

4D Scheduling: A Visualization Tool for Construction Field Operations

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Over the past decade or so, several innovative digital technologies have been implemented to streamline construction processes. These techniques include BIM, sub-contractor coordination using 3D models, model based estimating and scheduling. These technologies have helped to improve productivity, reduce waste and improve sustainability efforts. The use of 4D BIM simulation in field operations is one of these technologies that is expected to improve field operations on a construction-site. Evidence suggests that 4D scheduling implementation needs improvement, while it is simultaneously endorsed by researchers to become an essential part of the construction phase. In this paper, a qualitative research is undertaken to investigate how 4D technologies can best be implemented on the construction-site. The qualitative research involved interviewing construction superintendents regarding the use of 4D technology on the construction-site. Participants were asked about the role that 4D technologies and visualization had in communicating the schedule to various stakeholders on a project. The data from the semi-structured interviews was analyzed using qualitative content and thematic analysis techniques. Results from the qualitative data suggested a strong connection between a superintendent's need for project schedule communication to stakeholders and the use of digital visualizations to achieve the same. Superintendents invariably considered meeting the project schedule and updating the plan as a key responsibility. The data analysis was used to propose a framework for implementing 4D BIM technologies on a construction-site.

Key Words: 4D Scheduling, BIM, Schedule, Field Operations, Construction Communication

Introduction

In the past decade, the use of building information modeling (BIM) has proven to be an effective tool that has helped to increase productivity and coordination between stakeholders (Merschbrock and Munkvold, 2015). The use of BIM has increased in popularity in the construction industry resulting in reduced schedules, lower cost, and improved productivity (Dodge Data & Analytics, 2016). More recently, BIM is being integrated into field operations through mobile technology, laser scanning, and robotic field layout (Marzouk and Zaher, 2015). Current research indicates an expanding use of BIM in field operations for workspace planning, progress tracking, safety, and other activities. Four-dimensional BIM (4D BIM), or simulation-based modeling, can be defined as the combination of a three-dimensional (3D) BIM model and a project's construction schedule. This integration allows users to visually understand the length and order of activities in the construction process, as well as foreseeing potential problems before they become an issue in the field (Trebbe et al., 2014). In fact, over 60 percent of the respondents to a global industry survey indicated that further enhancing visualization through the use of BIM would increase return on investment (Dodge Data & Analysis, 2014).

Currently, 4D BIM simulation is not routinely implemented in construction field operations. Research indicates that using 4D BIM may be less effective when 3D BIM models lack sufficient detail to properly sequence the work in a 4D model. This weakness is often overcome using an on-site virtual design and construction (VDC) engineer capable of inserting missing levels of detail in a 3D model (Jacobi, 2011; Harris and Alves, 2013; Tulke et al., 2008). The limitations that currently prevent 4D simulation from being a staple in field operations are eroded by the misconception that "*little empirical evidence exists that shows the value of 4D CAD technology in practice*" (Trebbe et al., 2014, p. 84). Despite these factors, research has found that 4D BIM can be an effective communication and problem solving tool, as evidenced in a case study conducted by Trebbe, Hartmann, and Doree (2014, p. 83) who used 4D CAD to help BIM coordinators "*work together in the planning phase to rule out unwanted conflicts between work activities*". Furthermore, Harris and Alves (2013) found that the flexibility of 4D BIM over 3D BIM added value to field operations.

The research presented in this paper explores extended uses of 3D BIM combined with a construction schedule to produce a 4D visualization tool that may be used in construction field operations. It is necessary to begin this research by understanding more about the construction coordination process so that improvements can be suggested for 4D BIM technology. Therefore, this research sought to conduct interviews with construction superintendents because they are commonly responsible for the coordination of field operations.

Literature Review

Visualization of construction operations has changed dramatically over its lifetime. Originally, 2D drawings were used for visualization as a means of communicating the construction plan from the design team to the contractor and owner (Goedert and Meadati, 2008). Over the past several decades, construction techniques have stayed relatively the same while technological innovations and improvements have made it possible to communicate the construction plan more clearly and share digital data with multiple stakeholders on a project. Studies in the literature have shown that construction industry professionals recognize the potential of 4D scheduling technology (Dang & Bargstädt, 2015; Wang et al., 2014). While 4D scheduling has undergone extensive research and development in the academic community, there have been very few studies in the application of 4D technology in real-world situations.

Harris and Alves (2013) conducted a literature review that implied a knowledge gap in the architecture, engineering and construction (AEC) industry when it came to understanding the potential benefits of using BIM to support the trades. The authors conducted a case study that identified the applicability of 4D BIM in field operations and concluded three reasons in support of 4D BIM: 1.) waste due to improper activity design, 2.) trade stacking and decreased productivity, and 3.) waste due to incomplete access ways. In each scenario, it was noted that the use of 4D visualizations such as '4D BIM videos', '4D sequencing illustration', and '4D animation' provided more information to the trades. While the authors noted that these visualizations could help to reinforce commitments made by sub-contractors and assist in assessing the planned activities with the trades, Harris and Alves (2013) did not present any feedback from industry professionals on these ideas.

Sampaio and Viana (2014) advocate the use of 4D visualization technology in construction education. The authors used software from Eon Studio to generate 4D simulations as learning tools for students. Additionally, these 4D instructional applications were found to streamline the education of tradesmen while fostering collaboration. Although their work pertained to the construction of bridges, it expanded the current assumption of how 4D simulations may be used. These types of simulations allow learners to interact with the model and repeat processes until a desired level of understanding has been reached. And by standardizing these learning tools, 4D simulations that could be used to educate tradesmen have the potential to become "*reusable, accessible, durable and interoperable*" (Sampaio and Viana, 2014, pg. 159). Brito and Ferreira (2015) presented research on 4D modelling to improve visualization and communication between stakeholders. Although the authors did not adequately define which stakeholders were being referenced (i.e. managers, tradesmen, or both), each stage of the construction process was discussed in their research. Through their research, Brito and Ferreira made a point of highlighting 4D BIM's limitation in visualizing the activities of interior building construction. The authors combatted this point in their research through the utilization of split screen views with hidden levels and transparency to generate a 4D simulation that could expose the interior construction activities in a better way. By constructing multi-scheme 4D simulations of a single commercial building along with surveying construction professionals, Brito and Ferreira found that construction managers highly valued the use of 4D models to foster communication between the stakeholders. On the other hand, less enthusiastic opinions were held by constructors who were more conservative with their opinions about the technology (Brito and Ferreira, 2015). Brito and Ferreira did not discuss a comprehensive strategy for implementing 4D scheduling on a construction project to support field operations.

Several other studies in 4D scheduling indicates that the topic is being actively researched in academia (Liu and Li, 2013; Guan et al., 2015; Hamzeh et al., 2015). Furthermore, the results of research conducted by Harris and Alves (2013) for the application of 4D BIM to enhance communication and collaboration on-site are relevant and encouraging. However, there is a need to further investigate the topic since the adoption of BIM related technologies are increasing in the construction industry and newer processes are being incorporated. This research differentiates itself by examining current industry needs that could be fulfilled with 4D technologies while improving communication and collaboration in construction field operations. A comprehensive strategy to incorporate the use of 4D scheduling in construction field operations is also presented in this research.

Research Method

The primary purpose of this research was to investigate the use of 4D BIM as a visualization tool to assist in field operations. A qualitative research strategy using semi-structured interviews as the primary data collection method was adopted to conduct this study. Participants in this study were classified as "superintendents", or those individuals that were most likely responsible for orchestrating the daily activities of a construction-site; partly inclusive of quality control, sub-contractor coordination and maintaining the construction schedule. At the time of the interviews, the participants were working on projects from the following states: Alabama, Georgia, New York, Tennessee and Texas. The companies that these individuals were employed in ranged in size from $100 million to over $1 billion (based on annual construction volume). Only one individual was employed with a smaller (less than $100 million annual construction volume) company. Additionally, the participants reported a range of 10 - 40 years of relatable construction experience.

The participant selection was organized to obtain an expert opinion about the use of 4D technology jointly with the management and control of field operations. It has been reasoned that data saturation occurs at twelve (12) interviews and so this study was limited to twelve interview participants (Francis et al, 2010). Additionally, it was discovered that eleven of the twelve participants were employed with companies that in some way, have established BIM in pre-construction, field operations or are utilizing this technology in both parts of their respective organizations. This is an important distinction to note. It allows those individuals with relatable BIM experience to participate in a deeper discussion about ways in which 4D BIM could be used in field operations. It can also be reasonably argued that companies that ranged in size from $100 million to over $1 billion would likely have funding available to support BIM in field operations.

Where possible, participants were interviewed in-person at their place of employment. Time and travel expense limited the researcher's ability to meet all participants face-to-face and so the use of an on-line web conferencing tool was used to conduct some of the interviews. The interview instrument used in this research study was constructed from data found in the literature review and questions were developed to support the research objectives mentioned in the earlier parts of this paper. To validate the interviewing instrument a pilot questionnaire was developed and scrutinized by a former construction professional who was not a part of this research study. The modified interview instrument, in its use with the interview participants, allowed for meaningful conversation and helped to reveal valuable insights. Consequently, the interview was grouped into three short sections, designed to last between 20 to 30 minutes in total. Those sections were: 1.) scheduling and sequencing as a superintendent's responsibility, 2.) methods of communicating the schedule and sequencing on-site, and 3.) 4D BIM in field operations. Once the location and time for the interviews were established, an opening segment of the semi-structured interview allowed the interviewer and interviewee to briefly introduce themselves and to discuss any questions that the interviewee had prior to beginning the interview. For each participant, the interview was conducted by asking questions related to the following themes.

Interview Section One: Scheduling and sequencing as a superintendent's responsibility.

The initial grouping of questions enabled the participants to speak to their strengths as schedulers and coordinators. It also allowed them to become comfortable in developing the conversation regarding the role of the superintendent in implementing the construction schedule on-site. Data from these conversations would provide a basis for establishing the expertise of the participants while adding to the validity of the data that was gathered through the remainder of the interview.

Interview Section Two: Methods of communicating the schedule and sequencing on-site.

The second grouping of questions turned to the discussion of current practices regarding communication with a focus on recent technological adoptions and sub-contractor outlook on these technologies. Responses from the participants in this grouping reflected preferences and experiences that were valuable in gaining the necessary qualitative data for this research.

Interview Section Three: 4D BIM in field operations.

The final grouping of questions was developed to facilitate a dialog about the implementation of 4D BIM in field operations. A demonstration of a 4D simulation was used which allowed the researcher to show the participants various examples of how 4D BIM could be used on a project. The researcher's motivation in utilizing a 4D BIM demonstration was to trigger thought and conversation about ways that this technology could be used on-site. Some of the discussion entered the speculative but was ultimately an important part of the data gathering process and the research effort.

Results

Content analysis and thematic analysis techniques were used to code and analyze the data collected. Content analysis was first performed first with the intent of looking for key words and issues that were repeating within the data. The data was analyzed a second time using thematic analysis techniques to seek key themes emerging from the data for each category of interview questions.

Overall Content Analysis

After the interviews were completed, a qualitative content analysis was performed and seven focus topics were established: 1.) superintendent responsibilities, 2.) creating, updating and communicating the schedule, 3.) communicating the sequence of work, 4.) factors of BIM strategy in the construction process, 5.) methods of on-site communications, 6.) sub-contractor needs during construction and 7.) 4D BIM in the construction phase. Each of these focus topics were a result of the participant's experiences in field operations and emerged through the interview process. The focus topics were condensed and refined to this preceding list through the process of transcription, coding, and analysis.

Overall Thematic Analysis

The thoughts and opinions expressed by the participants were examined from a thematic perspective and seven focus themes emerged. Moreover, this analysis was conducted apart from the overall content analysis to preserve the originality of the findings. The following focus themes were established: 1.) superintendent role, 2.) industry influence, 3.) the schedule, 4.) 4D BIM, 5.) sequencing, 6.) new technology and 7.) the role of BIM. While several focus themes coincidentally overlapped with focus topics, a thematic analysis was chosen to embolden the qualitative data analysis that speaks directly to the practices in field operations.

Interview Section One: Scheduling and sequencing as a superintendent's responsibility

Content Analysis: The content analysis supports the notion that the superintendent's responsibilities cover a wide range of activities throughout the course of a project. However, all participants stated that during the construction phase of the project, schedule was their main priority. Moreover, it was determined that schedule creation/coordination, updating, and sequencing of activities with sub-contractors were the main superintendent responsibilities even though each participant undertook the tasks slightly differently. For the purposes of this research, no one methodology toward scheduling was regarded superior to another. Of the methodologies used to schedule a project, most participants agreed that the look-ahead schedule was the most valuable instrument. Participants indicated that look-ahead scheduling facilitates thoughtful planning of materials and manpower and typically involves all stakeholders. As one participant recounted, "*The ultimate goal is you walk across the finish line, you're not sprinting across* [it]".

Thematic Analysis: The superintendent's role in a project is directly affected by their share of responsibility to the project and their level of relatable experience. One participant commented that, "*Scheduling and sequencing are crucial to what I do every day*". Most participants, whether knowingly or unknowingly, employed the procedures of "Pull Planning" and regarded communication with trade contractors as a continuous task of navigating conflict while maintaining positive momentum for the project. The sentiment is highlighted by a participant stating, "*Some sub-contractors need more supervision than others*".

The inquisitive nature of the participants drove them to continually seek out newer technologies that could support better communication on the project, "*when new tools come out I will test them to see if they're beneficial or cumbersome*". Participants committed considerable personal effort into making sure that good communication was supported by the best technology available, even though none of them noted this responsibility as solely theirs. A point that would later become noticeable in the participant's interest in using 4D BIM in field operations.

Interview Section Two: Methods of communicating the schedule and sequencing on-site

Content Analysis: Many participants were specific in distinguishing a difference between scheduling and sequencing which is summarized by the following definitions. The schedule is the time line and means to how a project will be completed. The sequence is the method of organizing disassociated groups of people to work in the same area without encouraging chaos and unsafe working conditions. Apart from this distinction, unanimously, participants agreed that communication with sub-contractors is an important part of the superintendent's daily routine. The participants had varied responses about the frequency and settings for their meetings, but they did agree on the need to be clear about outcomes and to communicate those to a broadly diverse audience. A greater majority of the participants still prefer to utilize Gantt Charts, paper plans and color-coded plans; all two-dimensional (2D) technologies. However, 3D capable software, such as, Assemble, Autodesk BIM 360, BIM, BIM Box, Navisworks, Synchro and VICO are increasingly a part of the scheduling conversation on projects. As such, when the superintendent is aware of these technologies by name, it becomes evident that they are seriously considering them for use on their projects.

There are several supporting reasons that surfaced during the interview which further support the use of BIM on a construction-site. Superintendents from a variety of backgrounds and experiences have used this technology to coordinate and sequence sub-contractors, evaluate the construct-ability of a project, market a project to an owner and perform quantity surveys. During the interview, the participants most frequently referred to "BIM Coordination" as one of the prime factors of a BIM strategy on-site. This supports the role of BIM as an effective tool in the communication of schedule and sequencing.

Thematic Analysis: A theme present during the second section of the interview was that the project schedule is a continually changing plan and at times an iterative process of checking, monitoring, and updating. According to the participants, the project schedule is assembled in a level of detail useful to the superintendent and to the trades. Both scheduling and sequencing emerged as a theme in this section of the interview and while both themes overlap, it is important to define what factors make them unique. According to the participants, sequencing is an ongoing conversation, "*even when the structure of a project is being built we still work on sequencing*". Sequencing is the process of how strategic decisions are made that affect all the stakeholders on the project. Methods used in the management of sequencing involve both 2D and 3D technologies. According to the participants, sequencing using a 2D methodology is still very common. Many participants value the use of color-coded floor plans (2D methodology) because of their past successes with using this methodology. However, others prefer the use of 3D sequencing because of its more recent proven effectiveness in the field. As noted by one participant, "*anything that can help promote clear communication helps out tremendously*". While some participants noted that they do not routinely use visual tools for communication, they did note that in some of their smaller impromptu meetings, visual tools were very helpful. Visual tools are more effective in the casual one-to-one meetings with trade contractors; a perception shared among the participants that visual tools were not helpful when communicating to larger diverse groups.

Interview Section Three: 4D BIM in Field Operations

Content Analysis: Questions relating to the main theme of this research were reserved toward the end of the interview allowing the researcher to understand the participants' current understanding of 4D BIM. While 4D BIM did come up in two of the participants' interviews, it is a tool often unused by them. Three sub-themes were identified in speaking to the participants about 4D BIM: 1) familiarity with the technology, 2) current use in the industry, and 3) potential uses that were suggested by the participants. In terms of familiarity with 4D BIM technology, 67% of the participants were already familiar with 4D BIM. These participants understood the basic definition and could elaborate on their understanding, although some were unsure of its potential benefits. A third of the participants were completely new to the idea of 4D BIM, but easily understood the basics after observing a 4D BIM demonstration. This familiarity did not correlate to the participants' use of 4D BIM, in fact, only 33% of the participants were active users of 4D BIM. As evidenced by the participants, they believed in its ability to facilitate communication across different levels of knowledge, "*almost everyone could follow a 4D model and have a conversation about it*".

Thematic Analysis: While the content analysis of the interview regarding questions about 4D BIM's use focused on participant familiarity, it was apparent that a common theme had surfaced about 4D BIM's perceived limitations. One participant commented that 4D BIM was a "*show piece*" for the owner or a marketing tool. Others still, commented on 4D BIM's lack of interior visibility, "*In the finishes stages of construction, repeatable work is about finding the most efficient sequence...I wish 4D BIM could be helpful in the finishes stages*". More importantly, 4D BIM's limitation came in its perceived ease of maintain-ability by the participant. The participants noted that they were constantly moving on their projects, and while they may have time during their week to update a 2D schedule, most seemed uninterested in the idea of having to update a 4D schedule. A common line of questioning from the participants was, "*who is going to do it*?" and "*how much is it going to cost*?" From the interviewer's perspective, many of the participants preferred a VDC expert on-site to consistently update the 4D BIM model as construction progressed.

A Proposed Framework for 4D BIM

The aim of this research was to "*evaluate visualization methods in field operations and determine how 4D BIM visualization tools can effectively be implemented in this process*". To summarize the findings in context with this aim, a framework was developed to implement 4D BIM on a construction site. The proposed framework is presented in Figure 1 and it demonstrates a framework for implementing 4D BIM in construction field operations and is a product of the content and thematic analysis of the interviews with the participants in this research. The framework was developed as a cyclic process, divided into four quadrants. The process starts with the creation of a plan then moves to communication of the plan followed by the plan's execution and a continual process of updating. A more detailed description of each step is discussed below.

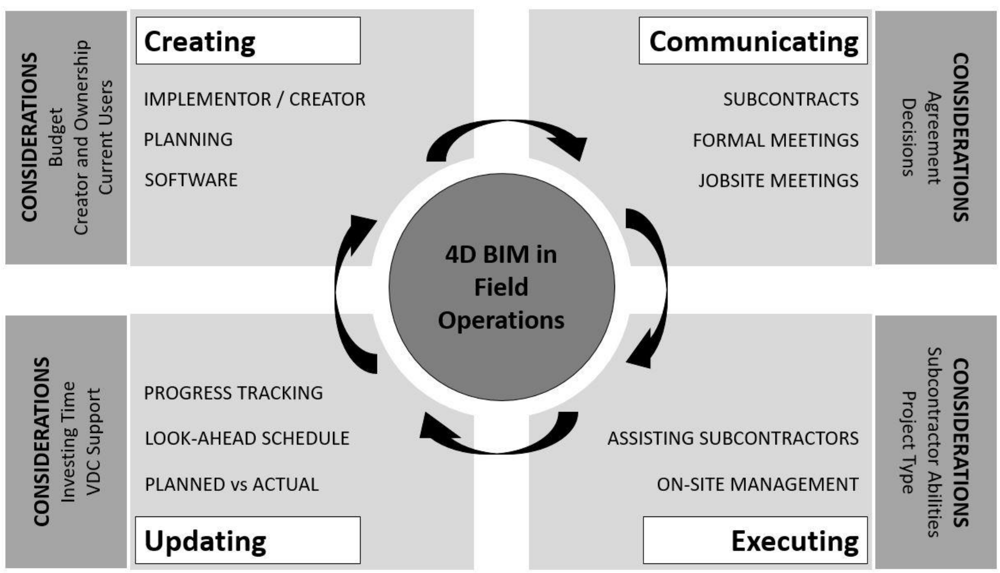

Figure 1: A proposed framework for 4D BIM for Construction Operations

Creating the 4D Plan: Creation of the 4D plan begins with the "Implementor" who will be tasked with determining how the plan is to be originated. The "Creator" either can be a member of the project team or could be out-sourced depending on the resources available to the project. Planning will include the discussion of schedule, sequencing, safety and a multitude of other resource driven activities. Other pertinent discussions may focus on the budget for the 4D BIM effort and ownership of the intellectual property created in this part of the process.

Communicating the 4D Plan: Communications enacted upon in a bidirectional manner allows for the ownership of decisions that are being made. The subsequent agreements being made are important to the team's formation. From here, an agreement on the method of communication and frequency further facilitate this part of the process.

Executing the 4D Plan: While executing the 4D BIM plan, attention to coordination, change orders, conflicts and safety will be routinely discussed. These discussions may have an impact on how the project is managed and may affect the selection of the trade contractors for a project.

Updating the 4D Plan: More of an iterative process, but one that is necessary, updating the 4D plan could be facilitated by look-ahead scheduling and planned versus actual scheduling. The need for a VDC support person may be required to make this process more fluid and efficient.

Discussion

The schedule is an important part of the construction process in that it sets the pace for how quickly work needs to be completed while facilitating the collaboration between superintendent and the trade contractors. Creating a project schedule, while considering the methods in the thematic review of this research allows the participants to set attainable goals by referencing either their 2D drawings or their 3D BIM model. By having a visual with which to compare expectations, sub-contractors will have a better understanding of the plan and their responsibilities within it, whether that happens at the outset of the construction phase or during a weekly scheduling meeting. As evidenced by the participants, the use of more innovative visual communications, such as, 3D BIM and/or 4D BIM, allows for better matching of expectations and commitments. Trade contractors would be more willing to make assurances of performing their activities on schedule by allowing them to participate during the planning stages of the project using 4D BIM technology tools.

Furthermore, reflecting back on the objectives of this research, a content and thematic review of the participants' responses to interview questions some concluding thoughts are presented. The current use of 4D visualization in the construction industry is limited to those large firms that can afford to invest in advanced technologies and supporting personnel. There are several examples of successful 4D BIM implementation on projects, however, as it stands, and in the opinions of the participants of this study, it is not necessarily significant at this time without a substantial investment of time and money. The outward benefit of using 4D BIM tools, as opposed to traditional tools, is enhanced communication as well as aiding trade contractors in different facets of their work. Conversely, 4D BIM is lacking in its ease of maintenance. Today's version of 4D BIM software architecture requires VDC professionals that can fluidly and efficiently maintain the data for best results. As previously mentioned, 4D BIM has many potential uses outside of communicating and sequencing. However, it is 4D BIM's unique characteristic in replacing 2D traditional methods with more data rich 3D methods that sets it apart as a visualization tool for the future, despite its limitation in cost and the need to have VDC trained professionals.

Conclusions and Recommendations

The site superintendent's role is key in maintaining and communicating the schedule to the various stakeholders on a project. As such, any technology that enables the site superintendent in furthering this effort is a valuable tool. 4D BIM can be an asset to the industry because its workflow encourages communication and collaboration while saving time and money - most of all it increases the conversation of sequencing in field operations. 4D BIM has the potential of augmenting the effectiveness of problem solving solutions through the creation of visually descriptive alternative simulations and sequences. While the time and resources to generate various sequences may be involved, it could be argued, that this investment is worthwhile when the outcome is a more equitable and efficient solution to a problem. 4D BIM has the potential to become a key component of communication between stakeholders of the construction project during the execution phase. The cumbersome nature of the software and the steep learning curve associated are a hindrance to the incorporation of 4D BIM in construction. Ultimately, software vendors must also respond to the needs of the industry by simplifying the process of 4D schedule updates so that project superintendents can maintain the data.

This research was limited to participants that classified themselves as "superintendents". Although the data collected is valuable at expanding the knowledge about 4D BIM in the construction industry, these findings must be validated.

To create a better platform for 4D visualization, the researcher suggests expanding the data collection to include VDC professionals. The opinions of these professionals may be used to validate or modify the findings in this study.

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