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An Investigation on the Impact of 4D BIM on Construction Scheduling

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Abstract

This research aims to investigate the impact of 4D BIM on construction scheduling and whether using 4D BIM reduces construction delays or not? Multi-dimensional Building Information Modeling (BIM nD) integrates different project applications with BIM, such as scheduling and estimation. 4D BIM is the process of linking the project schedule with the 3D model to generate relevant data for constructability analysis, safety planning, and building assembly. The methodology used in this paper consists of a comprehensive literature review on 4D BIM and then comparing the results with the data collected from a survey distributed to AEC industry professionals. Based on the findings, 4D BIM is improving project performance, enhancing decision making, and helping achieve on-time delivery. The main challenges are related to software interoperability issues and manually linking scheduling activities into model components. The three top barriers from survey results are (i) lack of training, (ii) high implementation cost, and (iii) software/hardware issues. Future research may focus on automating the 4D BIM process of linking scheduling activities into the model components. Another important research topic is the return on investment analysis for 4D BIM implementation on project objectives.

Keywords

Building Information Modeling, Scheduling, BIM, 4D, Construction

1. Introduction and Background

Building Information Modeling (BIM) is widely known for integrating all the construction project information across different stakeholders (Azhar, 2011). BIM 3D visualizes the building adding the elevation as a third dimension, known as the z-axis. However, BIM 3D includes spatial dimensions as 3D CAD and all the geometric and functional properties of the objects in the building model (Ding, Zhou, & Akinci, 2014). There have been additional dimensions associated with BIM 3D in recent years, such as time and cost. The fourth dimension of BIM (BIM 4D) is integrating the project Scheduling into the 3D model of the project (Gledson, 2016). This research aims to investigate the effect of 4D BIM on construction Scheduling and whether using 4D BIM reduces construction delays or not. The aim is divided into four objectives (i) investigate the status of 4D BIM adoption in the construction industry, (ii) discover benefits of 4D BIM for construction contractors, (iii) explore the status of software interoperability and the method of integrating the Scheduling into the 3D model, and (iv) identify the challenges and barriers of utilizing 4D BIM in construction delays.

The author believes, from his experience working in construction in Oil & Gas projects, when 4D BIM is implemented effectively in construction projects, huge benefits can be yielded for project stakeholders. Potential benefits are the simulation of the project timeline, better trades coordination, clearer data for project stakeholders, and improved decision making. For example, there will be a positive influence on management decisions, emphasizing critical path activities on a weekly basis and improved procurement of materials on site. The main advantage of 4D BIM is seeing the Scheduling timeline associated in the 3D model. Every project stakeholder can easily understand the project Scheduling status and where the focus should be in the coming weeks. The project stakeholder should not have an engineering background or technical experience when looking at 4D BIM timelines compared to Gantt charts

for large construction projects. This is in addition to better site coordination between different trades and improved clash detection; thus, reducing change orders and improving As-build drawings.

A literature review is done addressing all these concerns and challenges in implementing 4D BIM in the industry. In addition, data about 4D BIM from a survey distributed to industry professionals will be utilized and compared with literature review results.

2. Research Method

As mentioned, the first step used in the methodology of this paper involves a literature review of 4D BIM implementation. The author started searching the Associated School of Construction (ASC) proceedings from 2005 to 2020. As mentioned in table 1, different search terms have been used to cover all the published papers related to BIM 4D. For example, the keyword "schedule" was used for scheduling to cover the papers talking about schedule or scheduling.

Table 31. Key terms used for search in ASC proceedings.

No.	Keyword used	Research Area	Papers Published
1	Building Information Modeling, Building Information Modelling, BIM	BIM	70
2	Schedul, Scheduling, Schedule	Scheduling	44
3	BIM 4D	BIM 4D	1
4	Building Information Modeling and Scheduling	BIM 4D	0

Then, the author expanded the search to other scientific databases, i.e., Scopus, Web of Science, and Google Scholar. The same keywords were used, focusing on "BIM 4D" and "construction schedule". Since many papers are available about 4D BIM in these databases, different filters were used, such as within the last five years and most cited. After reading abstracts and some of the papers, the author finalized the search into 12 papers that match the most with the objectives of this research (see references list).

In addition to the literature review, information from industry professionals is extremely important as they are on the front line for BIM implementation. They can provide valuable information about the current barriers and challenges for executing BIM 4D. A survey was designed to collect as much data as possible from the industry professionals. The survey is divided into different sections, facilitating the survey flow using the blocks feature in Qualtrics software and software for designing and distributing surveys. The first section includes the consent question and the general information of the respondent's company, such as type of business, geographic location, company size, and company revenue. Also, it includes general questions about BIM, such as whether the company uses BIM or not, software usage, duration of using BIM, and frequency of using BIM. After that, the survey will start asking questions about each dimension of BIM. Starting with BIM 3D until the last dimension used, depending on the respondent's answer of how many dimensions the company uses. Each BIM dimension section in the survey contains main questions and matrix questions. In this paper, the focus will be only on the section results of the 4D BIM questionnaire. The main questions will ask about the software used and if the company uses BIM until the end of the project. The matrix questions are multiple-choice questions. They are the same set of questions for each BIM dimension which are six questions (i) Is 4D BIM regularly used at your company (meetings, preparation of reports, presentations for client...)? (ii) Is 4D BIM helpful in company meetings? (iii) Do you think 4D BIM has a significant influence on project management decisions? (iv) Your familiarity with 4D BIM Application (v) On the scale of 1 (lowest) – 5 (highest), please rate your competency of using 4D BIM Modeling and (vi) Please list the barriers in using 4D BIM (check all that apply).

Survey distribution started on November 18, 2020, by posting the survey link on LinkedIn weekly until January 30, 2021. The authors chose the largest five BIM groups on LinkedIn as the targeted audience. Additionally, the survey link was distributed for the Industry Advisory Board of Construction Management department members in Kennesaw State University. Furthermore, the authors distributed the link to their contacts in the BIM industry. A total of 67 survey responses was received by the end of January 2021. After asking the question of using BIM, 11 responses were incomplete, which means they started the survey but did not complete it. So, Qualtrics will save their partial answer, and thus these responses were omitted from the data analysis for this paper. Another 12 responses who answered "No" for using BIM were excluded from this research. Eight responses from the remaining 44 responses were excluded because the responses do not have recorded data. Incomplete response is one of the limitations of this

survey, where almost half of the responses were excluded because of partial information. Hence, as shown in Figure 1, a final of 36 responses with recorded data was analyzed and studied for this paper in the data analysis section below. Most of the complete responses came from the contacts of the writers and not from LinkedIn groups. This indicates the importance of a targeted audience when distributing long surveys and the limitation of the survey as a research method.

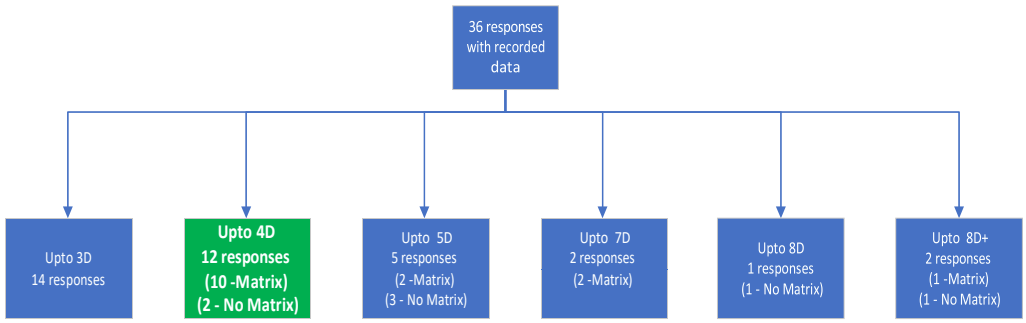

Fig. 1. Survey flow chart

3. Data Analysis and Results

The first objective is to investigate the status of 4D BIM adoption in the construction industry. (M.L.A.E. Borges, 2018) did a systematic mapping study of the current research in scientific paper format published from 2006 to 2016 about BIM 4D. (M.L.A.E. Borges, 2018) found the number of studies on 4D BIM has been increasing over the years where 51 articles out of 148 articles discuss the implementation of 4D BIM (about 32%). Most of the studies are case studies that indicate the current development, improvement, and implementation of 4D BIM among academic professionals as well as industry professionals (M.L.A.E. Borges, 2018). Nevertheless, 4D BIM is still not widely used by small-size companies in the construction industry (Sediqi, 2018).

Alternatively, figure 1 shows the number of survey respondents using each BIM dimension. The data is collected from two questions. The first question asks if the company utilizes more than BIM 3D, where 14 respondents answered “No”. Thus, there are 14 survey respondents out of 36 who use BIM 3D only. It means their companies do not use more than BIM 3D. The second question asks, “Up to how many dimensions is your company currently using?” where the respondent can choose only one answer from the choices (4D, 5D, 6D, 7D, 8D, or 8D+). Therefore,the data was analyzed from another perspective where the actual number of companies using BIM 3D is 36 (all the respondents) and not only the 14 companies who use BIM up to 3D. The number of companies that used 4D (12 respondents), 5D (5 respondents), 7D (2 respondents), 8D (1 respondent), and 8D+ (2 respondents) have been added to the 14 companies who answered “No” to the first question. Because when the respondents answered up to 4D, forexample, it means they used 3D in addition to 4D and not only 4D.

For BIM 4D, 22 survey respondents out of 36 use 4D BIM (61% of total survey responses). This indicates 4D BIM adoption is increasing among Architecture Engineering and Construction (AEC) industry stakeholders. It can be concluded that as the dimensions of BIM are increasing, the number of companies using them is decreasing. 4D BIM implementation is the highest dimension used with the 3D model.

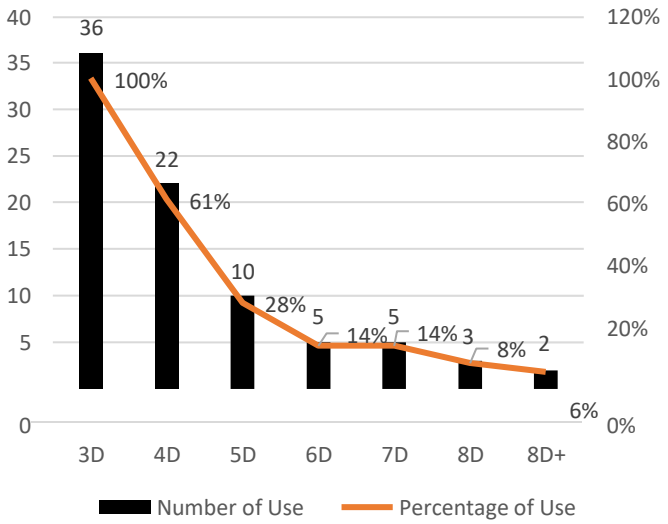

Fig. 2. Count of survey responses for using each BIM nD

The second objective is to discover the benefits of 4D BIM for construction contractors. (Martins, Evangelista, Hammad, Tam, & Haddad, 2020) found the following benefits of 4D BIM in their case study in Brazil (i) better representation of the construction project, (ii) evaluating different methods of construction, (iii) better communication among project stakeholders, (iv) improved project decisions, (v) valuation of resources of each construction activity, and (vi) visual preparation for site logistics and installation. These benefits will lead to achieving project objectives efficiently, such as finishing projects on time and within budget (Martins et al., 2020). In a different perspective for 4D BIM implementation, a case study of a megaproject in Australia was analyzed to assess the effect of 4D BIM visualization models on the communication of risk information (Datta, Ninan, & Sankaran, 2020). The authors discovered 4D BIM assisted in reducing different risks such as safety risk, interface risk, and program risk (Datta et al., 2020). (Hergunsel, 2011) found that 4D BIM can be very useful for updating progress on the project Scheduling as well as for monitoring and closing punch-lists. (Romigh, Kim, & Sattineni, 2017) did qualitative research about the importance of using 4D BIM on construction sites by interviewing construction superintendents. The results showed a strong requirement from superintendents to use 4D BIM as a tool on site to improve communication with different project stakeholders during the project execution phase (Romigh et al., 2017). 4D BIM is expected to improve site operations in the construction industry by enhancing construction planning and sequence of work (Romigh et al., 2017).

Similarly, twelve survey respondents out of thirteen believed that 4D BIM is useful in company meetings (see figure 3). These results from the survey show the value of 4D BIM in the construction industry.

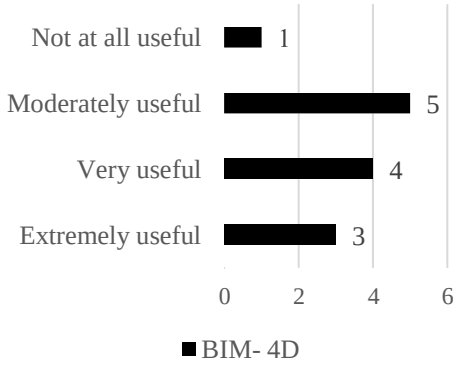

Fig. 3. Count of survey responses for using each BIM nD

The third objective is to explore the status of software interoperability and the method of integrating the Scheduling into the 3D model. Figure 4 presents the data collected from the survey when asking about software usage for BIM 4D. The survey results show Navisworks, BIM 360, and Synchro are the most used software for BIM 4D. Navisworks is the highest software being used in the industry (17 survey respondents out of 22; percentage of 77%). BIM 360 and Synchro come in second and third places, respectively (8 responses for BIM 360 and 7 responses for Synchro). This software is frequently found in case studies, discussed in this paper, from the literature review. In the case study in Brazil, (Martins et al., 2020) investigated the interoperability of Revit, Tally, Navisworks, and Green Building Studio. Although there is effectiveness of 4D BIM using Navisworks and BIM-Revit, there are some constraints found such as (i) massive use of separate software, (ii) software flaws carried out through project, and (iii) possible rise in project costs (Martins et al., 2020). When (Zhang & Laddipeerla, 2018) simulated two models for a bridge and an apartment and during importation, they found that IFC-based interoperability can be reached by using distinct architecture, engineering, and construction (AEC) objects. Although there is a lot of improvement in creating 4D BIM simulations with different commercial platforms (Navisworks, Synchro, and Navigator), going back from 4D simulations to Industry Foundation Classes (IFC) models is still missing (Zhang & Laddipeerla, 2018). Likewise, (Hergunsel, 2011) observed the availability of some challenges in 4D BIM simulation, such as using different platforms and interoperability of BIM tools.

Two main articles address auto-linking Scheduling to the BIM model and thus automation of BIM 4D. In the first study, (Taiebat & Ku, 2010) suggests a data model approach to auto-generate construction plans based on project stakeholder criteria. (Taiebat & Ku, 2010) believe when you use parametric and object-oriented modeling concepts, it will reduce the planner's work and let the planner achieve more accurate results. In the second study, (Elghaish & Abrishami, 2020) did an extensive literature review and found research gaps in integrating the Scheduling into the 3D model. Then, (Elghaish & Abrishami, 2020) did an exploratory case study to find a workable solution for automating the 4D BIM process. (Elghaish & Abrishami, 2020) propose a planning library similar to structural and architectural design libraries to help automate the 4D BIM process. In conclusion, (Elghaish & Abrishami, 2020) found the results presented a cost saving of 22.86 percent when automating BIM 4D.

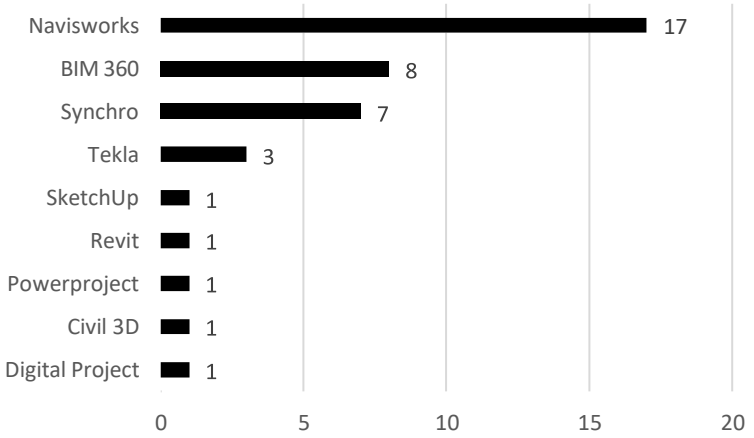

Fig. 4. Software usage for BIM 4D

The fourth objective is to identify the challenges and barriers of utilizing 4D BIM in construction delays. Even though a lot of challenges for 4D BIM can be identified from the literature review, the focus in this paper will be on the barriers from the survey results. In their case study, (Martins et al., 2020) identified different challenges for 4D BIM implementation, such as (i) use of different software, (ii) diverse scopes of construction projects, (iii) increase in cost, and (iv) training of project professionals. (Romigh et al., 2017) recognized the hardship of learning the current software in the market as the main barrier for utilizing 4D BIM on-site.

As per survey results and as shown in figure 5, lack of training is the highest barrier for 4D BIM (7 out of 15 responses: 47%). (Martins et al., 2020) also found the training of project stakeholders is difficult and expensive because of extensive use of multiple software for 4D BIM implementation.

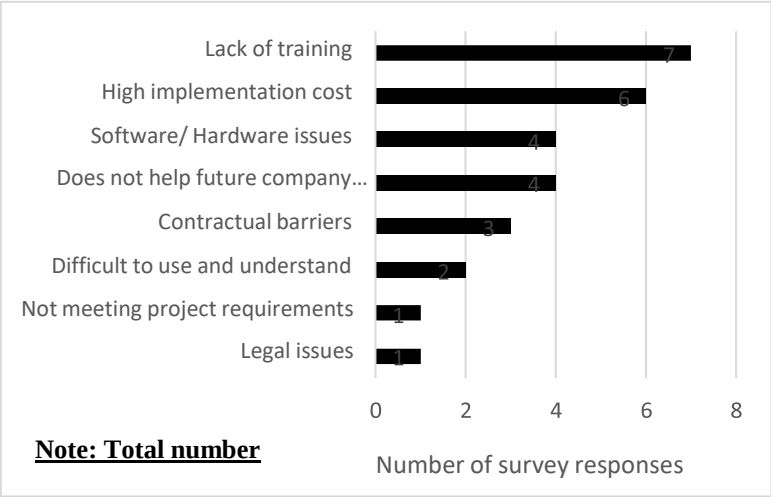

Fig. 5. 4D BIM barriers

Thirty-two percent (32%) of survey respondents (7 out of 22 respondents) are not using 4D BIM till the end of the project. After asking the following survey question about the reasons for not using 4D BIM till the end of the project, five responses were collected from the survey, as shown in table 2. The author grouped the reasons into two categories. The first category of reasons falls into barriers for not using 4D BIM till the end of the project. Time constraint appeared twice as a barrier; however, after reading response 1 in table 2, the survey respondent talks about the time required for linking Scheduling activities to the model components. Again, this validates the importance of automating the 4D BIM process, as discussed in the third objective, to save time. The second category falls into BIM usage for the beginning of the project only without any barrier.

Table 2. Reasons for not using 4D BIM till the end of the project

No	Response	Type
1	Time constraints of adding individual Scheduling activities to model components. Construction Scheduling has 1000+ activities with 25,000+ model components create a barrier to fully updating without hiring specific roles to maintain the 4D model. The simple analysis is competed on the front end of a job to prepare for site logistics	Barrier
2	Company policy	Barrier
3	Time	Barrier
4	Just for Construction Simulation in Tender Phase	Usage only at the beginning of the project
5	Linking Scheduling to models and updating them automatically	Usage only at the beginning of project

Future research may focus on feasibility studies and analysis of the return of investment on project objectives for implementing 4D BIM in construction projects. After the above data analysis, future research may focus on automating the 4D BIM process of linking Scheduling activities into the model components. Another important research topic is comparing similar projects with the only difference is using 4D BIM effectively. The results from such research will uncover whether using 4D BIM has a positive outcome on project objectives such as time, cost, and quality or not. Additionally, a return-on-investment analysis will motivate the construction industry to embrace 4D BIM in more projects and revoke the current barriers for 4D BIM execution.

4. Discussion, Limitations, and Future Studies

From a research perspective, the topic of 4D BIM has been vigorously investigated to determine its applications in construction planning, scheduling, constructability analysis, and control of production. However, our survey results reveal that its actual implementation in the construction firms is merely limited to the development of visualizations for owners and/or marketing purposes, with very few firms exploiting its full potential. Though the survey results

provided several reasons for its implementation, more systematic research is needed to investigate these underlying reasons further and develop strategies and best practices to encourage construction firms to move beyond 3D BIM. The authors plan to continue this study. More data will be collected to develop a framework for 4D BIM implementation in construction firms to improve project performance and productivity.

Conclusions

The 4D BIM is a current topic of interest for both academic and industry professionals. Despite the availability of many case studies, the question of whether 4D BIM reduces construction delays could not explicitly be found. However, based on findings, 4D BIM improves project performance, enhances decision-making, and achieves on-time delivery. Another benefit is better planning and preparation of work and thus an increase in the workers' productivity. Additionally, visual preparation for site logistics and installation will reduce costs by procuring materials in advance and delivering them just in time.

Moreover, clearer communication among project stakeholders is one of the important advantages of 4D BIM,where technical experience is not required for understanding construction Scheduling. The main challenges from the literature review are related to software interoperability issues and manually linking Scheduling activities into model components. The three top barriers from survey results, related to software issues as well, are (i) lack of training, (ii) high implementation cost, and (iii) software/hardware issues. Though a lot of improvement has happened in the last decade for 4D BIM software, more improvement is required in this aspect. For example, Autodesk has Revit to develop BIM 3D, link Microsoft Project Scheduling into Navisworks with BIM 3D, and thus build a simulation of BIM 4D. Using different software increases implementation costs and requires the training of project personnel for using the software. Furthermore, manually linking Scheduling activities into model components requires a lot of time and personnel. Finding a solution to automate the 4D BIM process with minimum software usage can lead to huge rewards in the construction industry.

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