ISSUES AFFECTING THEIR WIDESPREAD USE

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ABSTRACT

Building Information Modeling (BIM) and its different work-streams such as 4D planning (4D) are currently among the major drivers for change in the construction industry. Previous literature regarding BIM and 4D has endeavored to improve the technologies and prove their benefits within actual projects. There are limited empirical studies, which investigate the industry uptake of 4D and BIM and the factors affecting their widespread use. This paper aims, by using an empirical industry survey of consultants and contractors involved in the UK civil and building industry, to depict a holistic view of the issues hindering the industry uptake of 4D and BIM and present corresponding recommendations for each issue. To achieve this aim, the paper investigates: the current industry uptake of 4D and BIM, existing knowledge and depth of use, levels of understanding of benefits, and limitations to their implementation. The paper concludes that it is essential to direct the research into the non-technical identified issues since unless the gap between technology, end-users and their processes is bridged, usage will continue to be limited.

Keywords: 4D planning, Building Information Modeling (BIM), industry uptake.

1. INTRODUCTION

4D modeling, also known as 4D planning, combines the 3D graphical perspective of a model with the time dimension of a construction schedule (Koo and Fischer 1998), which allows for construction operations to be viewed sequentially as a virtual simulation, with the model containing 'logical, temporal and spatial aspects' (Koo and Fischer 1998). Building Information Modeling (BIM) is defined as the process of generating and managing information about a building during its entire lifecycle (BSI 2011) and was recognized as the future of the Architectural, Engineering and Construction (AEC) industry (NBS 2011). Whereas 4D was primarily aimed at the contractor within a project, since it incorporated the time aspect of the construction schedule, BIM covers multiple project stakeholder roles, from the design stage to the facility management stage. Much of the literature surrounding 4D planning and BIM systems identifies technological problems with existing systems and utilizes further technology to propose and test potential solutions. Very few researchers actively consider the industry uptake and reasons for the current level (either positive or negative) based on empirical studies. In spite of authors highlighting wide-ranging in-depth reasons ranging from technical to industry cultural reasons as barriers for entry of 4D and advanced systems, much of the work appears to be generated as an amalgamation of previous authors' comments or based on authors' own experience. This form of research methodology is also witnessed in Koo and Fischer 1998; Aalami et al. 1998 and Tsai et al. 2010. One of the few surveys attempting to quantify and understand the level of BIM adoption within the industry has been undertaken

by McGraw-Hill Construction in 2010. The research conducted an internet survey across the industry in the United Kingdom, France and Germany, to which 948 industry professionals responded. The survey covered a wide range of project roles, disciplines and levels of experience. In an abridged summary of the findings, the survey quantified the level of adoption within the UK as 35%, which was slightly lower than Germany and France at 36% and 38%, respectively. When subdividing by industry discipline in the UK, architects were identified as using BIM most with 60%, followed by engineers (39%) and contractors (23%) (McGraw-Hill Construction 2010). Although the research is thorough and based on large-scale empirical research, greater knowledge is still required regarding the current uses of BIM, the integration between the main stakeholders and the factors affecting the widespread use of BIM. The reason is that only through the understanding of the general industry and perceptions of those parties for whom the concepts are intended, can a future strategy for widespread use of the technology be developed.

To satisfy the research aim, the following four objectives have been set:

- To evaluate the level of knowledge and experience of 4D planning and BIM in the industry.
- To evaluate the depth of use of 4D planning and BIM in the industry, contrasting design consultants and contractors.
- To investigate the connection and integration between design consultants and contractors this may facilitate the use of 4D planning and BIM.
- To suggest possible limitations within the industry to the widespread implementation of 4D planning and BIM and propose possible solutions for greater adoption.

2. RESEARCH METHODS

An empirical industrial survey was employed and aimed to collect quantitative and qualitative data through a web-based questionnaire submitted to a selected sample of 52 consultants and 46 contractors within the UK civil and building industry. Both closed and open-ended questions were used, with the survey separated into three sections: general industry, BIM and 4D planning. Initially, a small-scale pilot study was utilized to develop the survey documents. A person within each perspective group who could be described as ‘experienced’ and who currently practices within industry was asked to review the final draft and comment on usability, relevance and completion period. To ensure the randomness in the selection of sample participants, the distribution list was generated by selecting organizations from the New Civil Engineer’s (NCE) Consultants’ (Tether 2011) and Contractors’ Files (Hansford 2010). To obtain reliable information and guarantee a good response rate, the authors opted to initially contact the companies (52 consultants and 46 contractors) to ask the details of an experienced professional who would be able to complete the survey. After the barriers to the widespread use of 4D and BIM have been identified, a literature review was conducted to analyze the existing initiatives addressing each of the categories of barriers identified.

3. RESULTS

3.1 Respondents’ profiles

From the distributed surveys 14 consultants responded, a response rate of approximately 27%, and 17 contractors (37%). The initial classification questions were used to identify the approximate industry positions in terms of organizational size and sector undertakings. The responding consultants covered a range of company sizes, based on turnover values. A summary of the values have been given in Figure 1. The respondents were asked to give percentage values, to the nearest 10%, for the sectors in which they operate. An amalgamation of the data (Figure 1) shows that the top three rated sectors are buildings (40% of the work undertaken), 15 % highways and 11% railways. For the contractors a poorer distribution of company sizes responded, with no small organization (classed as a turnover less than £10M) (Figure 1). The sectors in which work is undertaken has a similar trend to the consultants, with the same highest rated top four sectors (Figure 1).

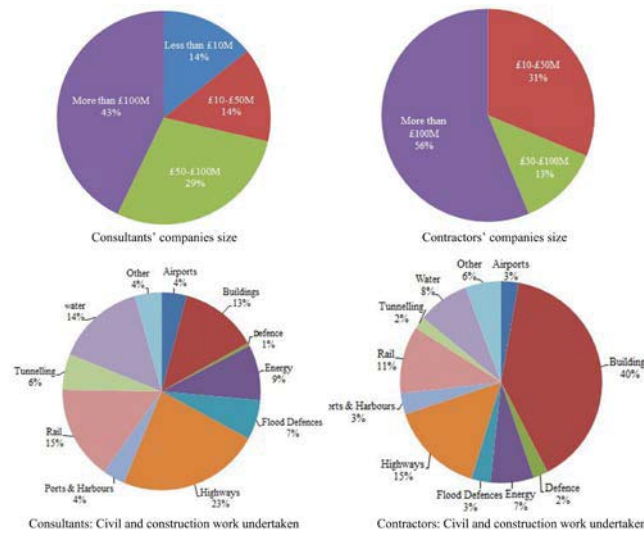


Figure 1: Profile of consultants and contractors interviewed

3.2 Knowledge and experience of BIM and 4D in the industry (objective 1)

Regarding BIM, from the consultants' perspective, a little over half (54%) stated they were aware of the concept (Figure 2), with a working and practical knowledge base selected more than an educational background (Figure 3). Indeed, when investigating the benefits, a wide knowledge was indicated, suggesting experience rather than theory. For the contractors, a greater percentage (63%) stated they were aware of the concept (Figure 2), with 56% gaining the knowledge from a working/practical position (Figure 3). The respondents revealed a relatively thorough knowledge of uses and benefits covering some of the analytical, visualization and communication factors linked to their operations as well as the basic idea related to the improvement of the design process. This demonstrates a greater rounded knowledge through consideration of the entire BIM applicability and of the consultant's position within the process.

For 4D planning, 36% (Figure 2) of the consultants indicated they had awareness, with 60% gaining their knowledge through working/practical levels (Figure 4). The open-ended questions demonstrated that the consultants have very little knowledge and experience of 4D planning, over-and-above being aware of the concept's existence. From the contractors' perspective, a high proportion (80%) of participants indicated they were aware of the subject (Figure 2). Of those, over 60% stated their knowledge was gained through a working/practical position (Figure 4). From viewing the benefits of 4D planning stated by the respondents, it is clear a thorough well-rounded knowledge of the uses and advantages exists. Indeed, this is demonstrated by the fact that participants (71%) have instigated the use of 4D on a project, indicating a significant knowledge and understanding of the technique, together with confidence in both the concept and the benefits that can be achieved by the project team. In conclusion, with regard to BIM, there appears to be a similar awareness indicated by both stakeholders, with the consultants showing a slightly lower percentage. From the consultants a level of confidence and ability with the concept was suggested since many stated they can and do use BIM for design and as a form of information transfer.

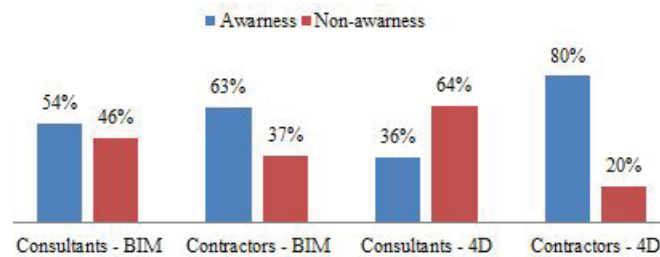


Figure 2: Awareness of BIM indicated by the respondents

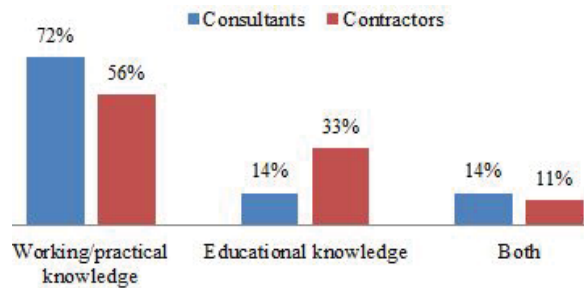


Figure 3: Awareness of BIM indicated by the respondents

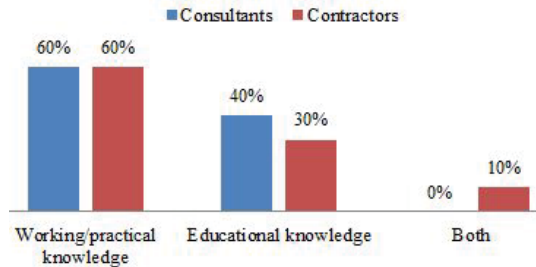


Figure 4: Awareness of 4D indicated by the respondents

Conversely, 4D planning showed a divide between the stakeholders, with the contractors being fairly knowledgeable and experienced in the concept. In contrast, consultants have poor knowledge and experience and have little awareness of the benefits afforded, which may demonstrate a lack of collaboration between the two stakeholders.

3.3 Depth of use of 4D planning and BIM (objective 2)

The consultants' answers regarding BIM, suggest that it has a wide applicability and use across multiple sectors and large proportions of each company's undertakings, when comparing the sectors in which it has been used. A further demonstration of the increased depth of knowledge and use may be concluded from the consultants' comments that 75% have experienced its use following the client's request. From the contractors' data, their depth of use is unclear, although 56% stated they had been involved with its use more than once.

Regarding 4D planning, 60% of the consultants, who were aware of the concept (36%), indicated they have used the technique (been involved with the use) more than once. One respondent called it "standard practice on our major projects" and another said it was used on "all but the most advanced and complex projects". These two comments suggest interestingly, that 4D planning is not universally used but its selection for use is based on project specific factors such as size and/or complexity.

From the contractors' data, of the 80% of respondents having heard of the concept, 70% have used the technique more than once, suggesting it is proven and established within their organizations. In addition, a relatively even spread of use in civil and building sector operations was highlighted, with the approach being utilized for multiple analysis options. A slight negative to this is that only 43% stated it is used during the construction operations of a project. This finding is reinforced later when asked to comment on possible limitations to 4D planning implementation, when concerns were raised about the skill level and time required to update the model during construction.

It appears there is a relative divide between the depth of use of the two concepts between the two stakeholders. The consultants demonstrated a greater use of BIM with wide areas of application, whereas use is limited among the contractors. The use of 4D planning appears to produce similar conclusions but from opposing stakeholders' positions. A further evidence of the divide between stakeholders was identified when answers regarding the information format used and transferred between project phases and parties were analyzed. The consultants stated that BIM was used by approximately a third of

participants within their companies for design purposes and shared between other trade designers. However, a significant reduction in information transfer was noted when the consultants were asked about the information transferred to the contractors, which was mirrored by the opposing question to the contractors. In addition, where consultants did transfer BIM models to the contractors they were “for information only” or “3D models with some of the BIM attributes”. It can be concluded that based on concepts and techniques which benefit from integration and collaboration between key project stakeholders and which can provide benefits to multiple stakeholders in return, the depth of use appears to be somewhat isolated among these most influential stakeholders provided that there is more integration in the process.

One salient link could also be drawn between general industry and current uses of the technology is in the limited uptake within the highways sector. This comparison is made only for 4D as BIM originated and is used in the Architectural world. Figures 5 shows a comparison of the sector’s general overall industry percentage taken from the NCE’s Consultants’ (Tether 2011) and Contractors’ Files (Hansford 2010) compared to the survey’s findings. From this comparisons, it could be concluded that there may be a fundamental limitation within the 4D technique or within the highways industry, which prevents its adoption and usage.

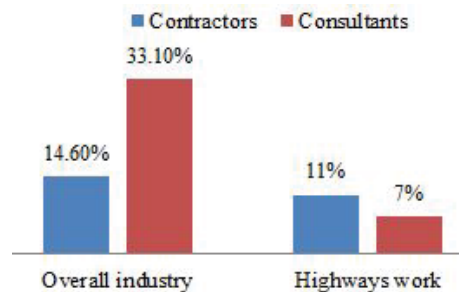


Figure 5: Highways work undertaken by respondents utilizing 4D planning

3.4 Impact of collaboration between design consultants and contractors on the use of 4D and BIM (objective 3)

Integration between consultants and contractors was more difficult to quantify since direct questions may have little weighting or validity. However, the open-ended questions asked to the consultants and contractors allowed the overall understanding of this issue. With respect to both 4D and BIM, while the consultants noted that collaboration, communication and integration between stakeholders could be very beneficial for the implementation of such systems which in turn can encourage integration and communication, other answers suggest that in actuality integration and collaboration are limited. The contractors stated (57%) that 4D planning is not integrated with the design phase. In addition 38% expressed concerns over integration and collaboration between project stakeholders as being key limitations to the implementation of BIM.

The contractors further indicated a lack of integration through their comments regarding general inefficiencies within the traditional design and planning aspects of a project. Statements such as “lack of awareness of plant access”, “general buildability” and “impractical design details and specification” were all aimed at the consultant and provide the impression that the contractor feels these regular faults are easy to repair, particularly from their position and with their knowledge and experience.

To investigate further the integration and collaboration issues, the contractors were asked about their usual entry point into a project. 38% of respondents noted that entry during or after the design phase is dependent on the contract type. Therefore, a desire for integration could be limited by the overall contract/project type. In addition, when analyzing the benefits stated by both stakeholders, regarding both 4D planning and BIM, the statements generally did not consider benefits to the other party (with exceptions). For example, one of the consultants mentioned that “one of the benefit of BIM is to achieve more accurate design, overcoming layout problems i.e. making sure the building stacks up”; another consultant quoted “with BIM, we can achieve better team working and design coordination”. This

somewhat self-indulgent consideration of benefits could be as a result of, and/or the cause of, limited project stakeholder integration. From this, it can be concluded that there is a status quo cycle inhibiting both the adoption and enhancement of the technology. In fact, while these technologies are capable of resolving many of the inefficiencies currently present at the critical interface between the stakeholders, such technologies require integration and collaboration among the stakeholders, which is currently lacking.

3.5 Limitations to widespread use and implementation of 4D and BIM in the industry (objective 4)

A key means of appreciating the true position a technology holds within an industry is to understand the perceived and actual barriers that may prevent its widespread implementation. From satisfying the previous objectives, certain feelings and perceptions regarding the concepts have been already considered as limitations to implementation. These can be summarized as follows:

- The consultants appear to have a very limited knowledge of the benefits of 4D planning;
- 4D planning use may be based on project size and/or complexity rather than a widespread blanket use;
- Stakeholder project entry points are defined by the contract type and sometimes do not allow a suitable degree of integration as required by 4D and BIM;
- Many of the benefits known and stated by the respondents are linked to their own operations, suggesting a self-centered operational position.

From posing direct specific questions regarding the main limitations and barriers to implementing 4D planning and BIM within the industry, as well as from the answers given to other open-ended questions, common themes were identified. The coding of responses approach was used to identify common categories for the detailed information contained in the open ended answers. The possible limitations were listed and a category given to each to describe the general subject-matter of the comment. Further analysis found common topic descriptions across respondent type (consultant and contractor) and technology/concept (4D planning and BIM). By combining and grouping the findings, there appear to be six common factors considered by consultants and contractors to be key limitations to the widespread use of 4D planning and BIM. Without having the ability to investigate what the respondents specifically intended by the ‘technology’ and ‘too advanced’ categories, it was felt unwise to consider them further in the discussion. Some comments overlapped more than one category (or had the potential to) but have only been included once in the primary heading.

The six common factors considered by consultants and contractors to be key limitations to the widespread use of 4D planning and BIM are:

- Lack of tangible benefits for all parties involved;
- Lack of experience within the workforce;
- Lack of universal use;
- Cultural resistance/Resistance to change;
- Contract Type/Project Delivery Method inhibiting technology adoption;
- Time and Cost.

4. DISCUSSIONS

Understanding the barriers limiting the widespread adoption of technology is crucial for developing strategies for overcoming them. Therefore, the key limitations found in this survey were further investigated and linked to existing studies that attempted to tackle some of the barriers.

4.1. Tangible benefits

The lack of tangible benefits was noted by both consultants and contractors when responding to possible limitations to implementing 4D planning. ‘Cost’ and ‘time’ have also been included within the topic since they are closely linked. Most contractors and consultants noted that the cost of hardware, software and training, as well as the associated time to train to utilize the techniques, are primary factors. However,

as with any new technology or concept, it is crucial that benefits outweigh inputs required and that a return on investment is realized, with often some form of cost-benefits analysis being performed either implicitly or explicitly. The nature and far-reaching project benefits afforded by 4D planning and BIM, make them much harder to justify quantitatively and therefore demonstrate value in a tangible way. For example, from research it was identified the cost of training one person on BIM and providing them with the required materials is approximately £10,000 (Lane 2011). Yet benefits are commonly quoted as being improvements in “project integration”, “communication and collaboration” as well as “improving design and buildability”. The scientific and financially oriented civil and building industry would find it difficult to justify expenditure based on qualitative benefits. Few sources quote quantitative benefits (Eastman et al. 2011), those which do tending to be vague when providing figures. One of the few studies, which investigated industry drivers for implementing an advanced IT system was performed by Dawood and Sikka (2009). The researchers developed a list of key performance indicators for the construction industry in relation to the implementation of 4D planning. Through conducting questionnaire surveys and interviews of project managers and planners within the London construction industry, they proposed 9 key performance indicators affected by 4D planning, which can generate quantitative data.

The performance measures may be ideal for defining benefits in a tangible manner, particularly since they are already directly linked to the construction industry. However, any key performance indicator has to be accurately defined as construction projects, unlike manufacturing, are unique which make it challenging to apply key performance indicators without a valid set of assumptions and a record of historical data.

Another research group who undertook a more holistic approach to deal with the issue of defining metrics for Virtual Design and Construction (VDC) is the CIFE group at Stanford university. Their working paper (Kunz et al. 2011), presented a set of specific types of metrics and goals along with case study example. For example, to assess the importance of the visualization, which is the first step in BIM and 4D or other virtual construction management tool, they propose to use the number use the number of intended stakeholders who report that they have timely and meaningful participation in project reviews and then use schedule conformance such as $\geq 95\%$ of all design, construction and coordination activities started and completed within one day of their look-ahead schedule milestones. This kind of approach would contribute to prove the value of 4D and BIM for all stakeholders involved.

Whatever is the approach undertaken to quantify benefits, it remains the fact that without more definite quantified benefits it is unlikely that finances and resources will be committed to the systems. In an early report by Collier and Fischer (1995, p.52), the authors state that if the benefits of 4D planning can be proven then insurance companies “may begin to offer lower insurance rates to companies that use it”. This could be an asset in promoting advanced systems since reduced insurance premiums could represent a tangible financial saving to project stakeholders, therefore demonstrating added value. As a further solution to this ‘expenditure vs. added value’ paradox, it is crucial that motivational factors such as time and money, very important to a project-oriented industry, are understood when trying to sell the techniques to industry. In addition, a further emphasis within research should be focused on quantifying financial and time savings and identifying a correlation factor to enable savings to be more accurately predicted.

4.2. Lack of experience within the workforce

Workforce experience is a critical factor when deciding whether to implement a new technology since without suitable technicians, desired outcomes cannot be achieved. Indeed, the lack of experience forms a vicious circle since without experience the techniques will not be utilized and without utilizing the technique those people will not be trained or gain experience. It is believed that a first step in increasing levels of experience is to increase levels of awareness through formal education and training, which all technical engineering specialists undertake to achieve their necessary minimum qualifications. Therefore, concept promotion within higher education communities is vital, together with requests for syllabus inclusion. This would require closer collaboration between educational facilities, industry and institutional organizations such as the Institute of Civil Engineers (ICE). In addition, greater awareness

within the industry would provide a form of internal promotion and marketing, allowing insight to be shared with more senior employees. Indeed, other authors have come to a similar conclusion about expanding university courses when discussing a possible industry 'skills gap' with regard to 4D planning (Dawood and Sikka 2009). Indeed, in an article by Peterson et al. (2011) it is proposed that the teaching of project management courses can be improved by the use of BIM-based project management tools, which allow for more realistic assignments to be developed which show how standard management techniques/methods can be applied in specific project scenarios. Although the authors do not specifically describe the teaching and promotion of BIM as an advantage, teaching in this manner inherently demonstrates the BIM concept, software and tools to students who would subsequently be taking this knowledge into industry. In addition, educational facilities will form an indirect marketing step in the proliferation of the concept. With awareness being a crucial step in the learning process towards experience, its importance cannot be overstated.

4.3. Lack of universal use

The lack of universal use is another vicious circle, which is still evolving and inhibiting the widespread use of 4D and especially BIM technology. In fact, when companies use 'lack of universal use' or blame another party as an excuse for not implementing the technologies, they are further perpetuating the argument, as indicated by 7 respondents. This reason for limited implementation is completely understandable and logical especially when it comes to the fact that maximum benefits can be obtained when the technology is adopted by most stakeholders. Indeed, much of the literature highlights the advantages and need for multi-stakeholder input into use of the concepts to gain maximum benefits (Gao and Fischer 2008). "Everyone must be on board to make BIM effort worthwhile" (Eastman et al. 2011, p.187). Alternatively, this may be used as a simple excuse for why the concepts have not been utilized. Either way, a solution to this problem may be harder to achieve. Ideally, an internal or external 'push' or 'promote' force is required by an influential party to instigate the use throughout a project or the industry as a whole. From the findings of the survey it was identified that both consultants and contractors have, at times, instigated the use of the new technology. However, as noted by some respondents, their entry point and authority in a project does vary depending on the contract type and project delivery method making widespread instigation more of a 'suggestion' than a 'command'. Therefore, the ideal project role from which to 'push' the use of advanced technology such as 4D planning or BIM, may be from the client's position. Indeed, one of the respondents highlighted the client's project position in the statement: "BIM is a tool which needs to be used throughout the project, at the moment clients, because of their lack of awareness, seem not to require BIM models at tender stage, this would be the stage where the best use of them could be achieved." However, it has been argued that private and public clients lack the knowledge required to implement the advanced technologies (Bailey 2011). Indeed, within the McGraw-Hill Construction (2010) report, 55% of companies not using BIM stated that lack of client demand was the reason. In addition, it was also stated that when clients request its use "it immediately gains a level of value to users" and that "contractors are particularly swayed by owner demand" (McGraw-Hill Construction 2010, p.28). As an example of external push force affecting the whole construction industry, the UK government has recently made the use of BIM compulsory by all bidders and contractors on public sector projects (DBIS 2011). From this analysis, it is clear that the client, whether is public or private, can play, or has the ability to play, an important role in the widespread of 4D planning and BIM within the industry. However, there are barriers to overcome such as there being an appropriate level of knowledge and awareness amongst clients and 'pushing' use in the correct direction.

4.4. Resistance to change

Resistance to change in some form was indicated by some respondents and could be a fundamental barrier to the implementation. Within research, links have been drawn between implementation of IT in the construction industry and employee resistance (Hartmann and Fischer 2009). It is considered imperative that theories concerning management of change are considered when attempting to implement advanced IT-related concepts/technologies. Indeed, with the wide-scale organizational effects of 4D planning and

BIM, implementation should be considered a transformational and cultural change, which includes the flexibility to account for complex resistance factors, based on the emergent approach to change (Burnes 1996), described in change management literature. Indeed, the ‘cultural’ aspects of resistance were indicated by one of the respondents’ from the consultants position in the statement “traditional construction industry way of working”. There are some approaches described in literature, which attempts to explain the process of change management with specific focus on the implementation of information technology (IT) systems. For example, Stewart et al. (2002) proposed a frameworks for a specific change event related to the introduction of IT and information systems, with particular emphasis placed on introduction into the construction industry. However, this approach should be tailored to the individual organization (Stewart et al. 2002) especially, when implementing a relatively all-encompassing concept such as BIM, the deep-seated cultural aspects of the industry and employees need to be understood to a greater extent and specific allowances made in the planning process.

4.5. Contract Type/Project Delivery Method

Regarding integration of contractors within the design phase of a project, many respondents stated it depended on contract types. The irony is that while both stakeholders and concepts such as 4D planning and BIM require project integration, the overall project delivery system often prevents this from occurring. The traditional project delivery method, known as Design-Bid-Build (DBB), has a limited overlap between consultants and contractors and therefore integration and collaboration are minimal. In addition, difficult and adversarial relationships can form between consultants and contractors (Mulvey 1998). A delivery method of this type is not ideal for the use of 4D planning and BIM since integration, communication and collaboration are keys to success. An alternative delivery mechanism is the Design and Build (D&B) method. The D&B approach makes a single party responsible for both design and construction operations; consultants and contractors are therefore encouraged to cooperate and work together towards project completion (Koo and Fischer 1998). Researchers have drawn direct links between the D&B delivery method and the adoption of advanced IT concepts and tools. Koo and Fischer (1998) directly link D&B and 4D planning. In conclusion, from both the survey results and existing literature, it can be suggested that if concepts such as 4D and BIM are to be promoted and adopted in the construction industry, the project delivery type should be an active consideration since it has a significant effect on success.

5. CONCLUSIONS

This research aimed to present a comprehensive identification and classification of the issues affecting the industrial uptake of 4D and BIM using an empirical industrial survey and literature review as research methods. The empirical industrial survey was used to collect quantitative and qualitative data about four specific objectives: current industry uptake of BIM and 4D; existing knowledge and depth of use; levels of understanding of benefits; and limitations to implementation. The literature review was used to identify existing research and initiatives in each of the categories identified by the research. The study concluded that there are six categories under which all the limitations fall. These limitation categories were commonly noted with both contractors and consultants and for both BIM and 4D. Namely, these are: the lack of tangible benefits for all parties involved; the lack of experience within the workforce; the lack of universal use; the resistance to change; the contract type and project delivery method inhibiting technology adoption; time and cost. Only few respondents within the survey mentioned technical aspects of the technology, in terms of functionality and usability, as barriers to use. Each of the limitation categories was discussed and examples of existing initiatives and research tackling each limitation category was presented. The research demonstrated that the identified barriers are hindering the widespread use of BIM and 4D more than the technical barriers, despite current research is largely focused on technical advances. Based on the findings, it can be concluded that it is imperative that research is also directed to non-technical aspects such as education, training, key performance indicators

and process execution plans, since unless the gap between technology, end-users and their processes is bridged, usage will continue to be limited.

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