

Research Article

4D BIM Application in AEC Industry: Impact on Integrated Project Delivery

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Abstract: As project delivery approaches that are supported by Building Information Modelling (BIM) are continuously acknowledged throughout the Architecture, Engineering and Construction (AEC) industry, an innovative modelling approach called 4D BIM is starting to develop, which associates elements of 3D BIM with time and scheduling information. Traditional construction planning applications like bar charts and network diagrams fail to present and communicate the spatial and temporal or 4D components of construction schedules efficiently. As a result, they do not permit project managers to produce scheduling alternatives quickly to obtain the finest solution to develop a particular design. With 4D modelling, the whole period of a sequence of activities that is executed by those involved in the project can be presented visually. With the rising interest in BIM and the wider use of this and other technological innovations in the AEC industry, 4D BIM tools, which has been broadly employed, is becoming increasingly recognized among fundamental technological fields under BIM. This study aims to highlight and review numerous impacts of 4D applications on Integrated Project Delivery (IPD) on the AEC industry and suggest the ideal strategy to optimize the tools for rapid project delivery.

Keywords: AEC industry, BIM, building information modeling, integrated project delivery

INTRODUCTION

There are remarkable possibilities for advancement in the output of the Architecture, Engineering and Construction (AEC) sector. Despite that, other sectors are experiencing faster growth in productivity due to the implementation of new technologies. US General Services Administration (2007) reported that the rate of improvement of methods used in the AEC sector is very slow. Other sectors have achieved significant quality and productivity enhancements as a result of the use of object model technological innovation according to open requirements for interoperability. New technology enables users to improve the quality of design through virtual modelling prior to construction. Breakthroughs in building technology (Farhan *et al.*, 2012b, c; Al Yacouby *et al.*, 2012a) can optimize both economic and environmental performance of buildings (Umar *et al.*, 2012, 2013) and awareness among researchers, industry practitioners and the public in the development of new building technology solutions should be encouraged (Farhan *et al.*, 2012a; Al Yacouby *et al.*, 2012b).

As a result of a long term attempt by construction professionals, they have come up with a revolutionary application, which is Building Information Modelling

(BIM) that is designed to address a lot of the challenges faced in construction activities. National Institute of Building Sciences (NIBS) (2007) define BIM as “a digital representation of physical and functional characteristics of a facility, which serves as a shared knowledge resource for information about a facility that forms a reliable basis for decisions during its lifecycle from inception onward” (Allmang *et al.*, 2005), while Stanford University’s Centre for Integrated Facility Engineering (CIFE) Tenenbaum (1990) referred to BIM as Virtual Design and Construction (VDC).

Use of BIM to plan and schedule projects is typically referred to as 4D, where construction and designs come together. 4D scheduling can generate significant information for the project team such as the start and finish dates of elements as well as their criticality. It can also generate visualizations of the building design over time. Furthermore, it enables AEC specialists to evaluate options and select the best one at the design stage. Its capability to share knowledge resource minimizes the need to re-gather and re-format information, which results in better accuracy and faster rate of passed-on information and decrease in expenses due to lack of interoperability, automation of monitoring and evaluation and support of operation and

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maintenance works to boost the Integrated Project Delivery (IPD) in construction practices.

IPD is “a project delivery method that incorporates people, systems, business structures and practices towards a method that collaboratively harnesses the skills and experience of all participants to enhance project effects, raise value to the owner, minimize waste and increase efficiency through all stages of design, fabrication and construction” (Kent and Becerik-Gerber, 2010; Khanzode *et al.*, 2006; Thomsen *et al.*, 2010) or holistic method of building whereby project stakeholders and participants collaborate throughout the life cycle of the facility to develop efficient buildings (Elvin, 2007). This study aims to highlight and review numerous impacts of 4D applications of BIM on IPD and suggest the ideal strategy to optimize the tools for rapid project delivery.

Project benefits and limitation for exploiting 4D models: The private sector has witnessed numerous advantages of 4D modelling to all different stages of the project schedule. Projects on extremely limited construction schedules have integrated 4D modelling to actively coordinate sub-contractors and manage the schedule to be more cost-effective. 4D modelling has been implemented by owners, designers, engineers and contractors as well. The advantages of 4D modelling consist of enhanced coordination and visualization of the schedule. Stakeholders can operate using the 4D model in renovation projects to determine how tenants will be moved and what construction works are occurring near them as well as assess different options. In new projects, 4D models could be applied to demonstrate the sequence of construction processes and examine the space availability besides the logic and soundness of the construction schedule. At the moment, 4D models can easily indicate the schedule, determine physical conflicts and strengthen the design team synchronization, which help contractors to control the flow of information and work more effectively. Moreover, these models can help the developers to recognize possibly harmful activities as a result of time or location. Nevertheless, 4D models are neither intelligent nor automated. These models will not be able to change or enhance the schedule automatically. 4D models demand intimate interaction with the project team to absolutely realize their advantages. Creating the models can be extremely time-consuming and errors cannot be detected by the application (Fischer, 2008).

MATERIALS AND METHODS

Concept of 4D BIM: 4D BIM, a terminology commonly applied in the Computer Aided Design (CAD) field, indicates the intelligent link between 3D CAD elements or assemblies with time or schedule related information and enhances the 3D model that challenges the conventional practices of scheduling by including scheduled dates into model components,

enhances the plan of the project team and incorporates communication between numerous divisions. The schedule is connected to BIM models with the progress of time to evaluate alternatives and make the best decision (National Institute of Building Sciences, 2007). With 4D modelling, stakeholders can potentially better comprehend how the project impacts them. Additionally, they can use 4D models to improve understanding of estimated construction schedules for purpose of funding (Hartmann *et al.*, 2008).

4D models broaden the value of traditional 3D models designed throughout the BIM-enabled design process along with scheduling techniques with better understanding and cooperation among all project participants. Most of the crucial features related to these models will improve site planning by enabling monitoring of "what if" scenarios to improve various schemes. Models of installation conflicts, design clashes and work-flow management can be executed prior to starting off work. Construction series can be simulated to aid fast and valuable decision-making by the contractor, design team and owner. The whole process of developing a 4D model can be remarkably straight-forward provided that the BIM models have already been developed with adequate granularity. Individual components in a discipline's BIM model should be connected with discrete, date-driven construction activities, which are normally enclosed in the contractor's schedule. The 4D model developer employs a basic approach to link model components with line items in the construction schedule. In the event the 3D model has been created in comparatively close correlation with the anticipated fabrication or erection plan, then this method of assigning individual model elements to timeline activities can continue unencumbered. Nevertheless, when the 3D model has been developed regardless of such construction-related segregation, then re-modelling efforts are possibly needed to ascertain a precise linking of model elements to timeline activities (Kymmell, 2008). Due to this, it is essential for developers to align the model as near to actual circumstances as possible when it is recognized that a 4D model will ultimately be required for a project.

Business needs: 4D models for Integrated Project Delivery (IPD): 4D modelling can be applied in both new construction projects as well as reconstruction projects. In reconstruction and modernization projects, among common project issues are how and where to apply swing space and strategies to move tenants during construction. In many cases, tenants will need to know precisely where they are shifting to, the period and how the development inside the building will impact them. 4D models enable project teams to clarify most of these factors to every tenant. With regard to new construction projects, project teams can utilize 4D models to handle the construction schedule, coordinate the schedule

timeline with the location-based schedule, forecast and prevent interruptions among teams and activities and validate the soundness and appropriate series of the activities (Ho and Matta, 2009). Engineers and superintendents can exploit snapshots of 4D models to communicate short-term goals with the team and assess day-to-day progress. Consequently, efficient IPD projects need to generally occur through the entire project lifecycle. An excellent, diverse and possibly unlimited wide array of information about a building is produced during all phases of its lifecycle. IPD project teams can integrate this technological innovation at various points during the entire project lifecycle. Projects must deploy technologies at specific stages in support of certain possibilities. Figure 1 shows how 4D and BIM technologies can be applied during the entire lifecycle. Placement of IPD applications from top to bottom is based on its maturity. As shown in Fig. 1,

laser-scanning and 3D geometric models will be the easiest applications to use, while BIM models and analysis applications will be the most sophisticated.

IPD concepts are adaptable and could be used on numerous types of contractual arrangements. Techniques involved in integrated project delivery differ from conventional project delivery. In integrated project delivery, collaboration between the owners, main designer and leading constructor is from the design phase to the last handover and is implemented in an organized and efficient manner with trust. Therefore, the basic interaction is to share risk and benefit, which, as a result, promotes all parties involved to focus on the success of the project rather than individual targets (Azhar *et al.*, 2008). Interaction among main parties in traditional delivery projects has become increasingly hostile, which is disadvantageous to all parties involved. The IPD approach recognizes the tremendous

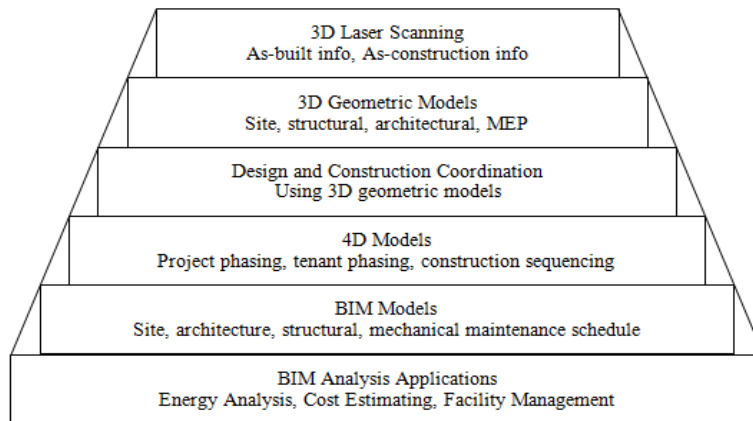


Fig. 1: 4D BIM applications for IPD throughout the project lifecycle

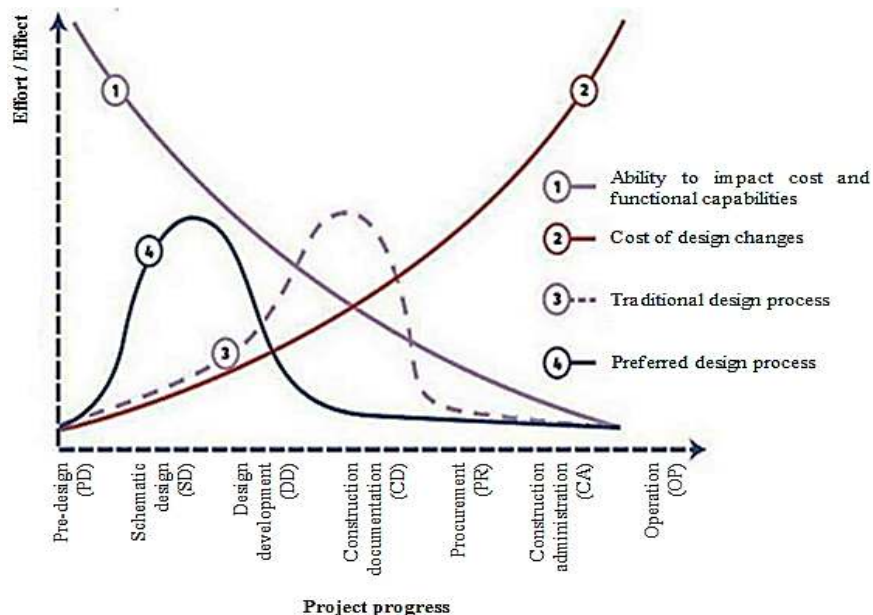


Fig. 2: 4D project effort/effect and their impact on IPD adopted from Construction Users Round Table (2004)

advantages of sharing information and insight by stakeholders and decision makers earlier to enhance workflow performance for all parties involved and increase chances of project success. All parties should include contingencies and contract conditions extensively with transparency to protect themselves from risk and uncertainties. The combination of use of BIM tools and implementation of the IPD strategy, issues can be resolved earlier before they become costly.

The Mac Leamy Curve (Construction Users Round Table, 2004) as shown in Fig. 2 shows that during the traditional design process, most of the outcome by the AEC team happens during the construction-documentation stage, which is when the capability to manage 4D and cost is very low. In the integrated project process, documentation is produced in the earlier stages, which is when the capability to manage costs is significantly higher and cost of modifications is comparatively lower. Figure 2 further demonstrates how IPD shifts the maximum effort/effect to the earlier design phases of the project, which improves performance of the final design product and reduces its cost by minimizing errors and the need to fix them. This certainly will lead to less Request for Information (RFIs) and change order requests later on in the construction stage. 4D BIM modelling can significantly contribute to early detection of problems and is important to effectively accomplish the collaboration needed for IPD.

BIM that is integrated under the IPD will be able to develop a strong visualization of the project, recognize the actual construction conduct, overall performance and various related information. BIM with IPD will additionally present reliable information and minimize RFIs, change orders and the actual remodel in the construction area. BIM employed in this process could also assist the procedure for generating as-built drawings and delivering an entire and correct record drawing and 4D information.

RESULTS AND DISCUSSION

4D models in the project lifecycle: Pre-design is the preliminary process used for 4D models. It is employed to organize project planning throughout the feasibility phase. For instance, the model enables you to ascertain various phasing series and swing space configurations in order to optimize the construction schedule. These models enable assessment of numerous options with

detailed evaluation at a reasonably low cost for the team and owner. Furthermore, it can evaluate different alternatives based on whether or not an important tenant would leave the building. The next stage is the design development of the model that can be used to boost constructability of the design in order to determine positive aspects of numerous construction processes. This stage of 4D models can often enhance the construction schedule, phasing and/or tenant sequencing. Additionally, the models can be used to communicate the phasing plan to the tenants. Then, the selection/construction bidding that requested 4D models in the Request for Proposal (RFP) demonstrate the contractor's capability and path to accomplish the task. If the work is complex, 4D models can be applied to comprehend tenant phasing and/or construction activities series during bidding. If ever the building contractors fully understand the space and restrictions better, the bids end up being more precise, which additionally permit bidders to know project constraints and anticipations better for a seismic upgrade project. Lastly, construction stages where 4D models are applied can be used as temporary elements of construction coordination and constructability evaluation. These comprise of knowing how and where trades will work over duration of time and comprehending traffic and site flow processes. On-site, these kinds of models can be utilized for bi-weekly construction progress evaluations and also to assess as-built with as-planned schedules for management and claims purposes. 4D models can additionally be applied during this last stage to communicate with tenants during the construction process. Moreover, it can be applied to connect the utility and control system modifications needed during specific times and their effects, particularly for re-modelling projects. Due to the fact that 4D models are dependent on 3D models, 3D construction coordination can be a by-product of 4D modelling as shown in Table 1. This differs according to the degree of detail and cannot be correct in all circumstances.

Recommended strategy to optimize 4D for successful IPD: Businesses demand to optimize achievements of the IPD process at the preliminary phase and there is a need to determine project possibilities. All projects encounter a distinctive mixture of restrictions and obstacles. The recommended model, Figure 3 exhibits some suggested project areas that 4D BIM technologies can support. Generally, opportunities in every project

Table 1: 4D models in the project lifecycle

Phase	3D model	4D schedule+time
Feasibility study	Project	Construction project
Concept design	Building elements	Construction schedule of building elements (4D)
Design development	Systems/components	Sub areas/building units/disciplines
Construction documents	Parts	Activities

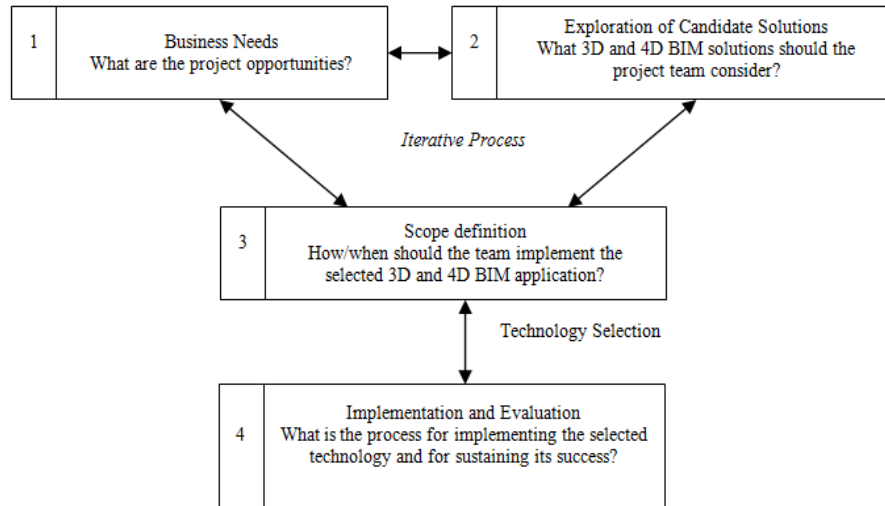


Fig. 3: Proposed 4D model to optimize IPD process

area consist of enhanced quality, reliability, coordination and performance.

A large amount of 3D-4D BIM technological innovations are being developed, to select the most suitable 3D and 4D BIM technologies for any particular project, project teams must execute an extensive assessment. The expertise of project team members, maturity of technologies employed and accessibility to resources, such as financing, must be considered when analyzing feasibility. Furthermore, the project team must observe the exchange of 3D-4D BIM information between team members, procurement of 3D-4D BIM services and suitable times during the lifecycle of the project when 3D-4D BIM technologies should be employed.

After opting to use employ 3D-4D BIM, the project team need to guarantee their capability to sustain success throughout the entire period of its use by continuously evaluating throughout its implementation. Stakeholders must clearly understand their role and obligation and the responsibilities of the other team members. The use of 3D-4D BIM can affect the role of a project manager and their degree of involvement in the technology can vary depending on personal interest, availability and level of comfort with the technology. Project teams must continuously assess the 3D-4D BIM project based upon the metrics set up during planning. Moreover, lessons learned and appropriate project data need to be taken to be able to build best practices for future projects.

CONCLUSION

3D BIM allows designers to create visuals that can be shown to customers before starting construction works. Furthermore, application of 4D BIM in addition to 3D BIM enhances project planning and leads to improved quality of final product with minimized waste

of resources. Use of 4D BIM modelling is increasing in the AEC sector and provides many benefits to all parties involved such as improved coordination, easier transfer of project planning and reduction in time and cost.

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