CO4240

Technical Review: Analysis and Appraisal of Four-Dimensional Building Information Modeling Usability in Construction and Engineering Projects

Robert Lopez[1], Heap-Yih Chong[2], Xiangyu Wang[3] and Jeff Graham[4]

[1] *Research Fellow, School of Built Environment, Curtin University, Perth, Australia;*

[2] *Senior Lecturer, School of Built Environment, Curtin University, Perth, Australia;*

[3] *Professor, School of Built Environment, Curtin University, Perth, Australia; International Scholar, Dept. Housing & Interior Design, Kyung Hee University, Seoul, Korea;*

[4] *Business Development Manager, Track'em Pty Ltd, Perth, Australia.*

Abstract

Building Information Modeling (BIM) fundamentally requires the importation of a three dimensional (3D) model with a series of repository data. Numerous studies were conducted to clarify the philosophy of BIM and promote its adoption in construction and engineering projects. The primary contributions this research presents to the construction engineering and management body of knowledge would be the technical review, analysis and appraisal of various issues concerned with the usability of four dimensional (4D) BIM. The research aims to determine the readiness and development of 4D BIM. The technical literature review was conducted on this information of various BIM software websites, journal articles, brochures and videos against their required 4D elements. Comparative analysis was conducted to compare the technical (TECA) and project planning functionality (PPFA) aspects for developing 4D models with features provided by available BIM software. This analysis yielded matrices which can be used to help guide decision making on which BIM software to invest in. The results reveal that all of the software has in their way served the purpose for developing the 4D BIM model.

Keywords: BIM; 3D; 4D; Comparative; Software; Planning; Scheduling

Introduction

Recent efforts in promoting Building Information Modeling (BIM) generally have been well received. The cost benefits and return on investment of using BIM are regularly demonstrated to be both promising and encouraging (Lee et al., 2012; Giel and Issa, 2013; Love et al., 2013). Moreover, guidelines for using BIM software have been developed for its use by various project stakeholders (Eastman et al., 2011). Lately, the National BIM Standard (in the United States) has been combined with Building Smart in developing a comprehensive roadmap, namely the 2021 Vision Task Force (NBIMS-US, 2013). Many similarly documented sets of mandates can be seen on the adoption of BIM from governments, such as in the United Kingdom and Singapore. It is foreseeable from this that BIM will be a mandated technology by other countries within construction and engineering projects in the near future (McAdam, 2010; Arensman and Ozbek, 2012).

This paper promotes an expanded appreciation of BIM by investigating its fourth dimension (4D) aspects and extending recent efforts toward them by looking into the details of their application. In doing so it indirectly indicates what may not be available in 4D BIM technology. The research presented in this paper aims to determine the readiness and development of 4D BIM applications available for construction and engineering projects. The current challenges in the adoption of 4D BIM, that reflects what is lacking or needed within construction and engineering, would generally concern the slowness of its uptake by consultant designers and builders from their resistance to change.

A technical review was carried out to compare the required elements for effectively developing 4D BIM model with the attributes or features provided by software programs currently available in the market. This is a different approach from previous reviews in BIM mainly focused on academic publications only (Khosrowshshi and Arayici, 2012; Meittinen and Paavola, 2014; Volk et al., 2014; Shou et al., 2014), and it is hard to find a single study currently in existence that solely focuses on 4D BIM development. The technical (TECA) and project planning functionality (PPFA) aspects were reviewed for 4D applications and compared against the information of the selected software from the various sourced journals, credible websites, brochures and videos from reputable BIM software vendors and associations.

No precise data exists with regard to the details of 4D BIM development. The research presented in this paper would bridge the gap between the literature studies and market capabilities of BIM software. It would potentially serve to help improve the efficiency of informing the process of scheduling and sequencing of the construction / engineering project tasks in any given 4D BIM model. It would also provide an important insight on the transition from a three dimensional (3D) model into 4D BIM in a practical perspective based on the comparative analysis that has been undertaken. From these findings, BIM users are more informed to select suitable 4D BIM applications for given situations. These would be inclusive of situations during the planning, design and construction stages. This should translate into improvements in the overall performance of a construction / engineering project.

4D Usability Issues

Important to users of any BIM software package would be its relative ease of use or user friendliness. This refers to the recognition of certain icons or how many steps need to be performed in order to harness the 4D capability, as well as the overall alignment and 'familiarity' to real-world processes. Specific examples would include what the user needs to do to import a 3D model and Gantt chart into the BIM software program, amend them both, combine the two, as well as generate a playable movie to simulate construction with a scaled duration. Arayici et al. (2011), in their research on BIM adoption and implementation, had found that such situations would be where less compatible computer aided design (CAD) and project scheduling programs, particularly with newer operating systems, could lessen the user friendliness of the software package in its 4D capability. This might also include functionality that mirrors the real-world processes by supporting and allowing concepts like selecting only a specific discipline such as structural steel or hydraulic piping for simulation.

Several modern CAD software programs use the Extended Markup Language (XML) schema which when applied to BIM data has been defined as "building data in a simplified spatial building model for BIM collaboration". It is a simplified alternate language for designing in 3D from conventional CAD with the primary benefits of supporting high data streaming (TECA07) and providing for enriched standards of exchanging information (TECA02) (BIMXML, 2014). This would enable a two dimension (2D) drawing to be converted into a 3D model, through the extrusion function, that would then permit navigation in real time (PPFA12) via a fly or walk through. 4D would then be created automatically by linking and tracking planning activities with the 3D model (PPFA14) following the direct import or export of schedules (PPFA05) from other established planning software (TECA05) (Tse et al., 2005; Turkan et al., 2012; BIMXML, 2014).

4D planning and scheduling

McKinney et al. (1996) generally refer to the concept of 4D as the inclusion of information related to time. Benjaoran and Sdhabhon (2010), in their research on integrating construction safety management with BIM, advocate that the visual transition in project planning from the sole reliance on a builder's Gantt chart to the inclusion of a movie that simulates the construction process as fundamental in the 4D capability. Several BIM software packages would already allow within their functions, dynamic data transfers between 4D and planning software (PPFA04), as well as the scale of time to be adjusted in the creation of a construction program simulation movie. For instance, one second in reality could represent a minute, hour, day, week or month within the movie simulation. Supporting this would be the added function to create and filter work pack levels (PPFA02) to allow the construction team to visualize work-to-complete (PPFA13) (Hartmann et al., 2012; Kim et al., 2013).

Despite the allowance for data transfers between 4D and planning software, there would certainly be problems in the adoption of BIM within the construction industry. Some of these adoption issues have been reported by Gu and London (2010), as well as Hardin and McCool (2015). For example, a relatively small percentage of construction and engineering projects would presently involve the production of a 4D BIM model. This would be reflected by the limited experience, as well as practical understanding, within the industry on how BIM should actually be integrated into construction and engineering activities. Such unawareness would also serve to hinder the adoption of other BIM compatible technologies in construction and engineering (Gu and London, 2010; Hardin and McCool, 2015).

Moreover, up to 36% of builders would have regular involvement with 4D BIM models in construction projects (Hardin and McCool, 2015). This figure represents a clear indication that very few builders would presently be willing to maintain the schedule in the 4D BIM model as they progress throughout the construction process, primarily because this task is seen as in addition to their contractual responsibilities. The dynamic characteristics of any construction and engineering project would inevitably often complicate the time management processes of schedule maintenance. This issue would make the prospect of establishing the schedule before construction work begins very daunting for builders who are inexperienced with 4D BIM and concerned about the potential ramifications of their noncompliance (Gu and London, 2010; Hardin and McCool, 2015).

Construction requirements and the work breakdown structure

Procurement documents such as a purchase order with detailed line items describing detailed material specifications should be able to be generated (PPFA03) from a good BIM software package. Additionally, allowing for updates to be made to the imported Gantt chart schedule itself is fundamental to improve design constructability and onsite safety have been purported by Zhou et al. (2012), as well as Hu and Zhang (2011). However caution should be exercised when considering whether these updates could or should be passed back to the original schedule. For example, Shino (2013) advocates that this would also better cater for the dynamic nature of building codes, supply and use of materials, as well as construction and engineering projects with their changeable requirements without the need to re-import a schedule and repeat the process of allocating activities in their work breakdown structure (PPFA01) to components whenever updates are made. One should bear in mind which schedule is the ‘source of truth’ for contractual negotiations and variations. Avoidance of creating ‘silos’ of repeated and unlinked data should be paramount and careful consideration should be given to how this source of truth is maintained when making updates in the different software packages within the users engineering and design or BIM software tool suite.

Real time updating and tracking

The environment for updates to be made to the BIM software being used encompasses authentication, security, authorization and tracking (TECA06). According to Bryde et al. (2013), these benefits of BIM would not be limited to the design stages but continuous throughout construction in real time as part of an iterative process. This would be because of the inherent project context heavily supported by this technology. Kim et al. (2013) has attempted to automate the measurement of construction process through the use of remote sensors. The real time viewing of each task’s predecessors, successors and the effects on the project critical path (PPFA08) and float (PPFA07), viewable in the 4D model, are necessary to adequately inform members of the design and construction teams on the progress of the project. Otherwise it would be impossible for a BIM generated model to ensure the construction / engineering project stays on track toward, and not stray away from, its on-time completion date (Leite et al., 2011).

Interoperatability

Isikdag and Underwood (2010), in their research on facilitating BIM based synchronous collaboration, inferred that for the 4D capability to be truly effective in project simulation would require multidisciplinary inputs from collaborating design and construction teams into a ‘cloud’ of data. Toward this end, Gu and London (2010) suggest that data management

(TECA10) would require project clients to only engage with those organizations who have firstly embraced a culture of BIM and secondly that currently use software packages that enable the direct electronic inputs of their discipline related technical information into the 4D model in their research of its adoption in construction and engineering projects. The multi-user, multi-disciplinary collaboration, coordination and communication (PPFA10) interoperatability between various software packages that support the 4D capability of BIM then becomes a critical aspect of business (Steel et al., 2012). For web-enabled viewing (TECA08) and editing (TECA09) to work, it is important for all members of the design and construction teams in the same project to be using compatible BIM and scheduling software packages and programs (TECA01 and TECA04). This is so that they can be interfaced to yield the maximum benefits of the 4D capability (Cerovsek, 2011).

Data separation and the industry foundation class

Data on the trade sections to separate ductwork from plumbing layouts and fabrication or installation dates would normally be based on the standardized and consistent color coding (PPFA11) for the grouping of CAD components at different levels of detail and locations (PPFA15). This data would also be classifiable against a predetermined industry foundation class (IFC) so that when linked with the relevant BIM designed objects will potentially make this information accessible to more of the stakeholders involved (Venugopal et al., 2012). IFCs have been defined by Venugopal et al. (2012) as “the building blocks for interoperatability through its open and neutral data schema” (p. 411). The raison d’être of IFC compliance is therefore to create a neutral interoperatable environment containing a comprehensive amount of specific data that is accessible for generating reports of previous changes or records (PPFA09) across disciplines throughout the project lifecycle by various software applications (Venugopal et al., 2012).

Tse et al. (2005), in their research on the barriers of BIM adoption and interfacing, call for design data to strictly comply with IFCs to prevent their distortion or loss (TECA03). There would be an important issue with maintaining this compliance in 4D BIM. This concerns the lack of interoperability for the construction schedule via the IFC. The construction schedule would normally be created and imported into a BIM model to make it 4D without IFC compliance in mind. It is here where the potential would exist for design data to be distorted or lost (Tse et al., 2005).

DES modeling – application to 4D BIM software packages

Discrete Event Simulation (DES) modeling is a technique that can be used to quantify the impact that stochastic and dynamic factors have on a system. DES is advocated by Lu (2003) as an alternate to the design and analyses of complicated interactive and dynamic construction and engineering projects. Stewart and Pham (2006), in evaluating integrated transportation systems using discrete event simulation modeling, explained that once a well-constructed model has been developed and verified, a multitude of options can be evaluated in a quantifiable manner. Typically the variables considered and incorporated in 4D BIM software packages are deterministic in nature; such as changing the construction sequence in a defined manner. Real-world occurrences are frequently stochastic (random) and dynamic in nature. Considerable success has been recorded by Hoare (2007) for instance in the use of Discrete Event Simulation modeling within the operation phase of capital projects to more closely model and simulate ‘real-world’ events and outcomes thereby permitting more robust methods of planning for, avoiding and correcting for these events. Application of these methodologies to the engineering and construction phases of projects should improve the ability of 4D BIM software to more closely model real-world events thereby increasing the robustness of strategies defined using these BIM tools.

4D project planning functionality aspects for future research

Volk et al. (2014), in determining the future needs of BIM for existing buildings, generally suggest that the ability to interface dynamically or otherwise for the representation of material availability (PPFA06) via material tracking applications presents considerable opportunities for demonstrated project efficiency gains. A number of the targeted 4D BIM software packages demonstrate the ability to support this functionality (Volk et al., 2014). A detailed analysis and discussion of this facility is however outside the scope of this Technical Review and is recommended for future research.

Research Methodology

The technical review adopted an explanatory case study approach, where the information sourced on numerous packages of BIM software was reviewed for their relevant common aspects of technicality and functionality. This particular research methodology is about a causal-process tracing approach (Blatter and Haverland, 2012), which is able to explore the features of the software packages from the information sourced and explain the causal relationships of relevant capabilities with the required elements for construction / engineering project planning / scheduling in a given 4D BIM model. In this way, the causal-process tracing approach had the benefits of selecting multiple cases based on accessibility and relevance to the findings being sought, as well as generating data from more observations. These benefits would make this approach particularly suited in research situations to reveal temporal interplays leading toward particular outcomes and, in particular, determine what makes 4D BIM possible. Despite these benefits, the limitations of this research approach were found at times to be the need to gather further confirmatory counterfactuals and / or theoretical concepts in order to draw conclusions (Blatter and Haverland, 2012).

The selection of software was based on recommendations from the BIM related websites and organizations. These organizations were specifically Autodesk Incorporated (2014), Aveva Group (2014), Bentley Systems Incorporated (2014), Dassault Systemes (2014), Innovaya (2014), Intergraph Corporation (2014), Tekla Corporation (2014), RIB Software AG (2014), Synchro Software Limited (2014) and Vico Software (2014). Consequently, there would have been BIM software packages available on the market other than those reviewed in this study. The primary reasons why these did not undergo review were because they were generally less suitable for use in construction and engineering projects than the package selected from the same BIM software vendor, as well as their better perceived functional suitability in other industries such as manufacturing, health sciences or both. This study had therefore served to put each BIM software vendor's best proverbial foot forward in the context of which of their packages would best serve construction and engineering projects in their 4D capabilities.

The selected software was individually checked based on information provided from its official websites, product brochures and video tutorials. At the time, most of the software selected were also downloaded with full licenses and tested for its application in the relevant 4D BIM model. The unevenly diverse extent of information about the BIM software packages provided for review from this range of sources had the effects of increasing the time and effort expended in the field research to search for certain functional capabilities from some BIM software packages, which can easily be found in others, as well as the potential for the inability to find those that would actually exist. Subsequently, the information gathered from the software package information sourced were compared with the required 4D elements from the literature review and certain inputs from the authors themselves based on their collective professional experiences previously in BIM, building design, drafting, quantity surveying and project management.

Comparative Data Analysis

Various BIM software packages were specifically analyzed for their 4D general technical and project planning functionality aspects. These software packages were coded for ease of data analysis as follows: 'BIMS01 – Autodesk Navisworks®' (Autodesk Incorporated, 2014); 'BIMS02 – Aveva™ Mars' (Aveva Group, 2014); 'BIMS03 – Bentley® ConstructSim' (Bentley Systems Incorporated, 2014); 'BIMS04 – Dassault Systemes Delmia' (Dassault Systemes, 2014); 'BIMS05 – Innovaya Visual™' (Innovaya, 2014); 'BIMS06 – Intergraph SmartPlant® Construction' (Intergraph Corporation, 2014); 'BIMS07 – RIB Software AG' (RIB Software AG, 2014); 'BIMS08 – Synchro Pro' (Synchro Software Limited, 2014); 'BIMS09 – Tekla®' (Tekla Corporation, 2014); as well as 'BIMS10 – Vico Virtual Construction™' (Vico Software, 2014).

Analysis of 4D general technical aspects

The variable attributes that were used for comparing the 4D general technical aspects of various BIM software analyzed were coded for ease of data analysis as follows: 'TECA01 – Compatibility with operating systems'; 'TECA02 – Support of XML'; 'TECA03 – IFC compliance'; 'TECA04 – Interfacing with other software / programs'; 'TECA05 – Direct import / export of schedules from other established planning software'; 'TECA06 – Authentication / security / authorization / tracking'; 'TECA07 – High data streaming capability'; 'TECA08 – Web-enabled viewing'; 'TECA09 – Web-enabled editing'; as well as 'TECA10 – Cloud data management'. The software vendors were consulted to verify the existence of each of the 4D general technical aspects analyzed in their BIM software packages. The BIM software packages where these variable attributes for 4D general technical aspects exist are denoted with the word 'yes' where they correspond in the matrix illustrated as Table 1 (Autodesk Incorporated, 2014; Aveva Group, 2014; Bentley Systems Incorporated, 2014; Dassault Systemes, 2014; Innovaya, 2014; Intergraph Corporation, 2014; Tekla Corporation, 2014; RIB Software AG, 2014; Synchro Software Limited, 2014; Vico Software, 2014).

Of the potential for 100 matches between BIMS# and TECA# in the Table 1 matrix, 76 were actually found. TECA01, TECA04 and TECA06 were found in all 10 of the BIMS# variables for example. This was significantly more than the 24 matches that were not apparent. TECA02 was not apparent in either BIMS05 or BIMS09. TECA03 was not apparent in either BIMS04 or BIMS05. TECA08 was also not apparent in BIMS05. TECA05 was not apparent in either BIMS04 or BIMS06. TECA07 was not apparent in BIMS04, BIMS07, BIMS08 or BIMS10. TECA09 was only found in BIMS01, BIMS04 and BIMS08. TECA10 was found in BIMS01, BIMS04, BIMS08 and BIMS10.

Further, it was apparent from the matrix in Table 1 that the extent of TECA# variables found within each BIMS# variable had ranged between 50% and 100%. BIMS01 and BIMS08 were found to contain 100% and 90% of the TECA# variables respectively. BIMS02, BIMS03 and BIMS10 were found to contain 80% of these variables. These were followed by BIMS04, BIMS06, BIMS07 and BIMS09 which were found to contain 70% of the TECA# variables analyzed. TECA09 and TECA10 are covered by only three and four BIM software packages respectively out of the ten. This would reveal either the lesser importance of web-enabled editing and cloud data management as TECA# attributes or lack of their inclusion by seven and six of the BIM software developers respectively.

Analysis of 4D project planning functionality aspects

The variable attributes that were used for comparing the 4D project planning functionality aspects of various BIM software analyzed were coded for ease of data analysis as follows: 'PPFA01 – Work Breakdown Structure'; 'PPFA02 – Work pack level'; 'PPFA03 – Interacting materials with documents'; 'PPFA04 – Dynamic data transfers between 4D and planning software'; 'PPFA05 – Tracking with time'; 'PPFA06 – Ability to interface for procurement of materials'; 'PPFA07 – Real time viewing a task's predecessors, successors and effects on project critical path and float, or overlaying and comparison of what-if scenarios'; 'PPFA08 – Real time viewing of critical path in 4D model'; 'PPFA09 – Report generation'; 'PPFA10 – Support for multi-user, multi-disciplinary collaboration, coordination and communication'; 'PPFA11 – Standardized and consistent color coding'; 'PPFA12 – Real time navigation of 3D'; 'PPFA13 – Ability to create and filter work packages'; 'PPFA14 – 4D created automatically by linking between planning activities and 3D model'; as well as 'PPFA15 – Grouping of CAD components at different levels'. The software vendors were consulted again, but this time to verify the existence of each of the 4D project planning functionality aspects analyzed in their BIM software packages. The BIM software packages where these variable attributes for 4D project planning functionality aspects exist are denoted with the word 'yes' where they correspond in the matrix illustrated as Table 2. (Autodesk Incorporated, 2014; Aveva Group, 2014; Bentley Systems Incorporated, 2014; Dassault Systemes, 2014; Innovaya, 2014; Intergraph Corporation, 2014; Tekla Corporation, 2014; RIB Software AG, 2014; Synchro Software Limited, 2014; Vico Software, 2014).

Of the potential for 150 matches between BIMS# and PPFA# in the Table 2 matrix, 135 were actually found. PPFA10, PPFA11, PPFA12 and PPFA14 were found in all 10 of the BIMS# variables for example. This was significantly more than the 15 matches that were not apparent. PPFA01 was not apparent in either BIMS04 or BIMS08. Both PPFA02 and PPFA07 were also not apparent in BIMS08. Both PPFA03 and PPFA06 were not apparent in BIMS05. PPFA04 was not apparent in BIMS03. PPFA05 was not apparent in either BIMS04 or BIMS09. PPFA08 was not apparent in either BIMS02 or BIMS08. PPFA09 was not apparent in either BIMS01 or BIMS07. PPFA13 was also not apparent in BIMS01.

Further, it was apparent from the matrix in Table 2 that the extent of PPFA# variables found within each BIMS# variable had ranged between 73% and 100%. BIMS06 and BIMS10 were found to contain 100% of the PPFA# variables. BIMS02, BIMS03, BIMS07 and BIMS09 were found to contain 93% of these variables. These were followed by BIMS01 and BIMS05 which were found to contain 87% of them. Then BIMS04 and BIMS08 which were found to contain 80% and 73% of the TECA# variables analyzed respectively. PPFA08 is covered by only seven BIM software packages out of the ten. This would reveal either the lesser importance of real time viewing of the critical path in the 4D model as a PPFA# attribute or lack of its inclusion by three of the BIM software developers.

Discussions

From the comparative data analysis, all 10 of the BIM software packages were found to be sound in their 4D general technical and project planning functional capabilities. Indeed, all of them are compatible with most of the modern operating systems and other software programs for interfacing (Arayici et al., 2011; Cerovsek, 2011). All of them provide for some forms of authentication, security, authorization and tracking (Bryde et al., 2013). They all support multi-user and multi-disciplinary collaboration, coordination and communication (Arayici et al., 2011; Cerovsek, 2011). Consistent with conventional CAD software, they can all allow the grouping of CAD designed components at different levels of detail and locations. This is primarily through allowing for some standardization and consistency in drafting color coding for 3D object representation which can be navigated in real time. Fundamentally, they can all automatically transform a 3D model into 4D through the linking of its components to planning activities from a schedule (Becerik-Gerber and Rice, 2010). With these findings in mind, the authors of this paper would purport the following suggestions.

Some BIM software packages are presently more popular than others in construction and engineering. This may be based upon a number of factors of immediate relevance to the shorter term business interests of the organizations that implement them. One reason could be the initial cost outlay of their implementation. The better advocated save saving potential of their automated functions could be another reason. This would be influenced by the marketing and / or advertising efforts of BIM software vendors. Another could be for the purpose of eliminating the need to physically travel. With the software intended to be run from a main server, the BIM model could be designed, amended and accessed by geographically dispersed project team members simultaneously without the need to print and deliver drawings. The ability of the BIM software package to integrate file types from multiple CAD and scheduling applications has also been known as catalysts for their selection by construction and engineering practitioners (Hardin and McCool, 2015).

It would be advisable for the selection of BIM software not to be based solely on these reasons provided by Hardin and McCool (2015). Their selection should be preferably based on the prioritizing of aspects influenced by the surrounding environmental conditions within which a business operates. This is because some of these software packages were found to function better in certain other 4D general technical and project planning functional aspects than others. For instance, not all would better cater for 3D design through the data enriching potential of XML (BIMXML, 2014). Several were particularly suited to rigorous reporting procedures with their capabilities of viewing the scheduled critical path on a 4D model in real time and report generation for previous design changes or recordkeeping (Leite et al., 2011; Venugopal et al., 2012). Some extract data significantly quicker with their high streaming capability (BIMXML, 2014). Fewer better cater for internet dependency that enables for the editing and management of data in an online cloud environment (Isikdag and Underwood, 2010; Cerovsek, 2011; Chong et al., 2014). In addition, some vendors would even advertise certain aspects of their BIM software in attempting to set them apart from other equivalent packages currently available in the market (e.g. Autodesk Incorporated, 2014; Dassault Systemes, 2014; RIB Software AG, 2014; Vico Software, 2014).

Conclusion

This research contributes to the body of knowledge by presenting the technical review, analysis and appraisal of various issues concerned with the usability of 4D BIM software packages in construction and engineering projects. An expanded appreciation of BIM is promoted by this paper through its investigation of 4D and the details of its application. This contributes to the effective recent efforts in the promotion and regulation of BIM. The research presented in this paper has determined the readiness and development of 4D BIM applications available for construction and engineering projects. The 4D capability refers to the inclusion of information related to time. Important to users of any BIM software package would be its relative ease of use or user friendliness. This paper also indirectly indicates what may not be available in 4D BIM technology. 4D usability issues comprise planning and scheduling, construction requirements and the WBS, real time updating and tracking, interoperatability, as well as IFC.

The elements required to effectively develop a 4D BIM model was then compared with software programs currently available in the market to better inform BIM users. The comparative data analysis yielded matrices displaying the extent of BIM software functionality and interactivity of the 4D general technical and project planning aspects respectively. These matrices can be used to help guide the decision making on which BIM software package to invest in. All of the BIM software packages sampled and analyzed were found to be sound in their 4D general technical and project planning functional capabilities. Design and construction planning and operational efficiency can be improved by selecting the most suitable BIM application for given situations, as well as providing real time 4D information and visualization.

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Table 1 – 4D General Technical Aspects Matrix

4D Attributes – TECA#	BIM Software – BIMS#									
	BIMS01	BIMS02	BIMS03	BIMS04	BIMS05	BIMS06	BIMS07	BIMS08	BIMS09	BIMS10
TECA01 – Compatibility with operating systems (Mac, PC, XP, server, etc.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TECA02 – Support of XML for richer standards of exchanging data	Yes	Yes	Yes	Yes		Yes	Yes	Yes		Yes
TECA03 – IFC compliance	Yes	Yes	Yes			Yes	Yes	Yes	Yes	Yes
TECA04 – Interfacing with other software / programs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TECA05 – Direct import / export of schedules from other established planning software (Primavera / MS Project)	Yes	Yes	Yes		Yes		Yes	Yes	Yes	Yes
TECA06 – Authentication / security / authorization / tracking	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TECA07 – High data streaming capability	Yes	Yes	Yes		Yes	Yes			Yes	
TECA08 – Web-enabled viewing	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
TECA09 – Web-enabled editing	Yes			Yes				Yes		
TECA10 – Cloud data management	Yes			Yes				Yes		Yes

Table 2 – 4D Project Planning Functionality Aspects Matrix

4D Attributes – PPFA#	BIM Software – BIMS#									
	BIMS01	BIMS02	BIMS03	BIMS04	BIMS05	BIMS06	BIMS07	BIMS08	BIMS09	BIMS10
PPFA01 – Work Breakdown Structure	Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes
PPFA02 – Work pack levels	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes
PPFA03 – Interacting with materials and documents	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
PPFA04 – Dynamic data transfers between 4D and planning software	Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes	Yes
PPFA05 – Tracking with time	Yes	Yes	Yes		Yes	Yes	Yes	Yes		Yes
PPFA06 – Ability to interface for procurement of materials	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
PPFA07 – Real time viewing a task's predecessors, successors, effects on project critical path and float, or what-ifs	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes
PPFA08 – Real time viewing of critical path in 4D model	Yes		Yes		Yes	Yes	Yes		Yes	Yes
PPFA09 – Report generation for previous changes or records		Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes
PPFA10 – Support for multi-user, multi-disciplinary collaboration, coordination and communication	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PPFA11 – Standardized and consistent color coding (object representation)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PPFA12 – Real time navigation of 3D environment	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PPFA13 – Ability to create and filter work packages to allow construction team to visualize work-to-complete		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PPFA14 – 4D created automatically by linking between planning activities and 3D model	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PPFA15 – Grouping of CAD components at different levels of detail and locations	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes