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STRATEGIES TO DEVELOP EFFECTIVE BIM MODELS TO SUIT 4D MODELLING

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Abstract:
Rapid upsurge of technology accredited 4D Building Information Modelling (BIM) as a BIM centric scientifically-derived scheduling process. It upgrades the project outcome, by reducing the substantial uncertainty exists with quality, cost and time. However, 3D BIM models are being advanced not only for 4D models but also for many other visualizing and informative purposes. Hence, necessity ascends to verify whether generally developed BIM models satiate required features of 4D modelling. Consequently, research aims to identify and verify extent of suitability and practicability of using BIM models in 4D modelling. The aim accomplished through a qualitative approach utilized with a desk study, unstructured interviews and a content analysis. It documented strategies and recommendations on how BIM models could be technologically advanced to ensemble 4D visualization. It was revealed that, prevailing BIM models are not readily acceptable for 4D modelling, which need to be refined marginally for real-world approach. Structural work packages, plant, equipment and accessories of building works can be directly used to 4D modelling as already developed whereas, integrated elements and finishing need few adaptations. Despite of few limitations, it is recommended more than 90% of elements developed in BIM models can be used for 4D modelling with certain modifications.

Keywords: *4D Building Information Modelling (4D BIM); 4D modelling; Building Information Modelling (BIM); Project Planning*

1. Background

Due to the rapid growth of advance technologies man's pattern of living, working and the way of thinking is being reformed. The Architecture, Engineering and Construction (AEC) industry is one of the leading trade among other industries (Dawood, 2010), which may have significant changes in immediate future (Arayici *et al.,* 2011). In addition, AEC industry consumes huge amount of resources which causes a great impact on Gross Domestic Product (GDP), labour market and energy consumption, and also affect each and every country in the world (Gang, 2013).

According to Cooke (2013), when compared to other industries, the process of constructing buildings is primarily a labour demanding development which is engaged in a series of sequenced activities to construct a homogeneous product in order to meet the necessities of the client. Further, Arayici et al., (2011) discovered that current practice with two dimensional drawing tools have many drawbacks such as timescales, duplications, delays, over production, and effective design coordination. Hence, new technologies are being developed in solution base to increase efficiency in processing, planning and productivity and new technology identified as Building Information Modelling (BIM) gives many solutions to AEC industry too (Boton *et al.,* 2013).

Azhar (2011) stated that BIM can be used to develop an accurate simulation of a building, which is digitally constructed in 3D model can be used for planning, design, construction, and operation of a facility. One of the key benefits of BIM is to empower understanding and communication among the participants (Manning and Messner, 2008) through visualization of how the final product may look like (Hergunsel, 2011). Emerging research attempts are currently paying attention in the provision of project planners and managers with computer-based advisory tools especially with BIM to visualize the construction plan in a 4D model (3D model+ time) (Heesom and Mahdjoubi, 2004). 4D planning possess the potential to increase the communication efficiency and interpretation ability among the project team members (Sebastian, 2010). Further, it can assist identifying the effective construction strategies to shorten the project duration, judging schedule quality, and assessing their workability (Russell *et al.,* 2009). In addition, developing principles of 4D planning gives a new opportunity for the representation of construction scheduling in an animation model which will be more advanced than the traditional grant chart project planning technique (Heesom and Mahdjoubi, 2004).

Although the technology is gradually capturing the world, according to the Staub-french and Khanzode (2007), many project teams have realized that, implementing 3D and 4D modelling on practical projects is a complex process that requires a high coordinated effort and time. This knowledge gap, is one of the reasons for the low adoption of information systems among AEC professionals (Hartmann et al., 2009). Under this context, the coordination between 3D and 4D models should be analysed in order to increase the efficiency of construction scheduling.

1.1 AIM

The research aims to identify and verify extent of suitability and practicability of using BIM models in 4D modelling.

1.2. OBJECTIVES

Hence, the set objectives of the research were;

- Identify BIM models and 4D models with their features and modelling tools.
- Investigate into elements of the construction programme which need to be visualized using the model.
- Identify BIM elements which require to be incorporated in construction planning.
- Find alternative methods available to model BIM elements
- Assess usability level of BIM elements made with alternative objectives for 4D modelling.

2. Literature Synthesis

A comprehensive literature synthesis was carried out to review the current knowhow level and effectiveness of the 4D construction planning which visualize and simulate the expected construction planning at pre contract stage.

2.1. CONSTRUCTION PLANNING

Construction planning is a critical task in the early phases of a construction project determining the success or failure of a project (Allen and Smallwood, 2008). Moreover, Eastman *et al.,* (2011) defined that construction planning involves in scheduling and sequencing activities in time and space, taking into account resources, procurement, spatial constraints and other concerns in process. However, according to Heesom and Mahdjoubi (2004) there is a lack of skills in the area of construction planning, thus the continuous deterioration of the capability in effective construction planning of construction projects and additionally it impose heavy burden on project teams members. Additionally, Huang *et al.,* (2007) stated that many project planners still rely on the traditional project planning techniques.

For the aforementioned issues as Akintoye and Macleod (1997) stated, there are different solutions within the industry, whereas most efficient solution is highly rely on the virtual planning, which combines the 3D model and scheduling.

2.2. BIM AND 4D TECHNOLOGY

BIM is one of the most promising technological achievement of the AEC industry in recent years (Lee *et al.*, 2006). Even if a BIM model features are more similar of a 3D geometrical model, it encompasses a much higher level of intelligence as it integrate information used by other building analysis applications such as cost estimating, energy simulation, day lighting, Computational Fluid Dynamics (CFD), space planning and building code checking with in the model (Kumanayake and Bandara, 2009).

4D BIM is an advanced visualization technique which integrate 3D BIM model with schedules, with respect to increase the communication efficiency and interpretation ability of the project team members (Dawood and Sikka, 2007). Many authors agree that 4D BIM integrate schedules with the 3D models to simulate the construction of a project which has potential to increase the information sharing among the project team participants which assist in the problems associated with site logistics and site layout at the construction period (Dawood and Sikka, 2007; Eastman *et al.*, 2011; Zhang *et al.*, 2000).

2.3 4D PLANNING AND VISUALISATION

As previously discussed construction planning mainly involves with scheduling and sequencing activities in time and space frame. However, traditional methods are requiring more improvements as planners has to visualize in mind what they have planned and it require more time and costs (Chau *et al.*, 2003). Further, 4D technology is increasingly advancing and will have a great impact on the processes of construction management as presently adept (Wang *et al.*, 2004).

2.3.1. Expected changes for 4D visualization from conventional planning

In order to analyse 4D visualisation, it is essential to identify the process what is expected by the new technology. Table 1 analyses requirements stated by the following authors in their articles.

Table 1: Expected changes from conventional planning

Hartmann ***et al.*** (2009)	-Showing complex interdependence of tasks and the distortion as a result of focusing undue attention on particular activities**.** -Not to rely on individual experience**.**

Li *et al.* (2009)	-An effective computer-assisted technology for resource allocation and planning. -Minimize the mismatch between what is planned and actually needed. -Ability to predict whether the project will result in a profit or a loss in advance of construction. -Take real productivity rate of different machineries and manpower's into account. -Combine the three traditional techniques of resource allocation, re-source levelling and time-cost trade-off analysis.
Allen and Smallwood (2008)	-Reduce the occurrence of delays on projects.
Dawood and Sikka (2007)	-Communication of information among different stakeholders. -Provide spatial construction features or resource and working space requirements.
Huang *et al*. (2007)	-Visualizing construction-specific components such as scaffolding and other temporary works integrated in the 3D model.
Mckinney *et al.* (1996)	-Ability to identify construction problems prior to construction. -More information for construction planning. -Minimize the inability of Clients' understanding on project documents.

2.4 3D MODEL DEVELOPMENT PROCESS FOR 4D MODELLING

Eastman *et al.* (2011) alienated 4D modelling process into three main categories with respect to the inputs to develop a 3D model. In addition he described three methods as follows;

Table 2: Three categories of 4D modelling process

Manual method using 3D or 2D tools
• Planners used to create visualization by outsourcing. • An effective marketing tool but not an effective planning tool because of the limited possibilities to modify, update, and do real time scenario planning.
Built-in 4D features in a 3D or BIM tool
• Create 4D images is through filtering the relevant objects with tool like Revit. • Incapable of simulate construction with the time. • Assists tools, such as Tekla structures, Navisworks Scheduling, Synchro, and Vico Office to create 4D models basis of 4D images by enabling multiple links between the physical objects and the activities in the model.

Export 3D/BIM to 4D tool and import schedule
• Coordination of 3D model with schedules. • Requires 3D models from recognized software supported to IFC and schedule from general applications such as MS Project and Primavera.

3. Research Methodology

Primarily, through an extensive literature synthesis, the distinct features of BIM and 4D modelling tools, elements of the construction programme which need to be visualized using the model and BIM elements which require to be incorporated in construction planning were identified. Afterwards, a programme of recently completed eight-storey building has been used as the case for the analysis to verify the work packages. Subsequently, the work executed by a work package related to modelling was identified and the available options for developing models in Revit 2014 were obtained through a desk study. To verify the accuracy of description and modelling requirements of the work items, unstructured interviews were conducted. At last, the comparison between modelling requirements and available modelling options are being evaluated and critically analysed using content analysis technique.

4. Research Findings

Findings have been summarized considering both usability and practicability in developing 4D models.

4.1 USABILITY OF BIM MODELS IN 4D MODELLING

In this section, three levels of usability, such as direct (A), modified (B) and impossible (C) usable options, for each option proposed in the analysis were discussed. Moreover, those levels of options, related usability in 4D modelling, are grouped in table 3.

Table 3: Level of Usability in 4D modelling

No	Level of Usability in 4D modelling	Total number option relevant to the level
1	The experimented model can be directly used in the 4D models without modifications	38
2	The experimented model can be used in the 4D models with some modifications	34
3	The experimented model cannot be used in the 4D models or there are no options available to develop the required model or new options are needed to model the requirement for 4D	1

It is clearly presented in figure 1 that around 52% of options can be directly usable to 4D modelling without changes. Moreover, 47% of modelling options can be used in 4D modelling with some modifications.

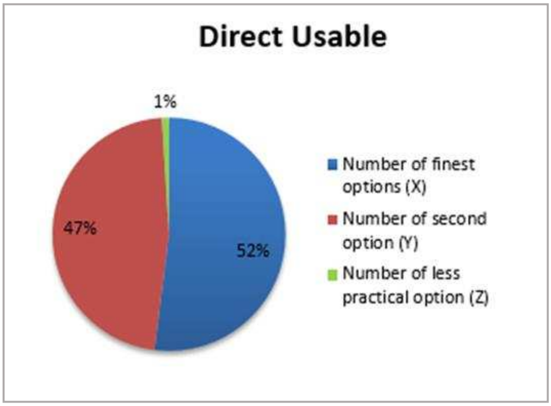

Figure 1: Graphical representation of level of usability in 4D modelling

4.2 PRACTICAL EXTENT OF USING OPTIONS TO DEVELOP MODELS

In this section, three levels of practical extent of using options to develop models, such as finest method (X), second method (Y) and less practical method (Z), for each option proposed in the analysis were discussed as grouped in table 4.

Table 4: Level of practicability of the option when modelling

No	Level of practicability of the option when modelling	Total number option relevant to the level
1	The best fitted method, for modellers, which is more likely adopt by modellers	43
2	The method which is used by modellers, if finest method of developing the model is not available	23
3	Hardly attainable method due to the complexity and practical difficulty	7

Figure 2 clearly presented that around 59% of options are likely used by the modellers. Moreover, modellers also can use 31% of modelling options if the finest option for modelling is not available. Therefore, almost 90% of options in the analysis can be used for modelling purposes.

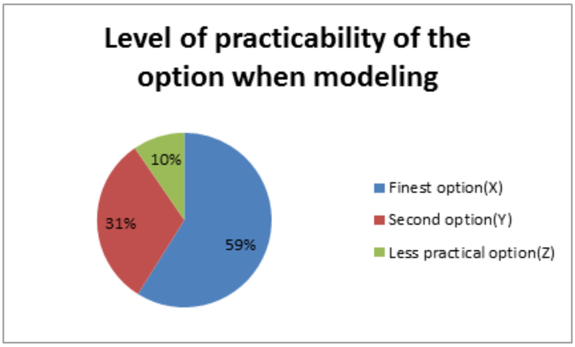

Figure 2: Graphical representation of level of practicability in 4D modelling

4.3 OVERALL COMPARISON BETWEEN USABILITY AND PRACTICABILITY OF OPTIONS

The table 5 enlighten the overall usability and practicability of the options.

Table 5: Over all comparison between usability and practicability of options

No	Level of Usability	**Number** options	(X)	(Y)	(Z)
1	Direct usable (A)	38	12	20	6
2	Partially usable (B)	34	31	3	-
3	Unusable (C)	1	-	-	1

Figure 3 explain the percentages of options as whole. Accordingly, 17% of available options can be directly usable and finest options which reveal that the 17% of the BIM models can be directly used in 4D modelling.

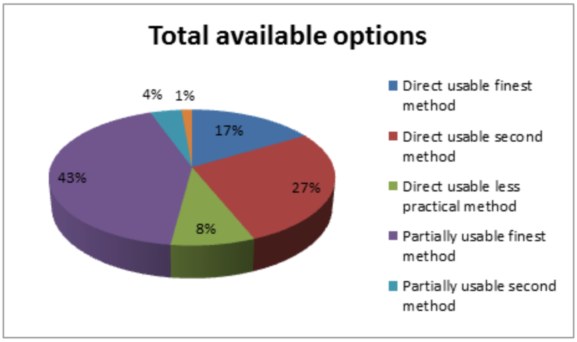

Figure 3: Graphical representation of total available options

Further, the figure 4 shows that, 91% of partially usable options are the finest method which modellers adopt in developing the general BIM models. Moreover, the balance 9% of options are second option for modellers which may be the method used by modellers if the finest method is not available. Hence, there are no less practicable options in this category.

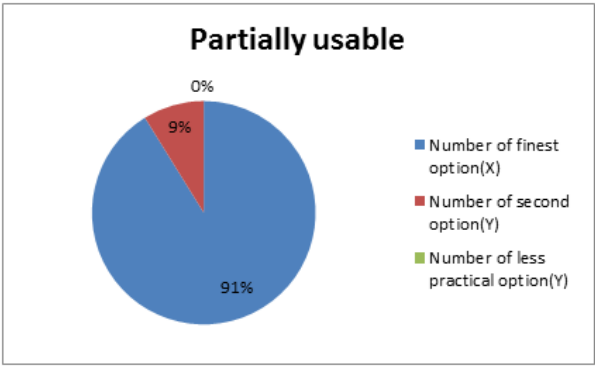

Figure 4: Graphical representation of partially usable option

Finally, there is only one option comes under the impossible options, to use in 4D models, which in the less practicable method.

5. Conclusions and Recommendations

Findings of the research revealed that BIM model of solid structural work packages, such as construction of beam, slab and column can be directly used in the 4D model without any modifications when the construction process in single step for one element. Moreover, work packages of equipment accessories also lays in the same group. However, in such situation, if the abovementioned work packages have to be visualised in several stages of construction, BIM model cannot be directly used in the construction process. Furthermore, practicality of such models is high, since the method used to model the specified work packages are widely used in actual modelling process.

Work packages related to finishing works which need to be visualise by adding layers to the existing elements, such as plastering for wall, can be directly used for 4D modelling nonetheless with some deviations to the actual BIM models. Therefore, the method and model developed to visualise such elements are not in accordance with the normal BIM models and it slightly varies. Further, work packages related doors and windows require independent visualisation to develop 4D models as frames of door and window are to be constructed in two work packages. However, the models for doors and windows are integrated in BIM models. Therefore, the separations of sub elements need to be done before use such models in 4D modelling. Likewise, most of the assembled elements used to modelling purposes such as assembled pile caps and assembled wall with the layers inside also require separation before use in 4D models. Furthermore, it is notified that near the half of BIM elements developed in the analysis comes under this group. Other than the above work packages, special works such as canopy at entrance and ceiling frame work need to be newly modelled or download families from internet. Therefore, modelling and developing models for elements rely on the new models and families.

Considering all the fact of the study, 31% of direct usable options are likely used by model developers. Accordingly, findings reveals that around 70% of options to develop BIM model appropriate to develop 4D models are not the best method used to modelling by modellers. Moreover, 16% of options which suit the 4D modelling are less practical method used by developers. That means, if this method is used other purposes of the BIM models get affected. Further, 53% of direct usable methods are second method of developing models used by developers which reveals the necessity of developing few tools which accommodate developers to use this method.

Furthermore, 91% of partially usable options, to develop BIM models, are likely used by modellers, which show that more practical methods used to develop BIM models are not suitable to develop 4D modelling purposes.

References

Akintoye, A.S. and Macleod, M.J., 1997. Risk analysis and management in construction. *International Journal of Project Management*, 15(1), 31–38.

Allen, C. and Smallwood, J., 2008. Improving construction planning through 4D planning. *Journal of Engineering, Design and Technology*, 6(1), 7–20.

Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C. and O'Reilly, K., 2011. BIM adoption and implementation for Architectural practices. *Structural Survey*, 29(1), 7–25.

Azhar, S., 2011. Building information modelling (BIM): trends, benefits, risks, and challenges for the AEC industry. *Leadership Manage*, 11(3), 241–252.

Boton, C., Kubicki, S. and Halin, G., 2013. Designing adapted visualization for collaborative 4D applications. *Automation in Construction*, 36(4), 152–167.

Chau, K.W., Anson, M. and Zhang, J.P., 2003. Implementation of visualization as planning and scheduling tool in construction. *Building and Environment*, 38(5), 713–719.

Cooke, T., 2013. Can knowledge sharing mitigate the effect of construction project complexity?. *Construction Innovation: Information, Process, Management*, 13(1), 5–9.

Dawood, N., 2010. Development of 4D-based performance indicators in construction industry. *Engineering, Construction and Architectural Management*, 17(2), 210–230.

Dawood, N. and Sikka, S., 2007. Measuring the effectiveness of 4D planning as a valuable communication tool. *International Journal of Information Technology in Construction*, 13(1), 620–636.

Eastmen, C., Liston, K., Sacks, R., and Teicholz, P., 2008. *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers, and contractors.* New Jersey: John Wiley & Sons, Inc.

Gang, Y.Z., 2013. BIM-based Project Management. In *International Quantity Surveying BIM conference 2013 Hong Kong*, 239–250.

Hartmann, T., Fischer, M. and Haymaker, J., 2009. Implementing information systems with project teams using ethnographic – action research. *Advanced Engineering Informatics*, 23(1), 57–67.

Heesom, D. and Mahdjoubi, L., 2004. Trends of 4D CAD applications for construction planning. *Construction Management and Economics*, 22(2), 171–182.

Hergunsel, M.F., 2011. *Benifits of building information modelling for construction managers*. Worcester: Worcester Polytechnic Institute.

Huang, T., Kong, C.W., Guo, H.L., Baldwin, A. and Li, H., 2007. A virtual prototyping system for simulating construction processes. *Automation in Construction*, 16(5), 576–585.

Kumanayake, R.P. and Bandara, R.M.P.S., 2009. *How it improves building performance* [online]. Master' Thesis, General Sir John Kotelawala Defence University. Available from *Building Information Modelling (BIM):* http://www.kdu.ac.lk/department-of-mechanical-enginee ring/images/Resea rc h_Publications/Mr.RMPSBandara/4.pdf [Accessed 02 July 2014]

Lee, G., Sacks, R. and Eastman, C.M., 2006. Specifying parametric building object behavior (BOB) for a building information modelling system. *Automation in Construction*, 15(6), 758–776.

Li, H., Chan, N., Huang, T., Guo, H.L., Lu, W. and Skitmore, M., 2009. Optimizing construction planning schedules by virtual prototyping enabled resource analysis. *Automation in Construction*, 18(7), 912–918.

Manning, R. and Messner, J.I., 2008. Case studies in BIM implementation for programmeming of healthcare facilities. *ITcon*, 13(2), 446–457.

Mckinney, K., Kim, J., Fischer, M. and Howard, C., 1996. Interactive 4D-CAD. *Computing in Civil Engineering*, 383–389.

Russell, A., Staub-French, S., Tran, N. and Wong, W., 2009. Visualizing high-rise building construction strategies using linear scheduling and 4D CAD. *Automation in Construction*, 18(2), 219–236.

Sebastian, R., 2010. Changing roles of the clients , architects and contractors through BIM. *Engineering, Construction and Architectural Management*, 18(2), 176–187.

Staub-french, S. and Khanzode, A., 2007. 3D and 4D modelling for design and construction coordination : issues and lessons learned. *IT Con*, 12(2), 381–407.

Wang, H.J., Zhang, J.P., Chau, K.W. and Anson, M., 2004. 4D dynamic management for construction planning and resource utilization. *Automation in Construction*, 13(5), 575–589.

Zhang, J., Anson, M. and Wang, Q., 2000. A New 4D management approach to construction planning and site space utilization (ASCE). In *Computing in Civil and Building Engineering*, 15–22.