Building Information Modeling (BIM): Benefits, Risks and Challenges

Salman Azhar, Michael Hein and **Blake Sketo**
McWhorter School of Building Science
Auburn University
Auburn, Alabama

Building Information Modeling (BIM) has recently attained widespread attention in the Architectural, Engineering and Construction (AEC) industry. 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 problems. In this paper, the benefits and possible risks of BIM and future challenges for the construction industry are discussed. First presented is the main concept of BIM with its advantages and possible applications in construction. Then the role of BIM in the construction industry and academia is discussed based on the results of three recent questionnaire surveys. After that, a case study of Hilton Aquarium project in Atlanta is presented to quantitatively illustrate the cost and time savings realized by developing and using a building information model. It is followed by data from 10 construction projects to determine the net BIM savings and BIM return on investment. At the end, BIM risks and future challenges for the construction industry are discussed.

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

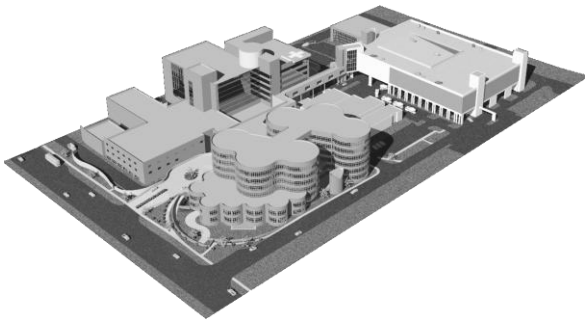
Introduction

Building Information Modeling (BIM) represents the process of development and use of a computer generated model to simulate the planning, design, construction and operation of a facility as shown in Figure 1. The resulting model, 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).

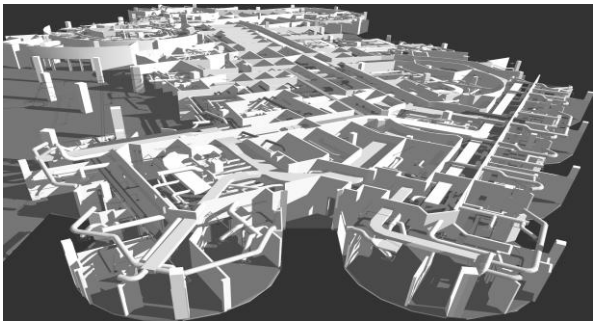
The principal difference between BIM and 2D CAD is that the latter describes a building by independent 2D views such as plans, sections and elevations. Editing one of these views requires that all other views must be checked and updated, an error-prone process that is one of the major causes of poor documentation. In addition, data in these 2D 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 (CRC Construction Innovation, 2007).

A BIM 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

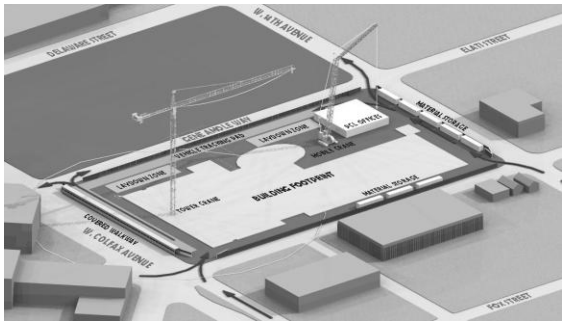
air conditioning unit within a BIM would also contain data about its supplier, operation and maintenance procedures, flow rates and clearance requirements (CRC Construction Innovation, 2007).



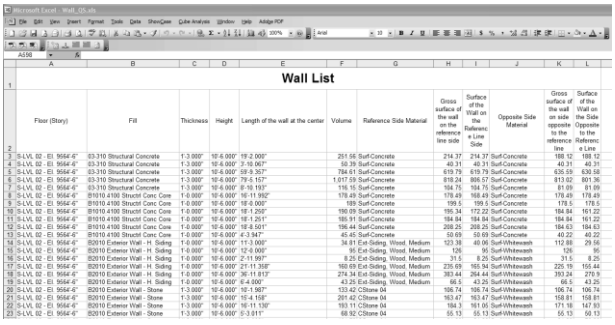
(a) 3D Architectural Model



(b) Integrated Sturcutral and MEP Model



(c) Site Logistic Planning Model



Wall List

Floor (Story)	Fill	Thickness	Height	Length of the wall at the center	Volume	Reference Side Material	Gross surface of the wall on the reference line side	Surface of the Wall on the Reference Line Side	Opposite Side Material	Gross surface of the wall on side opposite to the reference line	Surface of the Wall on the Side Opposite to the Reference Line
S-LVL 02 - El. 9564'-6"	03-310 Structural Concrete	1'-3.000"	10'-6.000"	19'-2.000"		251.56 Surf-Concrete	214.37	214.37 Surf-Concrete		188.12	188.12
S-LVL 02 - El. 9564'-6"	03-310 Structural Concrete	1'-3.000"	10'-6.000"	3'-10.067"		50.39 Surf-Concrete	40.31	40.31 Surf-Concrete		40.31	40.31
S-LVL 02 - El. 9564'-6"	03-310 Structural Concrete	1'-3.000"	10'-6.000"	59'-9.357"		784.61 Surf-Concrete	619.79	619.79 Surf-Concrete		635.59	630.58
S-LVL 02 - El. 9564'-6"	03-310 Structural Concrete	1'-3.000"	10'-6.000"	79'-5.157"		1,017.59 Surf-Concrete	818.24	806.57 Surf-Concrete		813.02	801.36
S-LVL 02 - El. 9564'-6"	03-310 Structural Concrete	1'-3.000"	10'-6.000"	8'-10.193"		116.15 Surf-Concrete	104.75	104.75 Surf-Concrete		81.09	81.09
S-LVL 02 - El. 9564'-6"	B1010.4100 Structl Conc Core	1'-0.000"	10'-6.000"	16'-11.992"		178.49 Surf-Concrete	178.49	168.49 Surf-Concrete		178.49	178.49
S-LVL 02 - El. 9564'-6"	B1010.4100 Structl Conc Core	1'-0.000"	10'-6.000"	18'-0.000"		189 Surf-Concrete	199.5	199.5 Surf-Concrete		178.5	178.5
S-LVL 02 - El. 9564'-6"	B1010.4100 Structl Conc Core	1'-0.000"	10'-6.000"	18'-1.250"		190.09 Surf-Concrete	199.34	172.22 Surf-Concrete		184.84	161.22
S-LVL 02 - El. 9564'-6"	B1010.4100 Structl Conc Core	1'-0.000"	10'-6.000"	18'-1.251"		185.91 Surf-Concrete	184.84	184.84 Surf-Concrete		184.84	161.22
S-LVL 02 - El. 9564'-6"	B1010.4100 Structl Conc Core	1'-0.000"	10'-6.000"	18'-8.581"		196.44 Surf-Concrete	208.25	208.25 Surf-Concrete		184.63	184.63
S-LVL 02 - El. 9564'-6"	B1010.4100 Structl Conc Core	1'-0.000"	10'-6.000"	4'-3.947"		45.45 Surf-Concrete	50.69	50.69 Surf-Concrete		40.22	40.22
S-LVL 02 - El. 9564'-6"	B2010 Exterior Wall - H. Siding	1'-0.000"	10'-6.000"	11'-3.000"		34.81 Ext-Siding, Wood, Medium	123.38	40.06 Surf-Whitewash		112.88	29.56
S-LVL 02 - El. 9564'-6"	B2010 Exterior Wall - H. Siding	1'-0.000"	10'-6.000"	12'-0.000"		90 Ext-Siding, Wood, Medium	126	95 Surf-Whitewash		126	95
S-LVL 02 - El. 9564'-6"	B2010 Exterior Wall - H. Siding	1'-0.000"	10'-6.000"	2'-11.997"		8.25 Ext-Siding, Wood, Medium	31.5	8.25 Surf-Whitewash		31.5	8.25
S-LVL 02 - El. 9564'-6"	B2010 Exterior Wall - H. Siding	1'-0.000"	10'-6.000"	21'-11.359"		160.69 Ext-Siding, Wood, Medium	235.69	165.94 Surf-Whitewash		225.19	155.44
S-LVL 02 - El. 9564'-6"	B2010 Exterior Wall - H. Siding	1'-0.000"	10'-6.000"	36'-11.813"		274.34 Ext-Siding, Wood, Medium	383.44	264.44 Surf-Whitewash		393.24	270.9
S-LVL 02 - El. 9564'-6"	B2010 Exterior Wall - H. Siding	1'-0.000"	10'-6.000"	6'-4.000"		43.25 Ext-Siding, Wood, Medium	66.5	43.25 Surf-Whitewash		66.5	43.25
S-LVL 02 - El. 9564'-6"	B2010 Exterior Wall - Stone	1'-3.000"	10'-6.000"	10'-1.987"		133.42 CStone 04	106.74	106.74 Surf-Whitewash		106.74	106.74
S-LVL 02 - El. 9564'-6"	B2010 Exterior Wall - Stone	1'-3.000"	10'-6.000"	10'-4.158"		201.42 CStone 04	163.47	163.47 Surf-Whitewash		158.81	158.81
S-LVL 02 - El. 9564'-6"	B2010 Exterior Wall - Stone	1'-3.000"	10'-6.000"	16'-11.139"		193.11 CStone 04	184.3	161.66 Surf-Whitewash		171.16	147.93
S-LVL 02 - El. 9564'-6"	B2010 Exterior Wall - Stone	1'-3.000"	10'-6.000"	5'-3.011"		68.92 CStone 04	55.13	55.13 Surf-Whitewash		55.13	50.13

(d) Quantiy Estimates

Figure 1: Different Components of a Building Information Model
(Courtsey of: PCL Construction Services, Orlando, FL)

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 (Khemlani *et al.*, 2006).

BIM Applications

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, for example, 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 their review of building projects.
- *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.

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.
- *Better production quality* – documentation output is flexible and exploits automation.
- *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.

Role of BIM in the Construction Industry and Academia

In this section, the role of BIM in the US construction industry and academia is discussed based on the results of three questionnaire surveys. The main findings of these surveys are:

Survey 1: Value from BIM Use

Kunz and Giligan (2007) conducted a questionnaire survey to determine the value from virtual design and construction (VDC) or BIM use and factors that contribute to success. The main findings of their study are as follows:

- The use of BIM is significantly increased across all phases of design and construction during the last one year.
- BIM users represent all segments of the design and construction industry and they operate throughout the US.
- The major application areas of BIM are, construction document development, conceptual design support and pre-project planning services.
- The use of BIM lowers overall risk distributed with a similar contract structure.
- At present, most companies use BIM for 3D/4D clash detections and for planning and visualization services.
- The use of BIM leads to increased productivity, better engagement of project staff and reduced contingencies.
- Currently there is a shortage of competent building information modelers in the construction industry and their demand will exponentially grow with the passage of time.

Survey 2: Top Criteria for BIM Solutions

This survey was conducted by Khemlani (2007) and the results were published in the October 2007 issue of AECbytes newsletter. The main objective of the survey was to identify the most important requirements that AEC professionals would like BIM solutions (software) to satisfy. Based on the compiled results, the 10 most important requirements were found to be:

- Full support for producing construction documents so that another drafting application need not be used.
- Smart objects, which maintain associativity, connectivity, and relationships with other objects.
- Availability of object libraries.
- Ability to support distributed work processes, with multiple team members working on the same project.
- Quality of help and supporting documentation, tutorials, and other learning resources.
- Ability to work on large projects.
- Multi-disciplinary capability that serves architecture, structural engineering, and MEP.
- Ability to support preliminary conceptual design modeling.
- Direct integration with energy analysis, structural analysis and project management applications.
- Industry foundation classes (IFC) compatibility.

She concluded that the AEC industry is still very much reliant on drawings for conducting its business of designing and constructing buildings as evident from the survey results. At the same time, AEC professionals also realize the power of BIM for more efficient and intelligent

modeling by placing a high premium on smart objects that maintain associativity, connectivity, and relationships with other objects and the availability of object libraries. She pointed out that users want a BIM application that not only leverages the powerful documentation and visualization capabilities of a CAD platform but also support multiple design and management operations. BIM as a technology is still in its formative stage and solutions in the market are continuing to evolve as they respond to user's specific needs.

Survey 3: BIM: An Education Need?

Dean (2007) carried out a research study to examine if BIM should be taught as a subject to the construction management students. He conducted two questionnaire surveys targeted at general contractors and ASC construction management programs in the Southeast. Based on the gathered data, he concluded in general that construction management programs should teach BIM to their students. The main reasons behind this conclusion were:

- Approximately 70% of the industry participants indicated that they are either using or considering to use BIM in their companies. This trend indicates that the BIM utilization in the construction industry is going to increase.
- Approximately 75% of survey participants consider employment candidates with BIM skills to have an advantage over candidates who lack BIM knowledge.

In another study, Woo (2006) pointed out that properly structured BIM courses would provide industry-required knowledge to prepare students for successful careers in the AEC industry. Instead of teaching a separate course, he suggested to reconfigure the existing construction courses to integrate BIM into the course contents.

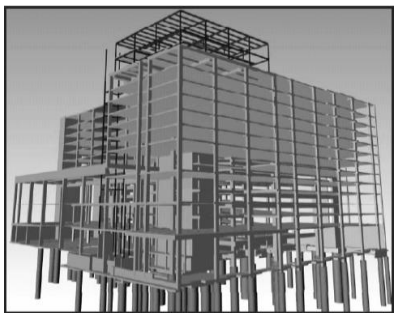
BIM Benefits: A Case Study

In the above mentioned surveys, the construction industry participants were unanimous that BIM usage results in time and cost savings. However, no data was provided to quantify these facts. The purpose of this case study is to illustrate the cost and time savings realized by developing and using a building information model for an actual construction project. The data for this case study is provided by Holder Construction Company, Atlanta, Georgia. The project details are as follows:

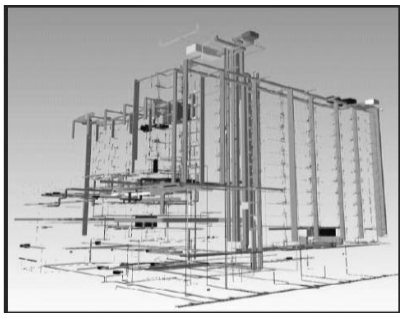
Project name: Hilton Aquarium, Atlanta, Georgia
Project scope: $46M, 484,000 SF hotel and parking structure
Delivery method: Construction manager at risk
Contract type: Guaranteed maximum price
Design assist: GC and subcontractors on board at design definition phase
BIM scope: Design coordination, clash detection, and work sequencing
File sharing: Navisworks used as common platform
BIM cost to project: $90,000 - 0.2% of project budget ($40,000 paid by owner)
Cost benefit: $600,000 attributed to elimination of clashes
Schedule benefit: 1143 hours saved

Holder Construction created 3D models of the architectural, structural and MEP systems of the proposed building as shown in Figure 2. These models were created during the design development phase using detail level information from subcontractors based on drawings from the designers.

(a) Architectural Model



(b) Structural Model



(c) Plumbing Model

Figure 2: Building Information Modeling for Hilton Aquarium, Atlanta, GA
(Courtesy of: Holder Construction, Atlanta, GA)

This method allowed project team members to perform their work in the comfort of their traditional 2D, drawing-based delivery process and eliminated the potential risk that is often associated with open sharing of digital models across stakeholders. Through frequent 3D coordination sessions, the project team was able to quickly identify and resolve system conflicts, saving an estimated $600,000 in extras and avoiding months of potential delays as shown in Table 1.

Table 1: An Illustration of Cost and Time Savings via BIM in Hilton Aquarium Project
(Courtesy of: Holder Construction, Atlanta, GA)

Collision Phase	Collisions	Estimated Cost Avoided	Estimated Crew Hours		Coordination Date
100% Design Development Conflicts	55	$124,500	NIC		*June 30, 2006*
Construction (MEP Collisions)					
Basement	41	$21,211	50	hrs	*March 28, 2007*
Level 1	51	$34,714	79	hrs	*April 3, 2007*
Level 2	49	$23,250	57	hrs	*April 3, 2007*
Level 3	72	$40,187	86	hrs	*April12, 2007*
Level 4	28	$35,276	68	hrs	*May 14, 2007*
Level 5	42	$43,351	88	hrs	*May 29, 2007*
Level 6	70	$57,735	112	hrs	*June 19, 2007*
Level 7	83	$78,898	162	hrs	*April 12, 2007*
Level 8	29	$37,397	74	hrs	*July 3, 2007*
Level 9	30	$37,397	74	hrs	*July 3, 2007*
Level 10	31	$33,546	67	hrs	*July 5, 2007*
Level 11	30	$45,144	75	hrs	*July 5, 2007*
Level 12	28	$36,589	72	hrs	*July 5, 2007*
Level 13	34	$38,557	77	hrs	*July 13, 2007*
Level 14	1	$484	1	hrs	*July 13, 2007*
Level 15	1	$484	1	hrs	*July 13, 2007*
Subtotal Construction Labor	590	$564,220	1143	hrs	
20% MEP Material Value		$112,844			
Subtotal Cost Avoidance		**$801,565**			
Deduct 75% assumed resolved via conventional methods		($601,173)			
Net Adjusted Direct Cost Avoidance		**$200,392**			

During the construction process, non-BIM-savvy stakeholders made use of Holder's visualization models through a free viewer (i.e. Navisworks). The collaborative 3D viewing sessions also improved communications and trust between stakeholders and enabled rapid decision making early in the process. Finally, Holder's commitment to updating the model to reflect as-built conditions provided the owner, Legacy Pavilion, LLC, a digital 3D model of the building and its various systems to help aid O&M procedures down the road (CIFE, 2007).

BIM Economics: Net Savings and Return on Investment

Data from 10 selected US based projects is presented in Table 2 to illustrate the net BIM savings and BIM return on investment (ROI).

Table 2: BIM Economics (CIFE, 2007)

Year	Cost ($M)	Project	BIM Cost ($)	Direct BIM Savings ($)	Net BIM savings	BIM ROI (%)
2005	30	Ashley Overlook	5,000	(135,000)	(130,000)	2600
2006	54	Progressive Data Center	120,000	(395,000)	(232,000)	140
2006	47	Raleigh Marriott	4,288	(500,000)	(495,712)	11560
2006	16	GSU Library	10,000	(74, 120)	(64,120)	640
2006	88	Mansion on Peachtree	1,440	(15,000)	(6,850)	940
2007	47	Aquarium Hilton	90,000	(800,000)	(710,000)	780
2007	58	1515 Wynkoop	3,800	(200,000)	(196,200)	5160
2007	82	HP Data Center	20,000	(67,500)	(47,500)	240
2007	14	Savannah State	5,000	(2,000,000)	(1,995,000)	39900
2007	32	NAU Sciences Lab	1,000	(330,000)	(329,000)	32900

As evident from Table 2, the BIM return on investment (ROI) for different projects varies from 140% to 39900%. Due to the large data spread, it is hard to conclude a specific range for BIM ROI. The probable reason for this spread is varying scope of BIM in different projects. In some projects, BIM savings were measured using 'real' construction phase 'direct' collision detection cost avoidance, and in other projects, savings were computed using 'planning' or 'value analysis' phase cost avoidance. Also, note that none of these cost figures account for indirect, design, construction or owner administrative or other 'second wave' cost savings that were realized as a result of BIM implementation. Hence the actual BIM ROI can be far greater than reported here.

BIM Risks

The first legal risk to determine is ownership of the BIM data and how to protect it through copyright and other 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 or disincentives that discourage participants from fully realizing the model's potential (Thompson, 2001).

When project team members, other than the owner and A/E, contribute data that is integrated into the BIM, licensing issues can arise. For example, equipment and material vendors offer designs associated with their products for the convenience of the lead designer in hopes of inducing the designer to specify the vendor's equipment. While this practice might be good for business, licensing issues can nevertheless arise if the vendor's design was produced by a designer not licensed in the location of the project (Thompson and Miner, 2007).

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).

As the dimensions of cost and schedule are layered onto the 3D model, responsibility for the proper technological interface among various programs becomes an issue. Many sophisticated contracting teams require subcontractors to submit detailed CPM schedules and cost breakdowns itemized by line items of work prior to the start of the project. The general contractor then compiles that data, creating a master schedule and cost breakdown for the entire project. When the subcontractors and prime contractor use the same software, the integration can be fluid. In cases where the data is incomplete or is submitted in a variety of scheduling and costing programs, a team member - usually a general contractor or construction manager must re-enter and update a master scheduling and costing program. That program may be a BIM module or another program that will be integrated with the 3-D model. At present, most of these project management tools and the 3-D models have been developed in isolation. Responsibility for the accuracy and coordination of cost and scheduling data must be contractually addressed (Thompson and Miner, 2007).

BIM 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.

In the past facilities managers have been included in the building planning process in a very limited way, implemented maintenance strategies based on the as-built condition at the time the owner takes possession. BIM modeling may allow facilities managers to enter the picture in the future at a much earlier stage, where they can influence the design and construction. The visual nature of the BIM allows all stakeholders to get important information before the building is completed. This includes tenants, service agents as well as maintenance personnel. Finding the right time to include these people will undoubtedly be a challenge for owners.

Conclusions

Building Information Modeling (BIM) is emerging as an innovative way to manage projects. Building performance and predictability of outcomes are greatly improved by adopting BIM. 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. As shown in this paper, average BIM return on investment is 9486%, which clearly depicts its lucrative economic benefits. 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. BIM represents a

new paradigm within AEC, one that encourages integration of the roles of all stakeholders on a project. This 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. As in most paradigm shifts there will undoubtedly be risks associated with this change. Perhaps one of the greatest risk is the potential elimination of an important checks and balance mechanism inherent in the current paradigm. An adversarial stance often brings a more critical review of the project in a kind of mutual guarding of their own interests among the participants. In the early stages of BIM, constructors worked from architectural plans since digital models were not shared by architects with contractors. The construction modelers inevitably discovered errors and inconsistencies in the plans as they created the BIM. This brought about a natural redundancy as the construction model put the design to this virtual building test. With a more trustful sharing of architectural drawings, which can be easily be imported and serve as the basis for the BIM model, there may be a loss of this critical checking phase. In other words when all players see themselves on the same team they may cease to look for and find mistakes in each other's work. In the past, a lack of critical review has been at least one of the component ingredients of building failure.

Disclaimer

The opinions and recommendations expressed in this paper are the authors' personal opinions and do not necessarily represent the official position of any participating organization.

Acknowledgements

The authors would like to express their gratitude to *Mr. Paul Hedgepath,* Holder Construction Company, Atlanta, GA and *Mr. Christopher Ritter,* PCL Construction Services, Orlando, FL for providing necessary data and feedback. This study is supported by the *Faculty Mentoring Grant* provided by the Office of the Vice-President for Research at Auburn University, Alabama.

References

Associated General Contractors of America. (2005). *The Contractor's Guide to BIM*, 1st ed. AGC Research Foundation, Las Vegas, NV.

Bazjanac, V. (October 23, 2006). *Virtual Building Environments (VBE) – Applying Information Modeling to Buildings* [WWW document]. URL http://repositories.cdlib.org/lbnl/LBNL-56072

Bernstein, P.G., and Pittman, J.H. (2005). "Barriers to the Adoption of Building Information Modeling in the Building Industry". Autodesk Building Solutions Whitepaper, Autodesk Inc., CA.

CIFE. (November 22, 2007). *CIFE Technical Reports* [WWW document] URL http://cife.stanford.edu/Publications/index.html

CRC Construction Innovation. (2007). *Adopting BIM for Facilities Management: Solutions for Managing the Sydney Opera House,* Cooperative Research Center for Construction Innovation, Brisbane, Australia.

Dean, R. (2007). *Building Information Modeling (BIM): Should Auburn University Teach BIM to Building Science Students?* Graduate Capstone, Department of Building Science, Auburn University.

Fischer, M., and Kunz, J. (November 12, 2006). *The Scope and Role of Information Technology in Construction* [WWW document]. URL http://cife.stanford.edu/online.publications/TR156.pdf

Khemlani, L. (November 22, 2007). "Top Criteria for BIM Solutions", *AECbytes*, October issue [WWW document] URL http://www.aecbytes.com.

Khemlani, L.; Papamichael, K.; and Harfmann, A. (November 02, 2006). *The Potential of Digital Building Modeling* [WWW document]. URL http://www.aia.org/SiteObjects/files/potentialofdigital.pdf

Kunz, J., and Gilligan, B. (October 23, 2007). *Values from VDC/BIM Use* [WWW document]. URL http://cife.stanford.edu/VDCsurvey.pdf

Rosenburg, T.L. (2007). "Building Information Modeling." [WWW document] URL http://www.ralaw.com/resources/documents/Building%20Information%20Modeling%20-%20Rosenberg.pdf

Thompson, D.,B. (2001). "e-Construction: Don't Get Soaked by the Next wave." *The Construction Law Briefing Paper* [WWW document] URL http://www.minnlaw.com/Articles/68553.pdf

Thompson, D.B., and Miner, R.G. (November 23, 2007). "Building Information Modeling - BIM: Contractual Risks are Changing with Technology" [WWW document] URL http://www.aepronet.org/ge/no35.html

Woo, J. H. (2006). "BIM (Building Information Modeling) and Pedagogical Challenges". *Proceedings of the 43rd ASC National Annual Conference*, Flagstaff, AZ, April 12-14.