

# BIM and 4D planning: a holistic study of the barriers and drivers to widespread adoption

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**Abstract:** *Building Information Modeling (BIM) and its different work streams, such as 4D planning (4D), are among the major drivers for change in the construction industry. The primary aim of this research is to create a holistic map of both the barriers and drivers affecting the industrial uptake of BIM and 4D through the use of an extensive literature review and a survey of contractors and consultants from the UK AEC (Architectural, Engineering and Construction) industry. This research demonstrates that while non-technical barriers such as the inefficiency in the evaluation of the business value of BIM and 4D; the shortage of experience within the workforce, and the lack of awareness by stakeholders are recognized by professionals as main barriers to BIM and 4D adoption, current research is still largely concerned with technical advancement of BIM and 4D technologies. A holistic map of the driving and restraining forces affecting BIM and 4D widespread adoption was provided. The tackling of the non-technical barriers identified will help bridge the gap between technology, end-users and their processes.*

**Keywords:** *4D Planning, Building Information Modeling (BIM), Industry Uptake*

## I. INTRODUCTION

The civil and building industry represents approximately 7% of the United Kingdom's gross domestic product (GDP), equivalent to approximately £110bn per annum [1] and encompasses almost all construction activities, ranging from buildings, highways, railways and bridges to water treatment facilities, energy production and airports. All construction operations are performed as projects and are unique in nature due to the location, specification, design features, construction sequence, etc. In any construction project, there are multiple stakeholders exerting control, input and influence over proceedings, the three key stakeholders being:

- The client – providing initial project impetus, requirements and capital;
- The design consultant – providing the technical expertise to complete the project design and specifications in accordance with the client's requirements;
- The main contractor – providing the construction expertise to transform the design into an actual physical product which conforms to design and specification.

BIM and its work-streams such as 4D planning has been an area of interest and discussion for the last decade in both industry and academia oriented literature and are considered among the major drivers for change in the construction industry. Very limited number of empirical and holistic studies could be found in peer reviewed literature about the industry uptake, barriers and drivers to

BIM and 4D widespread adoptions in the construction industry. This paper adopts a holistic approach using a combination of literature review and a field survey of consultants and contractors from the UK ARC industry in order to depict a comprehensive picture of the current challenges affecting BIM and 4D

## II. LITERATURE REVIEW

Traditionally, the primary method for the consultant to provide design information to the client and contractor is through two-dimensional (2D) paper-based drawings. Although these are able to convey substantial amounts of information in a relatively succinct manner, it does require a level of experience and technical knowledge to interpret the information. In addition, the relative complexity of representing a three-dimensional (3D) project in a 2D manner is inefficient in terms of time required to assimilate information, errors occurring between drawings and possible misunderstandings between interpretations [2]. It is argued that non-professionals may have difficulty in understanding 'technical' 2D drawings, which could prove virtually impossible without professional input [3].

One of the contractor's significant project tasks is to plan the sequence of activities required to complete construction within budget, time and resources constraints. The traditional method to sequence activities is to use Gantt charts commonly utilizing the Critical Path Method (CPM) or network diagrams [4, 5, 6, 7 and 8]. Given the importance of these project plans or schedules to the executing stage and control stages, sub-contractors,

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deliveries, overall project duration and cost, as well as forming the basis for many contract agreements, they are often produced by project managers using nothing more than the drawings, specification, contract documents and own experience and intuition. Similar to 2D drawings, activity schedules are inefficient in the amount of information which can be conveyed and a certain level of experience is required to understand them. Academic works have highlighted schedule inaccuracies [9 and 10]. From a questionnaire survey orientated towards earthwork operations, Shah et al. [9] state that '29%' of projects were delayed due to poor planning and scheduling. As a result of undertaking interviews with 24 project managers and planners, Dawood and Sikka [10] identified that the average activity 'hit rate' was approximately '55%', with the 'hit rate' being a measure of the number of activities having a zero start and finish variance. In addition, traditional scheduling techniques are also inefficient since they do not include the spatial [4, 5, 6, 7 and 8] or resource requirements [4 and 7] of an activity, which makes mistake identification difficult.

Advances in information technology (IT) have dramatically changed the industry, with increased power and speed allowing much more complicated and detailed designs to be produced and plans to be executed. Indeed, Computer Aided Design (CAD) has been referred to as the greatest advance in the construction industry [11]. Many researchers have long recognized the limitations of traditional design consultants' and contractors' techniques and have been endeavoring to incorporate the use of IT to improve efficiency of techniques and the industry as a whole. With the advent and growth of economically viable IT, new systems have been developed to improve information generation and sharing within the industry. From the technology and benefits of 3D modeling, 4D modeling, also known as 4D planning, combines the 3D graphical perspective of a model with the time dimension of a construction schedule [12, 27], which allows for construction operations to be viewed sequentially as a virtual simulation, with the model containing 'logical, temporal and spatial aspects' [27].

BIM is a revolutionary concept which emerged over the last few years BIM and was recognized as the future of the Architectural, Engineering and Construction (AEC) industry [32]. Building Information Modeling (BIM) is the process of generating and managing information about a building during its entire lifecycle [16]. 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 [23]. The 4D and BIM concepts and their applications within the business process are shown in Figure 1 and Figure 2.

Although BIM has been given a variety of definitions such as a data-rich, object oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility, there is still lack of understanding of

the meaning of BIM among researchers and construction stakeholders. For example, from a survey carried out in Finland, construction industry professionals see BIM as any CAD system using 3D data and include the use of 3D visualization [44].

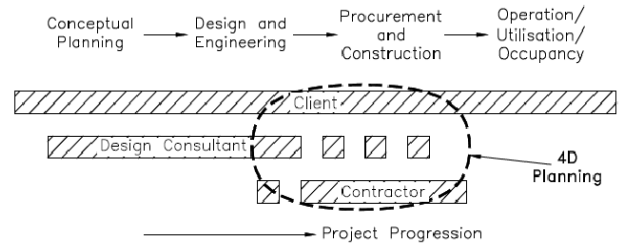


FIGURE I  
PROJECT PHASES, STAKEHOLDERS AND SCOPE OF 4D

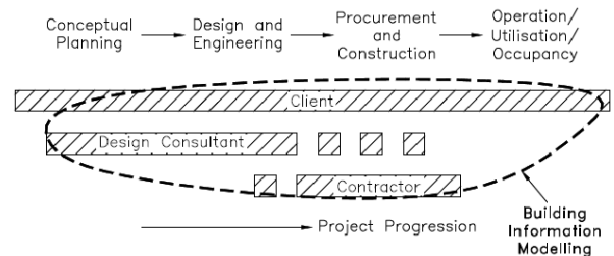


FIGURE II  
PROJECT PHASES, STAKEHOLDERS AND SCOPE OF BIM

In addition, the meaning of BIM varies between disciplines. Singh et al. [14] argue that the meaning of BIM for different disciplines varies according to their expectations. For example, design disciplines see BIM as an extension to CAD, whereas for non design disciplines such as contractors and project managers, BIM is more like an intelligent design management system (DMS) that can quickly take off data from CAD packages directly [14].

Much of the literature surrounding 4D planning and BIM systems identifies problems with existing technology and utilizes further technology to propose and test potential solutions; this research is vital for development and improvement of the technology. However, very few researchers actively consider the industry uptake and reasons for the current level (either positive or negative). Based on uses and benefits as well as improvements and developments of the systems, it may be hypothesized that industry uptake would be significant and rapidly growing. Indeed, the growth in use within the construction industry over recent years has been described as 'phenomenal' [33], although within the same subsection the authors state that implementing 4D systems 'remains a challenging task'.

Alternatively, other authors either state, or give the impression, that uptake is limited. An early 4D modeling report, Collier and Fischer [2] suggests reasons for slow adoption. A more contemporary work, Webb et al. [34] concludes that contractors within the construction industry 'have not yet accepted this potential "4D CAD on a large scale"'. Furthermore, regarding BIM, Hansford [11] states that "widespread adoption remains limited in construction"

and more worryingly that there is an “alarming ignorance over BIM”.

Although there appears to be some ambiguity surrounding industrial uptake of the systems, the fact that many researchers discuss problems and reasons for the current level seems to suggest a common underlying belief that uptake could be improved. 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, their own personal opinions or based on limited and sometimes inadequate research. Only a limited number of field studies could be found in the peer reviewed literature or in extensive industrial initiatives. 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 [29]. 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. The findings were sub-divided by country and general project discipline (architect, engineer and contractor) as well as being grouped under the name ‘Western Europe’ and compared to similar findings from North America. 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%). Furthermore, the report categorized what the participants responded as being the greatest value of BIM and what future adoption may [29]. Although the research is thorough and based on large-scale empirical research, greater knowledge is required regarding the integration between the main stakeholders and their impressions regarding project integration [29]. In fact, due to the large scale of the survey and strict use of closed questions the investigation of the challenges affecting the inter-organizational challenges within the supply chain are not well captured and understood in this survey as well as in other published surveys, which follow the same line. This is an important gap as only through the understanding of the general industry and perceptions of those parties, for whom the concepts are intended, can a future implementation plan be developed.

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

- Objective 1: To evaluate the level of knowledge and experience of 4D planning and BIM in the industry.
- Objective 2: To evaluate both the depth of use of 4D planning and BIM and the connection and integration between design consultants and contractors this may facilitate the use of 4D planning and BIM.
- Objective 3: To identify possible limitations within the industry to the widespread implementation of 4D planning and BIM.

### III. METHODOLOGY

To satisfy the research aims, a survey methodology which consists of quantitative and qualitative data obtained through a web-based questionnaire submitted to a selected sample of 52 consultants and 46 contractors within the UK civil and building industry. The surveys were tailored specifically towards the two participant groups, with over half of the questions being identical. To assist the research, both closed and open-ended questions were used, with the survey separated into three sections; general industry, BIM and 4D planning.

The distribution list was generated by selecting organizations from the New Civil Engineer’s (NCE) Consultants’ [32] and Contractors’ Files [26]. To obtain reliable information and guarantee a good response rate, the authors opted to initially contact 98 companies (52 consultants and 46 contractors) to ask the details of an experienced professional who would be able to complete the survey. 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 sector undertakings by asking the respondents to give percentage values, to the nearest 10%, for the sectors in which they operate. An amalgamation of the data (Figure 3 and 4) shows that the top three rated sectors are buildings (40%), highways (15%) and railways (11%).

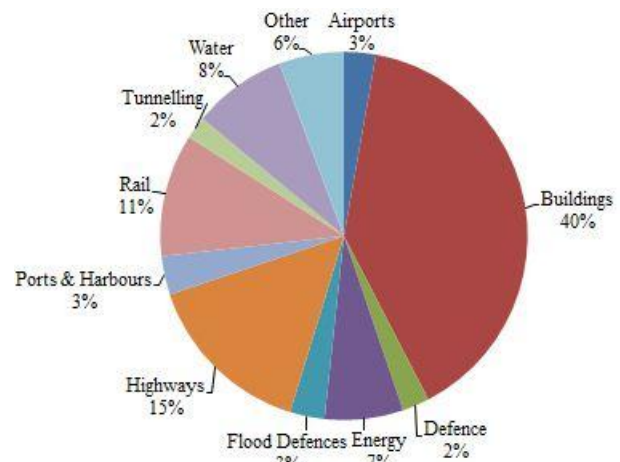


FIGURE III  
WORK UNDERTAKEN BY INTERVIEWED CONSULTANTS

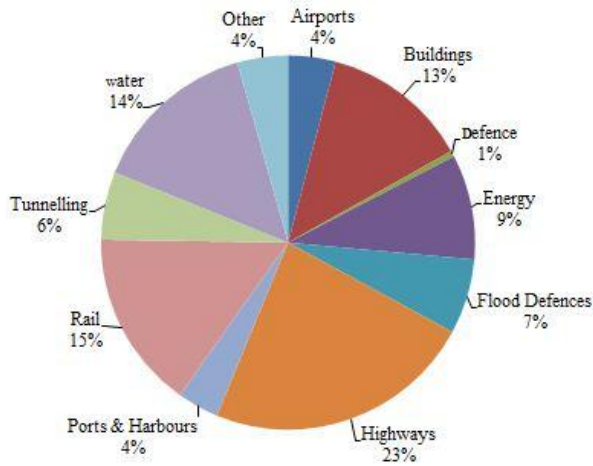


FIGURE IV  
WORK UNDERTAKEN BY INTERVIEWED CONTRACTORS

IV. RESULTS

To summarize the findings, the three objectives have been employed as a structure.

A. Objective 1: To evaluate the industry uptake in the UK and level of knowledge and experience of 4D planning and BIM in the industry

The proportion of yes/no answers by the consultants and contractors, with regard to their awareness of the BIM concept, did not show a significant difference at the alpha level of 0.05 (chi-squared = 0.221, df = 1, p = 0.638).

54% of consultants stated they were aware of the concept, with awareness deriving more from working and practical knowledge (72%) than from an educational background (figure 6). When investigating the benefits in the following questions, a wide knowledge was indicated, suggesting experience rather than theory. For the contractors, a greater percentage (63%) (figure 5) stated they were aware of the concept, with (56%) (figure 6) gaining the knowledge from a working/practical position. 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 main use 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 5) of the consultants indicated they had awareness, with (60%) (figure 6) gaining their knowledge through working/practical levels. 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%) (figure 5) of participants indicated they were aware of the subject. Of those, (60%) (figure 6) stated their knowledge was gained through a working/practical position. 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 (72%) 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.

Conversely, 4D planning showed a divide between the stakeholders, with the contractors being fairly knowledgeable and experienced in the concept.

Somewhat unexpected was the suggestion from the contractors' data that commonly occurring design and scheduling problems, which 4D planning and BIM techniques are intended to resolve, still occur. This could suggest 4D planning is not collaboratively used by contractors and consultants to ensure an error-free design.

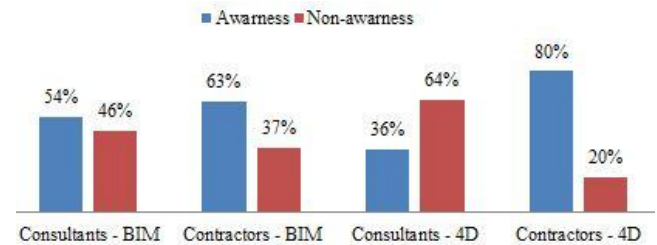


FIGURE V  
AWARENESS OF BIM AND 4D INDICATED BY THE RESPONDENTS

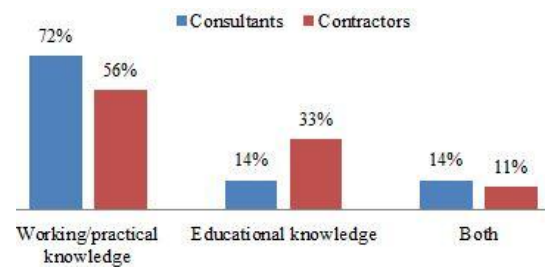


FIGURE VI  
HOW AWARENESS OF BIM IS GAINED BY RESPONDENTS?

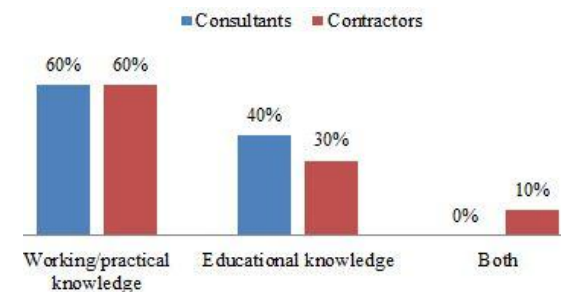


FIGURE VII  
HOW AWARENESS OF 4D IS GAINED BY RESPONDENTS?

B. Objective 2: To evaluate both the depth of use of 4D planning and BIM and the integration between design consultants and contractors



Regarding BIM, (75%) of consultants stated that they have used BIM technology more than once and have experienced its use following the client's request. Consultants' comments in the open ended answers suggested 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. 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, (61%) 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 (what-if scenario). 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. One of the most salient links 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 is originated and used in the Architectural world. Figure 8 shows a comparison of the sector's general overall industry percentage taken from the NCE's Consultants' [32] and Contractors' Files [26] compared to the survey's findings.

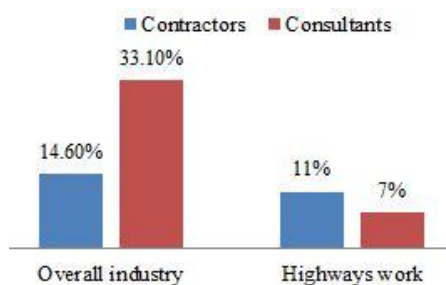


FIGURE VIII  
HIGHWAYS WORK UNDERTAKEN BY RESPONDENTS UTILIZING 4D PLANNING

From these comparisons, it appears that there is a relatively 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.

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'.

Integration between consultants and contractors was difficult to quantify with direct questions that could 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 concepts (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 help the integration and communication, other answers suggest that in actuality integration and collaboration is limited. 57% of contractors stated that 4D planning is not integrated with the design phase and 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, if adequate collaboration is in place.

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 do not consider benefits to the other party (with exceptions). 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 (Figure 9) inhibiting the technology adoption and enhancement. 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.

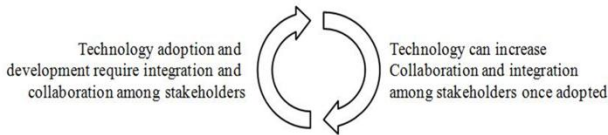


FIGURE IX

STATUS-QUO AFFECTING ADOPTION AND DEVELOPMENT OF BIM AND 4D

C. Objective 3: To identify possible limitations within the industry to the widespread implementation of 4D planning and BIM.

A key means of appreciating the true position a technology holds within an industry is to understand the barriers that may prevent its widespread implementation. From satisfying the previous two objectives, certain feelings and perceptions regarding the concepts have been 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;
- 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, links can be seen between stakeholders and technologies. The coding of responses approach was used to enable combining the detailed information contained in the open ended answer of respondents under a limited number of categories. 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). Tables 1 and 2 show the respondents' comments considered as possible limitations and the grouping of quotes.

TABLE I

POSSIBLE LIMITATIONS INDICATED BY RESPONDENTS TO IMPLEMENTING 4D PLANNING

Topic descriptions	Respondent comments
<b>Tangible benefits</b>	"Tangible benefits" <sup>09</sup> "Some people seeing all cost and no value" <sup>02</sup>
<b>Experience of workforce</b>	"Lack of planners who understand it" <sup>12</sup> "Lack of knowledge and skills" <sup>13</sup> "Lack of knowledge/understanding, ignorance" <sup>14</sup> "Availability of experienced users" <sup>07</sup> "Haven't really seen anything working properly yet" <sup>017</sup> "Generally what I have seen have been academic exercises" <sup>017</sup>
<b>Universal use</b>	"Not everyone on the project team will have access to the technology" <sup>013</sup>
<b>Resistance to change</b>	"Traditional industry way of working" <sup>14</sup> "Fear to give it a go" <sup>02</sup>

	"People" <sup>09</sup>
<b>Time and cost</b>	"Software cost" <sup>09</sup> "Staff training" <sup>09</sup> "Too expensive and time consuming" <sup>12</sup> "Cost" <sup>12</sup> "Requires to be constantly updated to be efficient" <sup>01</sup> "Needs to have experienced individuals inputting the parameters on a continual basis to achieve best results" <sup>01</sup> "Resources" <sup>02</sup> "Keeping the model up to date on a large project will prove difficult, especially so if the design is still being developed" <sup>05</sup> "Initial cost" <sup>07</sup> "Cost" <sup>011</sup> "Cost/time" <sup>014</sup> "Cost and time" <sup>016</sup> "Implementation has been cost prohibitive" <sup>017</sup>
<b>Technology</b>	"User friendliness" <sup>011</sup>
<b>Concept too advanced</b>	"Perhaps too advanced for many on the project teams including sub-contractors, etc" <sup>013</sup>

(∅ Contractors, ■ Consultants, I respondent's number)

TABLE II

POSSIBLE LIMITATIONS INDICATED BY RESPONDENTS TO IMPLEMENTING BIM

Topic descriptions	Respondent comments
<b>Experience of workforce</b>	"Only have a basic understanding of its operations" <sup>3</sup> "Lack of knowledge/understanding, ignorance" <sup>14</sup> "Remains to be seen if it will work" <sup>01</sup> "Availability of experienced users" <sup>07</sup> "Knowledge of how BIM works" <sup>013</sup>
<b>Universal use</b>	"Lack of universal use by the supply chain" <sup>5</sup> "Reluctance to adopt within some teams on perceived costs basis" <sup>7</sup> "The main problem seems to be architects and structures use BIM but mechanical do not" <sup>8</sup> "Requires buy in of designer and supply chain" <sup>01</sup> "All participant parties doing 'their bit' <sup>02</sup> "Clients not issuing BIM models at tender stage leading to redrawing of information" <sup>09</sup>
<b>Resistance to change</b>	"Cultural resistance" <sup>13</sup> "Traditional construction industry way of working" <sup>14</sup> "People lack of will to change" <sup>09</sup>
<b>Time and cost</b>	"Cost is fairly significant" <sup>3</sup> "Would require hardware upgrades" <sup>3</sup> "Significant training" <sup>3</sup> "Training costs" <sup>10</sup> "Time required to input data" <sup>10</sup> "I'm unaware of costs but would expect that it is uneconomic for small projects" <sup>05</sup> "Initial cost" <sup>07</sup> "Time/cost" <sup>014</sup> "Cost" <sup>015</sup>
<b>Technology</b>	"Technology and user friendliness" <sup>011</sup>
<b>Concept too advanced</b>	"Complexity of programme" <sup>10</sup> "Difficult to relate for practical daily use on site" <sup>01</sup> "Too advanced for some construction elements" <sup>011</sup> "Too advanced" <sup>013</sup>

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:

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

## V. DISCUSSION

Understanding the barriers limiting the widespread adoption of technology is crucial for developing strategies for overcoming them. Therefore, the key limitations found were further investigated and linked to existing literature.

### *A. Understanding the business value of BIM*

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. It is important that benefits are seen as adding value to the project and organization rather than as generic benefits. 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 [25, 14]. 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 orientated civil and building industry would find it difficult to justify expenditure based on qualitative benefits. Few sources quote quantitative advantages [21], with the ones that do, tending to be vague when providing figures. Without more definite quantified benefits it is unlikely that finances and resources will be committed to the systems. Furthermore, if a return on investment is not expected on the original project to which resources are committed, then implementation is unlikely. In a very early report by Collier and Fischer [2], 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’. Almost 2 decades from that statement, there are still ambiguity about the value of 4D and BIM. However, since then there have been a few studies which attempted to develop measure key performance indicators in order to demonstrate the business value of 4D planning and BIM.

Dawood and Sikka [10] developed a list of key performance indicators (KPIs) for the construction industry in relation to the implementation of 4D planning, which is a BIM use at the pre-construction and construction stage. The authors have identified possible performance measures, from literature and research, which can generate quantitative data. Then, they conducted questionnaire surveys and interviews of project managers and planners within the London construction industry and identified KPIs to measure benefits from 4D planning. These included KPIs measuring schedule performance (on time completion); safety (ie number of accidents per 1000man hrs worked); client satisfaction (ie number of client change orders) and communication efficiency (ie number of meetings per week and time spent on meetings). They then measured such KPIs for the following 2 years in multi-million pound projects, where 4D planning was used, in order to quantitatively measure the 4D planning benefits on construction. This approach was comprehensive, although it did not clearly explain the other factors which should be isolated in order to correlate benefits obtained with use of 4D planning. In fact, key performance indicators, in order to be used in construction as metrics, need to be accurately defined with all relevant assumptions, since construction projects are always unique and concurrently subject to many factors which could influence their outcomes. This could be very challenging at the initial stages; however, records of historical data and valid assumptions could lead to more rigorous metrics in future.

Another research group which undertook a more holistic approach to dealing with the issue of defining metrics for Virtual Design and Construction (VDC) is the CIFE group at Stanford University. Their working paper [28] presented a set of specific types of metrics and goals along with case study examples. For example, to assess the importance of visualization, one of the main uses of BIM, they involved experienced stakeholders in project reviews and measured performance related to value of visualization. They proposed and measured key performance indicators related to schedule performance such as “95% of all design, construction and coordination activities started and completed within one day of their look-ahead schedule milestones” [28]. Although limited to the visualization side of BIM, this approach would contribute to proving the value of BIM for all stakeholders involved.

Similarly, Sacks and Barak [36] studied the effect of BIM on the productivity of three-dimensional parametric modeling through experiments in which parallel activities were completed in 2D and 3D. While this type of experiment could show the BIM’s benefits, it is limited to productivity benefits of producing 3D BIM models and outcomes could be affected by the varying experience of users or their position on the learning curve of respective technologies.

These studies are suitable attempts of the path of proving the business value of BIM. However, there is a long way to go in this area as the reliability of measures will depend on the collection of large sets of data and the capability of correlating the KPIs to the use of BIM and 4D by isolating all other factors related to the uniqueness of projects in

construction. Finally, these approaches are required to demonstrate the value of the technology to all stakeholders as well as to the critical disconnect between organizations involved in the supply chain.

#### *B. 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, lack of experience forms a virtuous 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, 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 Institution 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 [11]. Today, schools such as PennState, Georgia Tech, University of Southern California, Montana State University and Stanford University have all implemented BIM curricula and are considered leaders in BIM education [42]. Worldwide, there are 103 schools introducing BIM into curricula, of which 75 are in the United States and only 28 in other countries [42] such as Australia, Denmark, Hong Kong, Finland, Germany, Sweden, the United Kingdom [41], and Israel [35]. However, there are significant limitations in the way BIM has been introduced in academia. Few universities are known to have implemented BIM multidisciplinary education environments, one being Stanford University, which was awarded for its experience of multidisciplinary analysis and modeling [13]. Although awareness is a crucial step in the learning process towards experience, there is still a gap in BIM education in terms of providing future professionals with multi-disciplinary skills which go beyond awareness to provide them real skills to face the real world challenges.

#### *C. Lack of Universal use*

The lack of universal use is another virtuous circle, which is still evolving and inhibiting the widespread of 4D and especially BIM technology. In fact, when companies use 'lack of universal use' as an excuse for not implementing the technologies they are further perpetuating the argument. 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 [21]. "Everyone must be on board to make BIM effort worthwhile" [20]. 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 is noted by some contractors, 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 clients' position. However, it has been argued that clients lack the knowledge required to implement the advanced technologies [13]. Indeed, within the McGraw-Hill Construction [29] 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" [29]. 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 [20]. From this analysis, it is clear that the client plays, or has the ability to play, an important role in the use of 4D planning and BIM within the industry. However, there are barriers to overcome such as there being an appropriate level of knowledge amongst clients and 'pushing' use in the correct direction.

#### *D. Resistance to change*

Resistance to change in some form was indicated by a large proportion of respondents and could be a fundamental barrier to implementation. Within research, links have been drawn between implementation of IT in the construction industry and employee resistance [27]. BIM was widely recognized as "a disruptive technology in design; ...we wonder what the industry and scholars can do to adapt the inevitable social, environmental, organizational and technical changes" [40]. In such a context, the grounded management of change theories, widely known in addressing disruptive change, should be considered and tailored to the construction industry, given the magnitude of BIM impacts on multiple stakeholders across the whole supply chain and project stages. In addition to the management of change theories, there is a need to make to reengineer existing processes into new processes that could emulate BIM workflows. Within this area, previous seminal work of Venkatraman (IT maturity and alignment models) and Davenport (process reengineering) could be used for the integration of BIM in organizations.

#### *E. 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 [29]. 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 [8]. The Design-build (DB) process was developed to consolidate responsibility for design and construction into a single contracting entity and to simplify the administration of tasks for the owner [48]. With the D&B method the client enters into a single contract with the D&B company, which then employs the required stakeholders as partners or sub-contractors. Technical stakeholders therefore become partners rather than individual project parties. Contractual issues as well as legal issues were widely acknowledged in the literature [37, 38, 39 and 40] as being major barriers to BIM adoption. However, very little research has been done in this area especially with regards to the legal issues.

Based on the results of the survey, which identified the barriers affecting the implementation of BIM and 4D in the UK construction industry, and the results of the review of initiatives from the scientific literature attempting to lower or overcome the barriers identified, a map of driving and restraining forces was produced to summarize the current situation (figure 10).

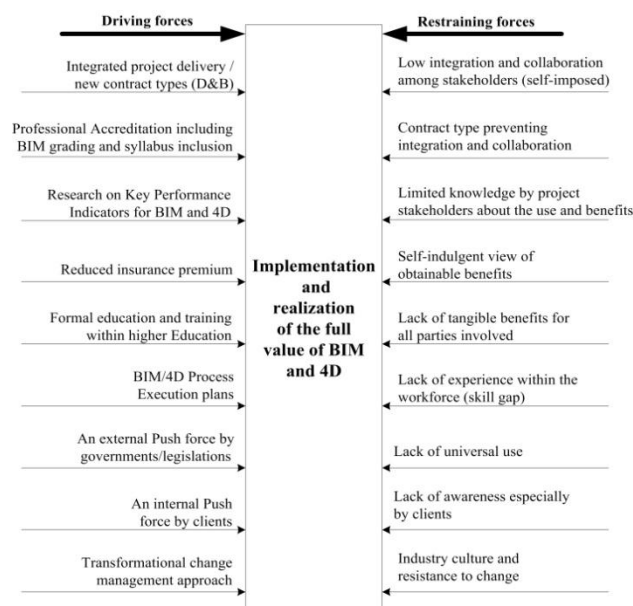


FIGURE X

DRIVING AND RESTRAINING FORCES AFFECTING THE IMPLEMENTATION AND REALIZATION OF THE FULL VALUE OF BIM AND 4D

## VI. CONCLUSION

This research aimed to present a holistic identification and classification of the issues affecting the industrial uptake of 4D and BIM. The research employed a survey data collection methodology, data coding and literature review. The survey was used to collect quantitative and qualitative data about three specific objectives: industry uptake in the UK and level of knowledge and experience of 4D and BIM in the industry; the depth of use of 4D and BIM and the integration between design consultants and contractors, and possible limitations to the widespread implementation of 4D and BIM within the industry. The sample of respondents consisted of 31 organizations (14 consultants and 17 contractors) in the UK construction industry. Data coding was used for the classification of respondents' qualitative answers. The literature review was used to analyze existing research and initiatives that is tackling some of the barriers in each of the categories identified.

Six main categories of barriers to the widespread use of BIM and 4D were identified. These were namely: the lack of tangible benefits for all parties involved or the understanding of the business value of BIM; the lack of experience within the workforce; the lack of universal use; the resistance to change; the contract type/project delivery method inhibiting technology adoption, and time and Cost. These barriers were commonly noted with both the stakeholders (contractors and consultants) and for both concepts (BIM and 4D). 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 barrier categories was discussed and examples of existing initiatives and research tackling some of the barriers identified were presented.

The research results could be used as a snapshot of the restraining and driving forces affecting BIM and 4D implementation in the industry within the context of developing a holistic strategy to increase the adoption of BIM and 4D in the industry. In particular, the review of the state-of-art-of initiatives identified within the industry (e.g. legislative requirement for BIM utilization) and literature (e.g. key performance indicators for 4D and BIM) as driving forces could be used by researchers and practitioners to further strengthen the driving forces and lower the barriers. Indeed, the findings of this research showed that non-technical barriers, such as the inefficiency to quantify the tangible benefits of BIM and 4D and lack of awareness by stakeholders, especially the clients, are affecting widespread use of BIM and 4D more than the technical barriers which were mentioned by respondents only in few cases, despite current research largely focusing 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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