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Building Information Modeling (BIM): A New Paradigm for Visual Interactive Modeling and Simulation for Construction Projects

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Abstract

The Architecture, Engineering and Construction (AEC) industries have long sought techniques to decrease project cost, increase productivity and quality, and reduce project delivery time. Building Information Modeling (BIM) offers the potential to achieve these objectives. BIM represents the development and use of computer-generated n-dimensional (n-D) models to simulate the planning, design, construction and operation of a facility. It helps architects, engineers and constructors to visualize what is to be built in simulated environment and to identify potential design, construction or operational issues. BIM represents a new paradigm within AEC, one that encourages integration of the roles of all stakeholders on a project. It has the potential to bring about great efficiency as well as harmony among players who all too often in the past saw themselves as adversaries. In this paper, the benefits of Building Information Modeling (BIM) for the AEC industries are discussed with the help of two case studies. These case studies illustrate the various tangible and intangible benefits achieved by all stakeholders by implementing BIM in their projects. At the end, light is thrown on various BIM related risks and future challenges for the AEC industries.

Keywords

Building Information Modeling (BIM), Virtual Design and Construction (VDC), n-Dimensional Modeling, Parametric Modeling, Facilities Management (FM)

1. Introduction

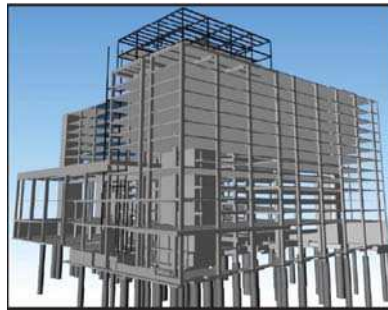
Building Information Modeling (BIM) is one of the most promising developments in the Architecture, Engineering and Construction (AEC) industries. BIM simulates the construction project in a virtual environment. With BIM technology, an accurate virtual model of a building is digitally constructed. When completed, the computer-generated model contains precise geometry and relevant data needed to support the construction, fabrication and procurement activities required to realize the building as shown in Figure 1 (Eastman *et al.*, 2008).

A Building Information Model, is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analyzed to generate information that can be used to make decisions and to improve the process of delivering the facility (AGC, 2005).

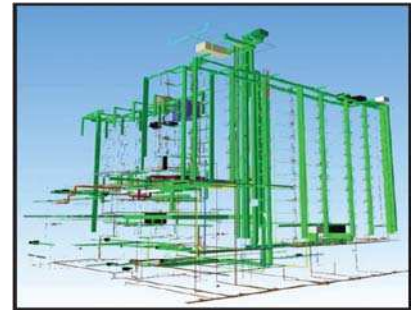
The principal difference between BIM and conventional 3D CAD is that the latter describes a building by independent 3D views such as plans, sections and elevations. Editing one of these views requires that all other views must be checked and updated, an error-prone process that is one of the major causes of poor documentation. In addition, data in these 3D drawings are graphical entities only, such as lines, arcs and circles, in contrast to the intelligent contextual semantic of BIM models, where objects are defined in terms of building elements and systems such as spaces, walls, beams and columns. A building information model carries all information related to the building, including its physical and functional characteristics and project life cycle information, in a series of "smart objects". For example, an air conditioning unit within a BIM would also contain data about its supplier, operation and maintenance procedures, flow rates and clearance requirements (CRC Construction Innovation, 2007). Figure 2 shows a comparison between the conventional CAD and the 'new' BIM approach.



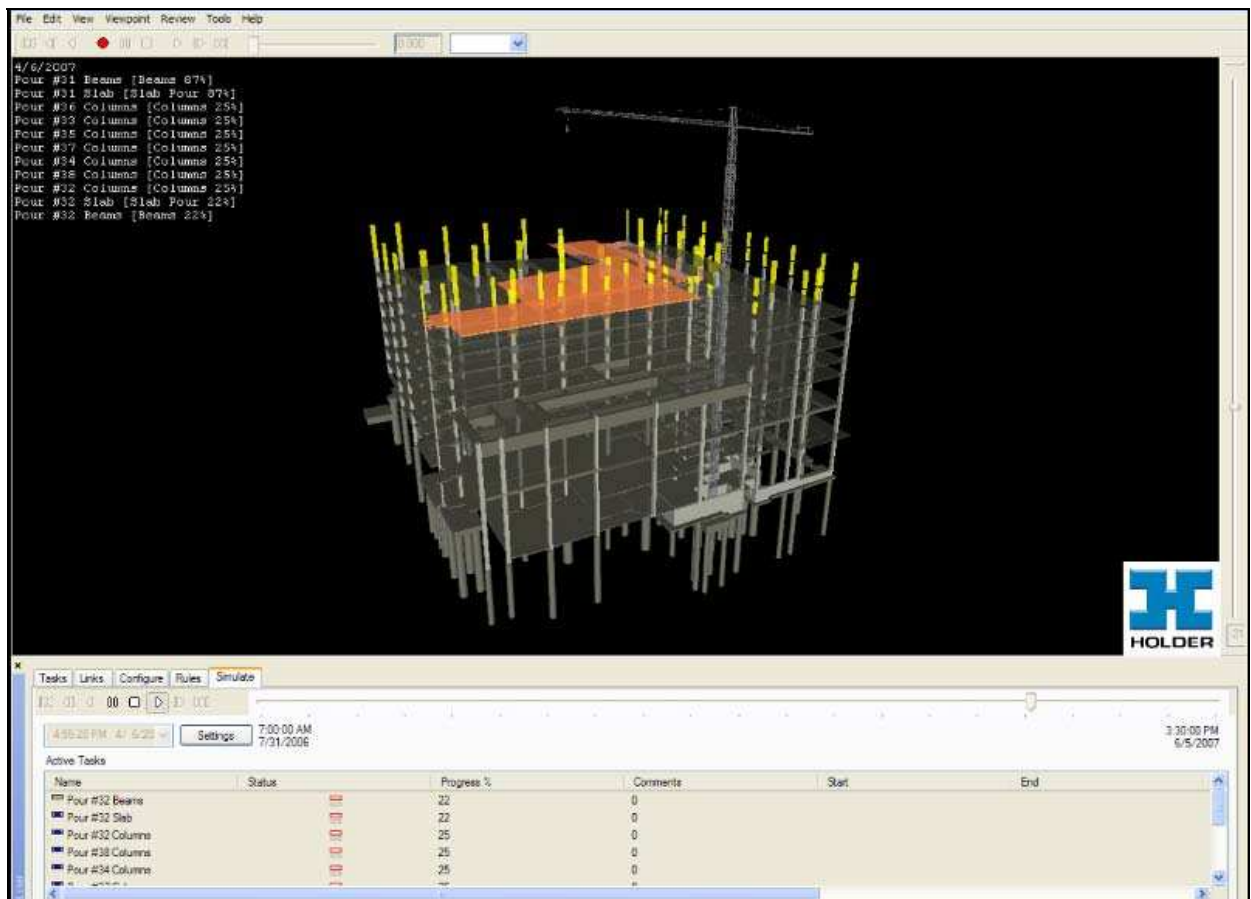
(a) Architectural Model



(b) Structural Model



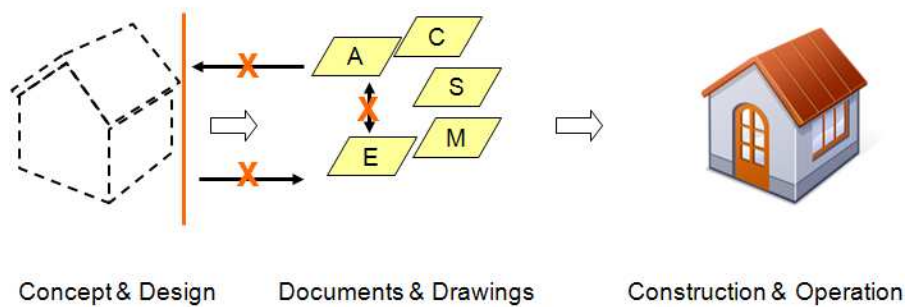
(c) Plumbing Model



(d) 4D Phasing Model (i.e 3D Model + Schedule)

Figure 1: Building Information Modeling for Hilton Aquarium, Atlanta, Georgia, USA
(Courtesy of: Holder Construction, Atlanta, Georgia, USA)

'Old' Process: CAD



'New' Process: BIM

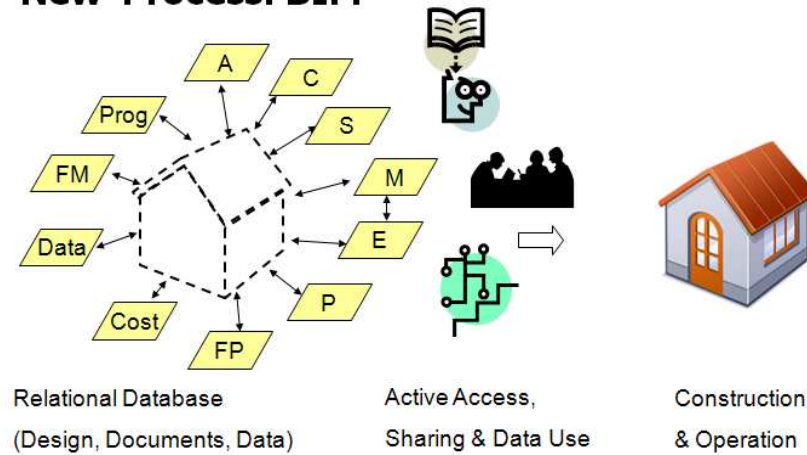


Figure 2: A Comparison between Conventional CAD and new BIM Approach

It is important to note that a building information model characterizes the geometry, spatial relationships, geographic information, quantities and properties of building elements, cost estimates, material inventories and project schedule. This model can be used to demonstrate the entire building life cycle (Bazjanac, 2006). As a result, quantities and shared properties of materials can be readily extracted. Scopes of work can be easily isolated and defined. Systems, assemblies, and sequences can be shown in a relative scale with the entire facility or group of facilities. The construction documents such as the drawings, procurement details, submittal processes and other specifications can be easily interrelated.

A building information model can be used for the following purposes:

- *Visualization*: 3D renderings can be easily generated in-house with little additional effort.
- *Fabrication/shop drawings*: it is easy to generate shop drawings for various building systems, e.g, the sheet metal ductwork shop drawing can be quickly produced once the model is complete.
- *Code reviews*: fire departments and other officials may use these models for building projects review.
- *Forensic analysis*: a building information model can easily be adapted to graphically illustrate potential failures, leaks, evacuation plans, etc.
- *Facilities management*: facilities management departments can use BIM for renovations, space planning, and maintenance operations.
- *Cost estimating*: BIM software(s) have built-in cost estimating features. Material quantities are automatically extracted and changed when any changes are made in the model.
- *Construction sequencing*: a building information model can be effectively used to create material ordering, fabrication, and delivery schedules for all building components.
- *Conflict, interference and collision detection*: because BIM models are created, to scale, in 3D space, all major systems can be visually checked for interferences. This process can verify that piping does not intersect with steel beams, ducts or walls as shown in Figure 3.

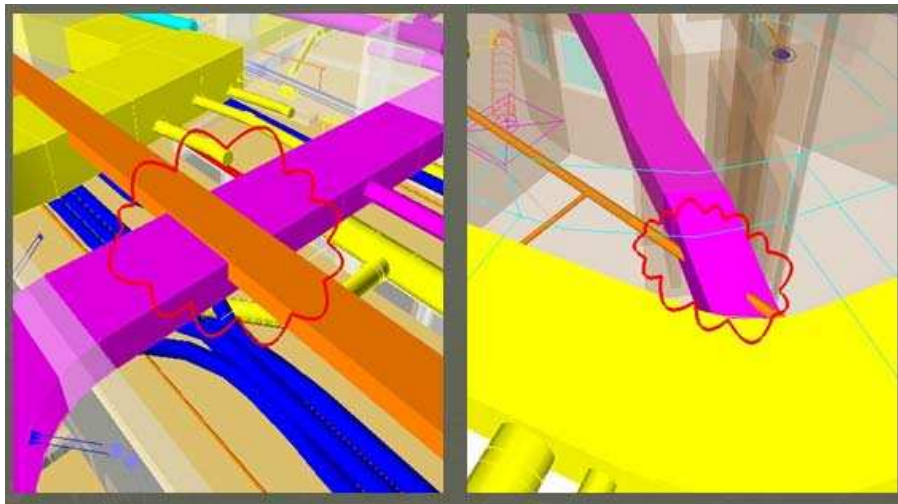


Figure 3: An Illustration of Clash Detections via Building Information Modeling
(Courtesy of: PCL Construction Services, Orlando, Florida, USA)

2. Building Information Modeling (BIM) Benefits

The key benefit of BIM is its accurate geometrical representation of the parts of a building in an integrated data environment (CRC Construction Innovation, 2007). Other related benefits are:

- *Faster and more effective processes* – information is more easily shared, can be value-added and reused.
- *Better design* – building proposals can be rigorously analyzed, simulations can be performed quickly and performance benchmarked, enabling improved and innovative solutions.
- *Controlled whole-life costs and environmental data* – environmental performance is more predictable, lifecycle costs are better understood.
- *Automated assembly* – digital product data can be exploited in downstream processes and be used for manufacturing/assembling of structural systems.
- *Better customer service* – proposals are better understood through accurate visualization.
- *Lifecycle data* – requirements, design, construction and operational information can be used in facilities management.

Stanford University Center for Integrated Facilities Engineering (CIFE) figures based on 32 major projects using BIM indicates benefits such as (CIFE, 2007):

- Up to 40% elimination of unbudgeted change.
- Cost estimation accuracy within 3%.
- Up to 80% reduction in time taken to generate a cost estimate.
- A savings of up to 10% of the contract value through clash detections.
- Up to 7% reduction in project time.

3. How to Develop a Building Information Model?

There are a number of BIM software applications available in the market. The top three softwares are as follows:

- Autodesk® Revit™
- Graphisoft® Constructor™
- Bentley® Architecture™

After discussion with different AEC companies, vendors and some self-testing, the authors picked Autodesk® Revit™ as their first choice. The Revit™ software package includes three software applications: Revit™ Architecture, Revit™ MEP, and Revit™ Structure. Revit™ Architecture has the 2-D capabilities of AutoCAD, as well as the 3-D modeling design functions. AutoCAD files can be imported to produce models. For estimating functions, information can be exported to other estimating programs which have been designed to work with Revit™ Architecture. Revit™ MEP is used for the design and modeling of mechanical/electrical/plumbing systems. Revit™ Structure is a modeling and drafting program that can model all types of materials and structural systems. All of the Revit™ programs use a centralized database so all changes are updated universally.

4. Case Studies

The purpose of the case studies is to illustrate various tangible and intangible benefits achieved by developing and using building information models for actual construction projects. The data for these case studies is provided by the Holder Construction Company, Atlanta, Georgia.

4a. Case Study 1: Hilton Aquarium, Atlanta, Georgia

Project name: Hilton Aquarium, Atlanta, Georgia

Project scope: \$46M, 484,000 SF hotel and parking structure

Delivery method: Construction manager at risk

Contract type: Guaranteed maximum price

Design assist: GC and subcontractors on board at design definition phase

BIM scope: Design coordination, clash detection, and work sequencing

A building information model is created comprising of the architectural, structural and MEP systems of the proposed building as shown in Figures 1a, 1b and 1c. The model was created during the design development phase using detail level information from subcontractors based on drawings from the designers. Using this model, the project team achieved the following benefits.

- Proactively identified 590 conflicts between structural and MEP components and resolved them prior to field installations
- Design coordination enhanced
- Additional cost increases avoided
- Enabled Owner scope revisions without issuing change orders
- Accommodated design changes

As show in Figure 4, through frequent coordination sessions, the project team was able to quickly identify and resolve system conflicts, saving an estimated \$200,000 in extras and avoiding months of potential delays

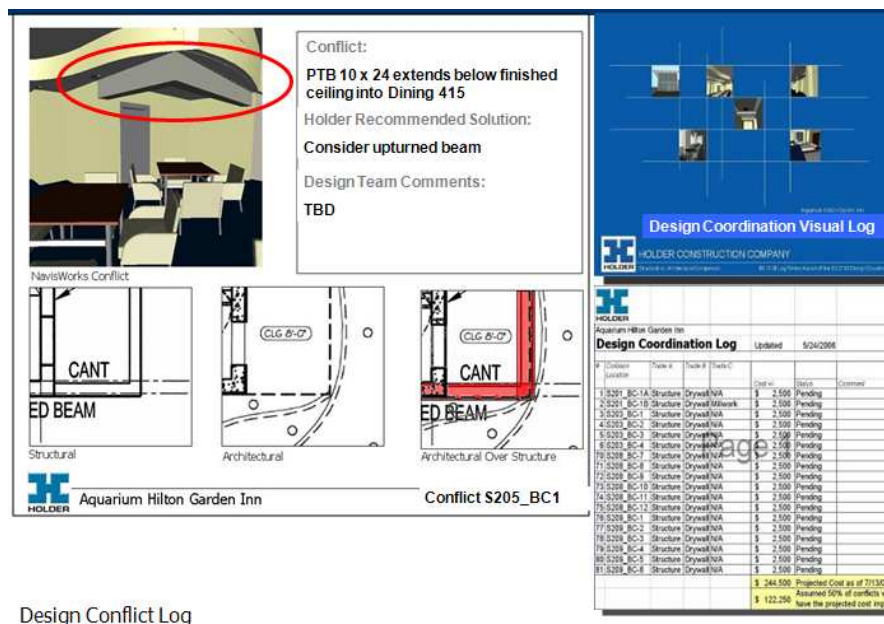


Figure 4: Virtual Examination of the Construction Models and Pre-construction Planning
(Courtesy of: Holder Construction, Atlanta, Georgia, USA)

4b. Case Study 2: One Island East Project, Hong Kong

This case study documents the implementation of BIM to manage the functional and financial relationships between design, construction, and facility management on a large, complex project by an owner-developer. The owner identified the potential of BIM to manage information more efficiently and save time and cost over the project life cycle. The brief project data is as follows:

Project name: One Island East, Hong Kong, China
Project scope: \$300M, 1,517,711 SF commercial building
Structure: Reinforced concrete
Exterior: Aluminum curtain wall
Owner: Swire Properties Limited
Contractor: Gammon Construction Limited
BIM scope: Design coordination, clash detection, and work sequencing

The One Island East (OIE) is a large commercial office building with seventy floors. Figure 5 shows a building information model of this facility.

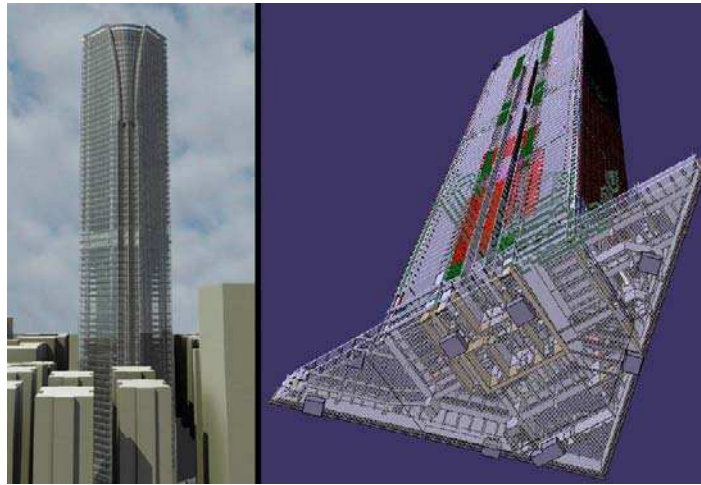


Figure 5: Building Information Model of One Island East (OIE) Project
 (Courtesy of: Gammon Construction Limited, Hong Kong)

Almost all coordination issues were managed using BIM. As shown in Figures 6-9, through BIM, over 2000 clashes and errors were identified prior to bidding and construction, which means that a substantial cost savings was achieved, compared to the incomplete design information inherent in a traditional 2D process.

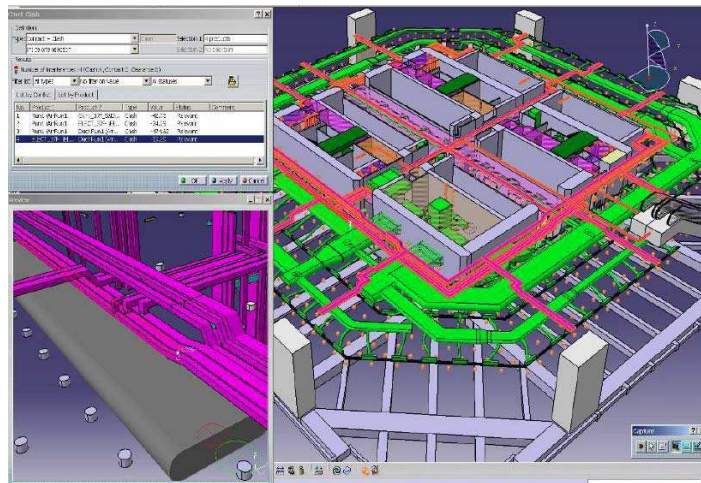
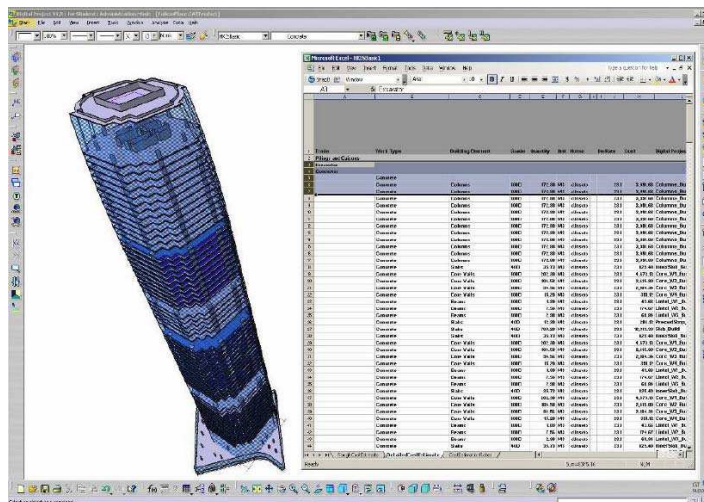
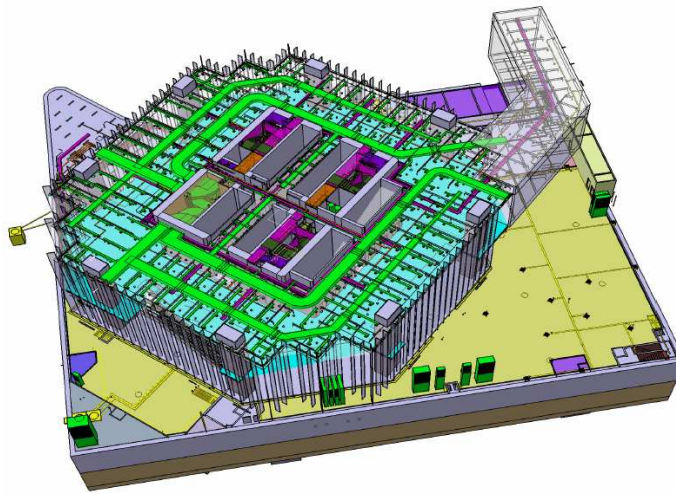


Figure 6: Automated Clash Detections in OIE Project (Gammon Construction Ltd, HK)



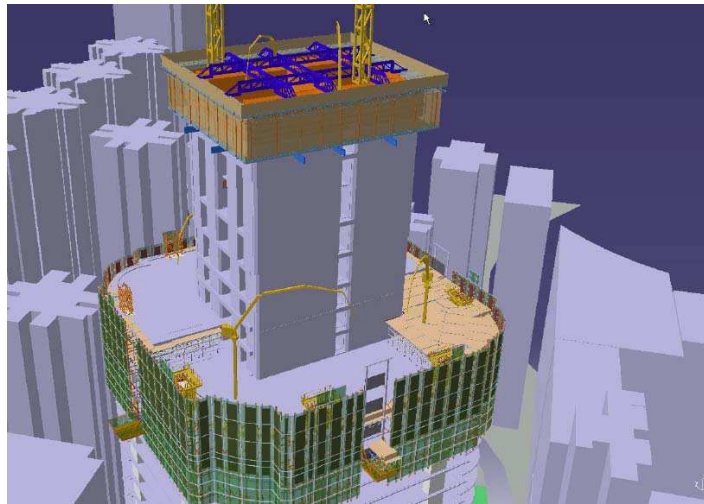


Figure 9: Construction Sequencing Model (Gammon Construction Ltd, HK)

5. Legal and Technical Risks Associated with Building Information Modeling

The first legal risk to determine is ownership of the BIM data and how to protect it through copyright laws. For example, if the owner is paying for the design, then the owner may feel entitled to own it, but if team members are providing proprietary information for use on the project, their propriety information needs to be protected as well. Thus, there is no simple answer to the question of data ownership; it requires a unique response to every project depending on the participants' needs. The goal is to avoid inhibitions that discourage participants from fully realizing the model's potential (Thompson, 2001).

Another issue to address is who will control the entry of data into the model and be responsible for any inaccuracies in it. Taking responsibility for updating BIM data and ensuring its accuracy entails a great deal of risk. Requests for complicated indemnities by BIM users and the offer of limited warranties and disclaimers of liability by designers will be essential negotiation points that need to be resolved before BIM technology is utilized. It also requires more time spent imputing and reviewing BIM data, which is a new cost in the design and project administration process. Although these new costs may be more than offset by efficiency and schedule gains, they are still a cost that someone on the project team will have to bear. Thus, before BIM technology can be fully utilized, the risks of its use must not only be identified and allocated, but the cost of its implementation must be paid for as well (Thompson and Miner, 2007).

The integrated concept of BIM blurs the level of responsibility so much that risk and liability will likely be enhanced. Consider the scenario where the owner of the building files suit over a perceived design error. The architect, engineers and other contributors of the BIM process look to each other in an effort to try to determine who had responsibility for the matter raised. If disagreement ensues, the lead professional will not only be responsible as a matter of law to the claimant but may have difficulty proving fault with others such as the engineers (Rosenburg, 2007).

6. Future Challenges

The productivity and economic benefits of BIM to the AEC industry are widely acknowledged and increasingly well understood. Further, the technology to implement BIM is readily available and rapidly maturing. Yet, BIM adoption is much slower than anticipated (Fischer and Kunz, 2006). There are two main reasons, *technical* and *managerial*.

The technical reasons can be broadly classified into three categories (Bernstein and Pittman, 2005):

1. the need for well-defined transactional construction process models to eliminate data interoperability issues,
2. the requirements that digital design data be computable, and
3. the need for well-developed practical strategies for the purposeful exchange and integration of meaningful information among the BIM model components.

The management issues cluster around the implementation and use of BIM. Right now, there is no clear consensus as how to implement or use BIM. Unlike many other construction practices, there is no single document or treatise on BIM that instructs on its application or usage (AGC, 2005). Several software firms are cashing in on the “buzz” of BIM, and have programs to address certain quantitative aspects of it, but they do not treat the process as a whole. There is a need to standardize the BIM process and to define the guidelines for its implementation. Another contentious issue among the AEC industry stakeholders (i.e. owners, designers and constructors) is who should develop and operate the building information models and how should the developmental and operational costs be distributed?

The researchers and practitioners have to develop suitable solutions to overcome these challenges and other associated risks. As a number of researchers, practitioners, software vendors and professional organizations are working hard to resolve these challenges, it is expected that the use of BIM will continue to increase in the AEC industry (Azhar et al., 2008).

7. Concluding Remarks

Building Information Modeling (BIM) has emerged as an innovative way to manage projects. Many researchers and practitioners have indicated that the BIM technology is set to become as indispensable to building design and construction as the proverbial tee square or hammer and nail. As the use of BIM accelerates, collaboration within project teams should increase, which will lead to improved profitability, reduced costs, better time management and improved customer/client relationships. On the other hand, teams implementing BIM should be very careful about the legal pitfalls such as data ownership and associated propriety issues and risk sharing. Such issues must be addressed upfront in the contract documents.

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