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The Potential of 4D Modelling Software Systems for Risk Management in Construction Projects

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Abstract

Any construction project is full of risks, which if not minimized or eliminated can jeopardise its outcome. The sources of risks vary from project to project. With refurbishment projects, information is scarce leading to making assumptions about them, which generally entail risks. On the other hand, very new and very large projects are complex involving many disciplines and generating too much information in the different phases of construction life cycle. Actions by stakeholders in the different phases related to the project information have implications on quality, cost and schedule-related risks. Building Information Modelling (BIM) has been hailed as a solution to many challenges in construction including risk management. Applications of BIM in quantity surveying, project planning, facilities management and sustainability have been extensively researched and now common in the scientific literature. However, research about risk management in a BIM-enabled environment is still very sketchy. This is compounded by the plethora of BIM software systems which overwhelm end-users to be able to make informed decisions about their uses in risk management. The work presented in this paper is the first step of a more comprehensive research aimed at improving the understanding of risk management in a BIM environment. The focus of the investigation is about the potential of and limitations of 4D BIM software systems in managing construction risks. A purely desk-top study has been adopted to achieve the aim of this study.

Keywords: BIM, construction, efficiency, nD modelling, risk

1. Introduction

Similar to most projects, construction projects are highly subjected to risks. This is further exacerbated by their complexities, dynamism and peculiar nature (Rostami *et al.,* 2015; Taillandier *et al.,* 2015). Rostami *et al.* (2015) argued that construction projects are subjected to more risks and uncertainties because of the varying range of activities and transformation involved from the planning stage to completion. Such activities include complex planning procedure, regularly bespoke and time-consuming design as well as costly production processes. Furthermore, construction projects are becoming increasingly larger and more complex in physical size and cost. If not effectively managed, the risk associated to this huge size can lead to losses (Chen *et al,* 2012). Also, projects are based on teamwork with different interested stakeholders, and the co-operation among them is formed around extensive, disparate and interrelated processes. People are very unpredictable in behaviour, compounded by unpredictable external environmental risk factors in delivering projects can be very high. Construction projects involve a lot of decision-making with consequences on the project's success or failure (in terms of cost, time and quality) and on its environment (Taillandier *et al.* 2015). Sawhney *et al.* (2014) argued that construction is confronted by challenges such as time and cost overruns, wastage, low levels of standardisation, fragmentation, inconsistent procurement practices and low use of technology. Studies by Abderisak and Lindahl (2015) revealed that cost and time overruns are quite common with increases in the range of 50-100% being more regular and an increase of over 100% is not an unusual case. The risk associated with cost and time overruns will have immense effects on the outcome of any project if not properly managed.

Digitization of construction using BIM offers innovative ways to effectively manage construction risks (Hartmann *et al,* 2012; Tomek and Petr, 2014). Mott MacDonald, a management, engineering and development consultancy, defines BIM as "a coordinated set of processes, supported by technology that adds value through creating, managing and sharing the properties of an asset throughout its lifecycle (Mott MacDonald, 2015)." In order to support BIM workflow of processes, a market for BIM technologies has significantly grown in recent years. Although the growth of BIM software is great, its huge number and other technical issues have posed challenges for end-users. Lee and Sexton (2007) argued that there is a lack of holistic information for relevant construction parties regarding the characteristics of the various software packages and their appropriate uses. Furthermore, issues of non-compatibility (interoperability) among software packages are still too common. Day (2011) argued that depending on the software put to use, BIM models get very large in file size as the level of detail increases and this poses problems to computers with limited memory sizes. Fazli *et al* (2014) claimed that one of the major weaknesses is getting different file formats to function properly when creating a combined building information model. When data is taken from the original BIM model, a certain value is attained and when converted into another file format, a different value can be generated. A recent study by Abanda *et al.* (2015) led to the identification of/and differences between 122 BIM software systems across different construction domains. However, the study was top level with lack of details on specific domains. Building on Abanda *et al.* (2015), this study aims to conduct a detail investigation of BIM risk management software systems with focus on interoperability amongst the different software systems. Three main objectives employed to achieve the objectives of this study are: an Investigation into why construction risk management is required; the identification of the various commonly used scheduling and 4D BIM software for construction risk management; an investigation into the interoperability amongst the scheduling and 4D BIM software systems.

To facilitate understanding, the remainder of this paper is divided into 4 sections. In section 2, the methods used to achieve the aim of this study are examined. To provide the context of this study, in section 3, risk management in construction is explored. This is followed by an assessment of the traditional scheduling and 4D BIM software systems, where emphases was placed on the type of operating systems supporting the software, the import/export file formats of the software and whether risk has been integrated into the software. In section 4, the key findings and how the study objectives have been achieved are discussed. The paper concludes by a way of summary in section 5.

2. Research methods

Given that the core of this study is based on interoperability, its definition is important to provide a context for the adopted research method. Generally four types of interoperability exist in the literature. These are syntactic, technical, semantic and organisation interoperability (Rezaei *et al*., 2014). For purposes of this study, the focus is on syntactic interoperability which refers to the ability of two (or more) separate systems or software programmes to communicate and exchange data (or information) with each other and use the data (or information) that has been exchanged (Rezaei *et al.,* 2014; Bahar *et al.,* 2013). With this definition in mind, four criteria for the different software to be reviewed were established. The first criterion considers whether the software can be installed on two most popular operating systems, i.e. Mac and Windows. The second was based on how legacy scheduling/risk management tools were integrated into 4D BIM tools. By integration we mean the ease with which 4D BIM can read into legacy scheduling and/or risk management tools. The third criterion is about the file exchange formats inbuilt into the software system. The last criterion is about whether risk is integrated as part of the scheduling or 4D BIM software systems. These criteria are captured in the framework shown by Figure 1.

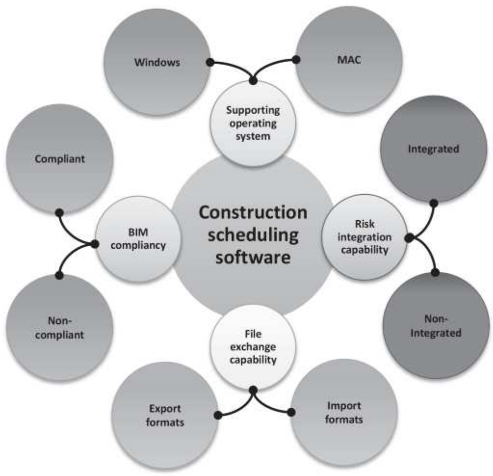

Figure 1: Factors qualifying the potential of construction scheduling software

Based on Figure 1, an extensive literature review from peer-reviewed sources and vendors' websites was conducted. Giving the emerging nature of BIM, peer-reviewed studies about BIM software are scarce and the few existing studies have tapped information from vendors' websites (e.g. Crawley et al. (2008) and Abanda et al. (2015)). In examining the vendors' websites, the specification documents were explored to identify the different operating systems, file exchange formats supported by the different software systems, whether scheduling and/or risk software was integrated in 4D BIM software systems and finally, whether risk has been integrated in the software. To further gain clarity about the set criteria for this investigation, some of the software were installed and explored. That led to the identification and inclusion of 34 project scheduling, 3 legacy risk management software and 20 4D BIM software systems.

3. Risk management and its digitization in construction

Risk management involves creating uncertainty awareness, qualifying the risks, managing the controllable risks and curtailing uncontrollable risks impact by risk allocation/appointment (Liu *et al,* 2007). There are many definitions of risk management, all portraying the fundamental goal of minimizing the impact of risk. According to Irimia-Dieguez *et al.* (2014), risk management is the systematic process of identifying, analysing and responding to project risk. Also, Tohidi (2011) defined risk management as the process of identifying and assessing risk, and applying methods to reduce it to an acceptable extent. Hence, risk management involves the process of determining the likelihood of risk to occur, taking necessary steps to examine its effects and fashioning out ways to prevent or lessen the effects, in the event that it occurs. Generally, managing projects revolves around the proper management of the delivery of project objectives in terms of time (scheduling), cost, quality and safety as most risks emanate from them. The focus of this study is on risk associated with construction project scheduling. In emerging BIM paradigm, 4D stands for scheduling in a BIM tool. As such the discussion ensuing in this section concerns the applications of risk management in traditional software systems and contemporary risk management approaches in BIM enabled environments.

3.1 Risk management in traditional scheduling software

Project scheduling is important for construction project managers as it facilitates their task of tracking and managing the triple constraints of time, cost and quality of projects (Faghihi *et al.,* 2014). Planning and scheduling in construction normally involves activity sequencing in space and time, taking into account other construction processes like procurement, resources, spatial constraints, etc. Traditionally, bar charts (Gantt charts) are used to schedule construction activities but these methods have been unable to show how or why certain activities are linked in a given sequence (Eastman *et al.,* 2011). Once these schedules are created, there appears to be no direct link between the computer-aided-design (CAD) drawings and the construction schedule. As the design progresses in typical project scenarios, the construction manager reviews any updated drawings, then updates the schedule to reflect these design changes where such clarification depends on the accuracy of the construction manager (Hardin, 2009). Eastman *et al.* (2011) further argued that the spatial components aren't adequately captured by the traditional methods and nor are they linked to the building model. Further claims were that scheduling (using the traditional methods) is manually intensive and often at times does not concur with the design thereby creating complications for project stakeholders to understand the schedule and its impacts on site logistics. Two most common software systems used in traditional scheduling are MS Project and Primavera. It is important to note that traditional software has been in existence for ages even before the advent of BIM and/or 4D BIM modelling. While some traditional scheduling software systems have compatible plug-ins with 4D BIM, others do not. Also some have integrated BIM while others have not. A summary of the different project scheduling software uncovered are presented in Table 1.

Table 1: An overview of construction scheduling software systems

Software	*BIM compliant*	*Export file format*	*Import file format*	*Risk analysis integration*	*Operating system*
Asta Powerproject	*Yes*	*HTML, CSV, MPX, XML, XER*	*PDB, MPX, XML, XER, DIR, STX*	*Yes*	*Windows/Mac*
ConceptDraw PROJECT	*No*	*XML, MMAP CDPZ, CDPX, CDPTZ, CDMZ, TXT,*	*CDPZ, CDPX, CDPTZ, CDMZ, TXT, MMAP, XML, MPP, MPT, MPX, XLSX*	*No*	*Windows/Mac*
Deltek Open Plan	*No*	*XML, CSV*	*XER*	*Yes*	*Windows/Mac*
Express Project	*No*	*Express Project files*	*Express Project files, CSV*	*No*	*Windows/Mac*
Fast Track Schedule	*No*	*HTML, MPX, XML, ICS, MMAP*	*MPP, MPT, XML, MPX*	*No*	*Windows/Mac*
Gantt Project	*No*	*CSV, MPX, XML, HTML, PDF, GAN,*	*CSV, ICS, TXT, XML, GAN*	*No*	*Windows/Mac*
MicroPlanner X-Pert	*No*	*TXT, DIF, CSV, XML*	*TXT, DIF, CSV, XML, MPX*	*No*	*Windows/Mac*
MS Project	*Yes*	*XML, MPT, MPP, CSV, TXT, XLS*	*MPP, MPX, XML, MPT, XLS, XLSX, XLSB, XLSM, CSV, TXT*	*Yes (2010 and later versions)*	*Windows/Mac*
Milestones Professional	*No*	*XML, PDF, MPX, CSV, TXT*	*XML, MPX, CSV, TXT, MPP, MPD*	*No*	*Windows/Mac*
Organiser	*No*	*ORG, HTML*	*ORG*	*No*	*Windows/Mac*
Phoenix Project Manager	*No*	*MPX, XML, XER, XLS, XLSX, SDEF, CSV*	*MPX, XML, XER, XLS, XLSX, CSV, P3*	*No*	*Windows/Mac*
PMA Netpoint	*Yes*	*XML, XER*	*XML*	*Yes*	*Windows/Mac*
Primavera	*Yes*	*XML, XLS, XER*	*XER, XML, XLS*	*Yes*	*Windows/Mac*
Project Commander	*No*	*XLS, MPX, TXT, CSV, WMF, DOC, PPT*	*MPX, TXT, CSV, XLS*	*Yes*	*Windows/Mac*
Project KickStart	*No*	*PRX, MPX*	*PRX, PRJ, MPX, CSV*	*No*	*Windows/Mac*
ProjectLibre	*No*	*POD, XML*	*MPP, MPX, XML, POD, PLANNER*	*No*	*Windows/Mac*
P2ware Project Manager	*No*	*PDF, HTML, XLSX, CSV, TXT, RTF, MHT, MPP, XML*	*XLSX, PLAN, MPP, XML, MPX*	*Yes*	*Windows/Mac*
Project Xpert	*No*	*MPX, XML, ICS, CSP, PRJ*	*CSP, MPP, MPX, XML, ICS*	*No*	*Windows/Mac*

Rational Plan Professional	*No*	*SRP, XRP, XML, XLS, MRP*	*SRP, MRP, XRP, MPP, XML, MPX, MPT*	*No*	*Windows/Mac*
Risky Project	*No*	*MPX, Decision Tree*	*MPP, XML*	*Yes*	*Windows/Mac*
Safran Project	*No*	*SP, MPD, MPX, XML, XER, DBF, P3*	*SP, SPP, ART, MPX, MPD, XML, XER, P3, PM, XML*	*Yes*	*Windows/Mac*
Sure Track Project Management Software	*Yes*	*MPX, P3, HTML*	*MPX, P3*	*No*	*Windows/Mac*
Turbo Project	*No*	*MPD, PEP, MPX*	*MPD, PEP, MPX*	*No*	*Windows/Mac*
Altiproject	*No*	*XLS, BusinessObjects*	*XLS, BusinessObjects*	*No*	*Mac*
Curio	*No*	*ICS, HTML, PDF, RTF, TXT, CSV*	*RTF, ICS*	*No*	*Mac*
iTaskX	*No*	*iTaskX (Project), iTaskX (Template), XML, MPX, OPML, TXT/CSV, MPP, ICS*	*OPML, TXT/CSV, ICS, MPP, XML, MPX, TXT, CSV*	*No*	*Mac*
iMindQ	*No*	*XLS, XML, PDF, HTML, CSV*	*XLS, XML*	*No*	*Mac*
Invoax Plan it	*No*	*HTML, CSV, ICS, XML*	*XML*	*No*	*Mac*
Merlin Project	*No*	*XML, MPX, MMAP, NovaMind, TXT/CSV, HTML, OPML, XLS*	*MPP, XML, MPX, XLS, MMAP, NovaMind, OmniOutliner*	*No*	*Mac*
OmniPlan	*No*	*ICS, CSV, MPX, XML, HTML, OmniOutliner, OmniGraffle*	*XML, MPX, MPP*	*No*	*Mac*
Project X	*No*	*ICS*	*ICS*	*No*	*Mac*
SG Project Pro	*No*	*PDF, XML, SGP*	*XML, SGP*	*Yes*	*Mac*
X Plan	*No*	*XML, ICS, xView, XList5*	*XML*	*No*	*Mac*
@RISK	*No*	*XLS, DOC, PPT,*	*MPX/MPP, XML, XLS*	*Yes*	*Windows/Mac*
Crystal Ball	*No*	*XLS, CSV, TXT, DIF, PDF, XPS, XML*	*XLS, XML, TXT, DIF, dBase*	*Yes*	*Windows*
Risk Solver	*No*	*XLS, PDF, TXT, XML*	*XLS, XML*	*Yes*	*Windows*

3.2 Risk management in 4D BIM software systems

Sebastian (2011) argued that BIM is not the same as the widely known computer aided design (CAD) because it goes beyond generating the traditional digital (2D or 3D) drawings. It is an integrated model in which all process and product information is combined, stored, elaborated and interactively distributed to all relevant project actors. Also, the proposed design and engineering solutions can be assessed against the client's requirements and expected building performance using BIM. The use of BIM during the construction phase can support good communication network between the building site, the factory and the design office (Sebastian, 2011). Fazli *et al.* (2014) also argued that communication processes that exist between stakeholders in a project can be enhanced massively through BIM. This is in contrast to traditional projects in which building visualizations (views) are made from scratch while BIM-based projects, the visualizations can be made from previously created models and can be monitored real-time. The schedule of construction is directly linked to the 3D model, enhancing visualization of the sequential construction or sequence activities of the building, thus allowing schedulers to visually plan and communicate activities in the context of space and time (Eastman *et al.,* 2011). Furthermore, Hartmann *et al.* (2012) discussed that project risks are communicated as a risk inventory using Gantt charts and sketches that however, do not allow project managers to completely visualize and understand risks, their location on site and their implications on project deliverables making it hard to collaboratively examine and mitigate project risks. The argument was that 4D models capture both the temporal and spatial aspects of schedules and communicate schedules more effectively than Gantt charts. In the experimental study carried out by Reizgevičius *et al.* (2013), they argued that 4D models can shorten construction time by 1/3. Furthermore, they claimed that the use of 4D CAD model can reduce mistakes to a greater extent (twice as much) in construction processes and help in detecting and removing them more quickly. In Hartmann *et al.* (2012), a case study showed that if time schedule is aligned well with existing risk management processes, design teams can use 4D models to visualize project risks in time and space. Mahalingam *et al.* (2010) discussed that 4D CAD are beneficial in the planning and construction stage where in the former, it will be useful in communicating the construction plans and processes to clients who can then visualize the project and convey their suggestions, approval or disapproval. In the construction stage, it will be particularly useful in comparing the constructability of work methods visually in order to detect conflicts or clashes. It also serves as a visual tool for contractors, clients, subcontractors and vendors to review and plan projects' progress. The summary of the 4D BIM software uncovered in this study are presented in Table 2. Even if many 4D software deal implicitly with many aspect of risk management (logistics, space, etc.), the risk analysis integration considered here is the explicit feature included in the software. It is important to note that some of the software systems are also 5D BIM systems, i.e. 3D plus cost dimension.

Table 2: An overview of 4D BIM software systems

Software	*Export formats*	*Import formats*	*Risk analysis*	*Operating*
Autodesk Navisworks	*3D DWF, DWFx, FBX, KML, NWD, NWF*	*TXT, ASC, DGN, PRP, PRW, DWF, DWFx, W2D, DWG, DXF, FBX, IFC, RVT, SKP, NWD, NWF, NWC*	*No*	*Windows*
AVEVA NET Player	*XML, PDF, PPT, HTML, SVG, DOC*	*HTML, XLS, XML, SVG*	*No*	*Windows*

Bentley ConstructSim	*XLS, IFC*	*ISO, XLS, DGN, DWG, PDS, PDMS, IGES, IFC*	*Yes*	*Window s*
Bentley Navigator	*IFC, PDF*	*IFC, DGN, DWG, DXF, SKP, PDF, IGES, KML,XML, XER*		*Window s*
Dassault Systemes CATIA	*3D XML, DWG, DXF, PDF, IGS*	*3D XML, DXF, CATProduct, IG2, IGS*	*No*	*Window s/Linux/ Unix*
Dassault Systemes Civil Design for Fabrication	*IFC*	*IFC*	*No*	*Window s*
Dassault Systemes Delmia	*IFC*	*XML, XER, IFC*	*No*	*Window s/Unix*
Dassault Systemes Optimized Planning	*IFC*	*IFC*	*No*	*Window s*
Digital Project Extensions	*IFC, XML, HTML*	*IFC, XER, XML, DWG, DXF, IGES, SDNF*	*No*	*Window s*
D-Studio 4D Virtual Builder	*4D PPT, IFC*	*XML, MPP, MDP, PP, IFC*	*No*	*Window s*
DESTINI Profiler (Beck Technologies)	*DWG, DXF, eQUEST, IFC, IGES, KML/KMZ, STL, XLS*	*PDF, DWG, DXF, XLS, RVT, PEE, MC2*	*No*	*Window s*
Innovaya 4D/5D Simulation and Estimating	*INV, HTML, DOC,*	*XML, INV, XER, XLS, RVT, MPX, DWG*	*Yes*	*Window s*
Intergraph SmartPlant Construction	*XER, IFC*	*XER, XML, IFC, DWG, DXF, DGN, PDS, PDMS, CAESAR II, SAT, XMpLant, CADWorx*	*No*	*Window s*
Onuma Planning System	*GBXML, IFC, COBie, KML, BIMXML, CityGML*	*IFC, OGC, OSCRE, COBie, XLS, KML, CSV, GBXML, XML, BIMXML, CityGML*	*No*	*Window s/Mac/L inux*
Solibri Model Checker	*IFC, PDF, RTF, XLS, SMC*	*IFC, DWG, DXF, DGN, SKP, SMC*	*No*	*Window s/Mac*
Synchro Software	*SP, XML, XER, IFC, XLS, P3*	*XML, P3, XER, IFC, SP, NP4*	*Yes*	*Window s*
Tekla Structures	*PDS, XML, PML, SCIA, HLI, DWG, DXF, DGN, IFC, SDNF, SKP, PDMS*	*IFC, DWG, DXF, DGN, XML, HLI, SDNF*	*No*	*Window s*
Vico Virtual Construction	*XML, XLS, DOC, PDF*	*IFC, SKP, DWG, sbXML, XLSx, XML, CAD-DUCT*	*Yes*	*Window s*
RIB iTWO	*IFC, XML, XER, MPX, RPA, RPD*	*IFC, XML, XER, MPX, XLS, RPA, RPD*	*No*	*Window s/Mac*
Visual 5D	*Avi, mpeg*	*Cinema 4d, Blender, 3ds max, .RVT*	*No*	*Window s*

4. Findings and discussion

Tables 1 and 2 provide an overview of some scheduling and 4D BIM software systems and how they integrate with BIM. The software systems were classified according to the different criteria set in section 2. A summary of how the research objectives were achieved will be discussed.

Table 3: How the research objectives were achieved

To investigate why construction risk management is required;
This was achieved through a literature review and discussed in sections 1 and 3. In section 1, the rationale for risk management in construction projects was examined. Then in section 3, the rationale and benefits for digitising risk management were discussed.
To identify the various commonly used scheduling and 4D BIM software for construction risk management;
This was achieved through an extensive literature review. Peer-reviewed and vendors' websites served as source of information. The findings from this review were presented in Tables 1 and 2.
To investigate the interoperability amongst the scheduling and 4D BIM software systems;
Once the software systems were identified, the specification manuals were read to determine the software characteristics (e.g. file import and export format). Furthermore, in some cases some of the software had to be installed and explored to determine whether it is compliant with BIM, types of file exchange formats and whether it contains risk components.

By achieving the objectives, four main findings were uncovered. Firstly, some traditional construction scheduling software are BIM compliant and also contain a risk analysis component. For example, Asta PowerProject has a risk component, and its project can be read by 4D BIM software system (e.g. Synchro). Secondly, most traditional scheduling software are not yet integrated in BIM and do not contain a component for analysing risk in construction (e.g. Project Xpert and Rational Plan Professional). Thirdly, some 4D BIM software systems have a risk analysis component (e.g. Synchro and Vico) while others do not (e.g. Navisworks). The last is that some scheduling and 4D BIM software systems can be installed on Mac and/or Windows operating systems. The findings from this study can be modelled using a Venn diagramme (Figure 2) which reveals the relationship between the different software systems.

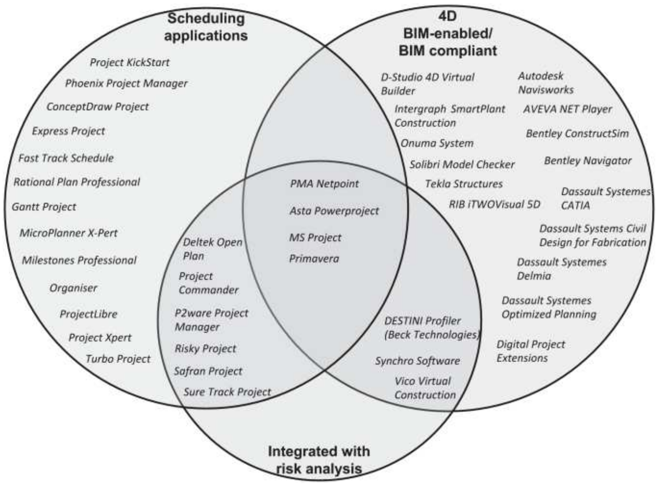

Figure 2: Software category summary

5. Conclusions

With construction projects increasingly becoming larger and more complex, there is the need for efficiency in the way construction activities are carried out. The construction industry is known for its inefficiencies, and amongst many, scheduling (time) risk is not left out. This study has explored the domain of risk management through which an understanding of the various problems that give rise to risks in construction projects was achieved. Consequently, some of the available traditional scheduling software systems were examined based on their compliance with BIM. However, it was clear that these software systems are not quite efficient in specifically managing scheduling risk. With the global advancement in technology, BIM has emerged as a technology capable of bringing more efficiency in the way the industry operates. It is in this regard that a critical appraisal of 4D BIM software systems was carried out. Although, BIM is still in its early phases, one of the benefits of BIM is that it can further enhance better risk management through 4D modelling. Through 4D modelling, project managers can be able to visualize the virtual construction of any project, identify any risk associated and make more subjective decisions rather than objective decisions. The traditional software systems are not capable of doing so but with 4D software systems, this is possible. This has been illustrated through the different literatures in this paper as well as the critical appraisal of some of the 4D software systems presented. Nonetheless, this study has not investigated how schedule risk management can be performed in a BIM environment. Future studies will focus on the processes of undertaking schedule risk management in a BIM environment for proper understanding of how to manage risk using BIM.

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