AC 2007-2900: BUILDING INFORMATION MODELING: A NEW FRONTIER FOR CONSTRUCTION ENGINEERING EDUCATION

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Building Information Modeling: A New Frontier for Construction Engineering Education

Building Information Models (BIM's) are 3D parametric, virtual representations of the built environment. These models can contain the same amount of information as present in an actual building. They are also capable of representing specific details to facilitate extended analysis as needed ahead of construction. For example, all the performance parameters of specific materials such as concrete masonry units or fabricated structural steel are linked to particular installations within the BIM. This allows for the possibility of integrated engineering design such as finite element analysis. Consequently, as BIM technology progresses and improves, it has important implications for the practical and educational aspects of construction engineering.

This paper explores the link between BIM implementation and onsite construction activity as experienced in a classroom setting. Starting with the design of a 36-unit multifamily residential project, students used BIM software to avoid conflict and enhance coordination ahead of actual construction. Live cost data were used to guide and inform the design process. This allowed students to make changes to building assemblies and components with an understanding of overall cost and schedule impact. Importantly, cross-discipline integration between design and construction dramatically decreased the time needed for cost estimating, planning and scheduling. It also facilitated reductions in consultant billings for specific civil, structural, and MEP design services.

Through a case study approach, this paper validates the use of Building Information Modeling as an integrated format for construction education. It demonstrates the advantage which a comprehensive interface can provide to an engineering student; one which depicts the integration between design and construction services. In such an environment, students are able to simultaneously comprehend both how the building is designed, and how it will be constructed. While additional research regarding the use of BIM's is underway by the authors, the findings contained herein point towards a larger role for its use in future projects and education.

Introduction

For centuries, the roles of architect and constructor were intertwined as 'master builder'. The knowledge of building materials and methods was implicit in the process of design. Indeed, innovations in buildings stemmed as much from creating new means of construction as they did from new building forms. Invariably, this tradition continued until the renaissance when the use of perspective representation and orthographic drawing was introduced. With these new forms of communicating information about buildings, the processes of building became increasingly legalistic, codified, complex and adversarial. In fact, today's standard AIA contracts state that "the architect will not be responsible for construction means, methods, techniques or procedures."[1] Fortunately, the introduction of Building Information Modeling (BIM) holds promise for ending the disassociation between constructing and designing, thereby paving the way for an increase in building innovations and the potential return of the 'master builder' role.

Software that allows for the three dimensional (3D) construction of a virtual building (i.e., BIM) will increasingly impact project delivery and the resulting interaction between architects, vendors, engineers and constructors. Due in part to redefined relationships between project stakeholders, BIM necessitates changes in education as well so that an integrated and consistent approach toward the built environment results as graduates enter the workforce. Yet, is BIM merely a tool to be taught and used to improve productivity while in school? Certainly, many schools of engineering, architecture, and construction are using BIM software already though questions remain regarding how it fits into curricula. Further, if students are to encounter the world of integrated design and construction once their course of study is complete, what are the components of an integrated construction education? Consequently, this paper addresses these questions through the lens of a case study which began in Fall 2006 at Texas State University and continues to the present. In addition, the authors demonstrate the importance of BIM as a new frontier for construction engineering education.

BIM requires an innovative approach to construction engineering education. In his 1985 book *Innovation and Entrepreneurship*, Peter Drucker outlined seven sources of opportunity for organizations in search of innovation[2]. Four sources come from inside the organization and three stem from the outside world. Each is listed in order of increasing difficulty and uncertainty:

- The unexpected success that is gratefully received but rarely dissected to see why it occurred
- The incongruity between what actually happens and what was supposed to happen
- The inadequacy in an underlying process that is taken for granted
- The changes in an industry or market structure that catch everyone by surprise
- The demographic changes caused by wars, medical improvements and even superstition
- The changes in perception, mood and fashion brought on by the ups and downs of the economy
- The changes in awareness caused by new knowledge

All are symptoms of change and, as such, serve as the template for this paper, its case study, and its projections regarding integrated practice. Accordingly, each source of innovation holds particular promise for the future of construction education.

The unexpected success that is gratefully received but rarely dissected to see why it occurred

Historically, the architecture, engineering, and construction (A/E/C) industry has embraced a performance equation wherein quality and scope are proportional to time and cost as can be seen in equation 1. Accordingly, if the scope of a building doubled, we would expect time and cost

$$\textbf{Quality} \times \textbf{Scope} = \textbf{Cost} \times \textbf{Time} \qquad \textbf{(eq. 1)}$$

to increase proportionally as well. However, given innovation, this equilibrium does not always hold true in the A/E/C industry. For example, Tulsa, Oklahoma-based BSW International pioneered an early form of BIM in 1986 known as a production work order using VisionAEL for their architecture and engineering work on 'big box' retail stores. Over 4,000 units later, they have demonstrated that cost and time can both decrease if the quality of contract documents (C/D's) and their accessibility are both improved (scope held constant)[3]. In fact, the number of C/D's was drastically reduced by BSW's PWO, thereby improving the clarity and confidence needed to construct each building. This seemingly counterintuitive finding is not dissimilar from the recent history of BIM in the shipbuilding and automotive industries[4], nor is it dissimilar from the authors' experience teaching at Texas State.

The authors were approached in August 2006 by the producer of a national cable TV show to design a student housing complex to be built in San Marcos, Texas as part of the capstone architectural design course in the construction program. The primary objective of the project's developer was to rapidly produce three executable designs for complexes consisting of nine individual buildings housing four units (i.e, 36 units) each at a target cost of $41 per square foot. As an incentive, the developer offered a $500 cash award for all members of the team judged to have achieved the best design from an aesthetic, functional, and financial perspective. Given a local construction cost of $74 per square foot for student housing, the ensuing competition sought to challenge the process by which the buildings would be designed and constructed. In this case, quality and scope would be held constant while every effort would be made to minimize project cost and time.

Figure 1. Winning team with project and award money.

The authors responded by establishing three teams of six students, each armed with Autodesk's Revit® v.9 BIM software. In addition, each team was assigned both a graduate student and a faculty mentor from the construction program to assist with estimating and project management, respectively. In most cases, teams possessed four construction students and two interior design students who were taking the course to complete their minor requirements. As a result, three well-rounded teams began and completed the competition during the course of the Fall 2006 semester. Following filmed presentations including animated walkthroughs, one team was selected as the winner for their project based on its design attributes and construction cost of $39 per square foot. This team can be seen with their project and award money in Figure 1. The initial target cost was successfully achieved, owing to the creativeness and background of the team paired with its particular implementation of BIM during the competition.

The incongruity between what actually happens and what was supposed to happen

Never before has a building representation tool been so demanding of its user. Indeed, the competent BIM operator must have an understanding of its use, knowledge of materials and construction methods, ability to think spatially, and good design sensibilities. Yet, these attributes only assist a student in competently engineering a building to accepted norms of performance (i.e., $74 per square foot in quantitative terms). Going beyond these parameters requires the ability to think critically and simultaneously about multiple aspects of an objective function in order to formulate a path forward toward a solution. In this case, the winning group developed a simple influence diagram as can be seen in Figure 2.

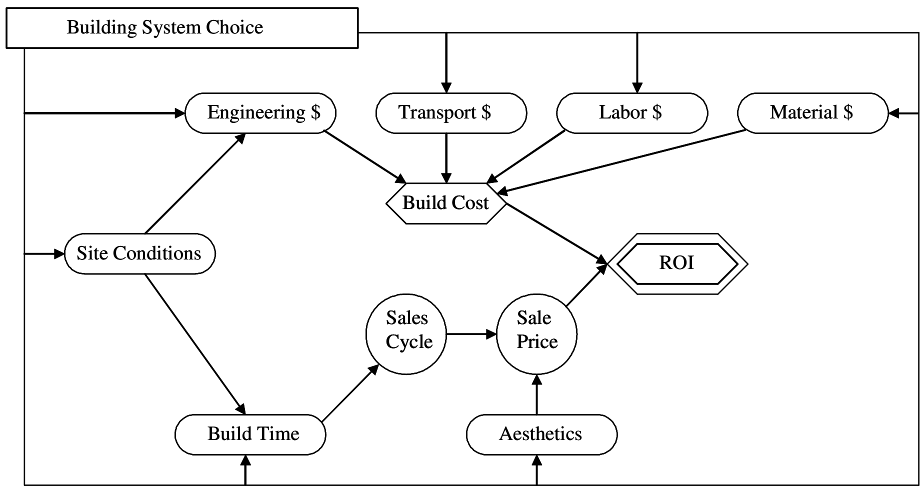

Figure 2. Influence diagram.

Instead of beginning design and then estimating its cost, each group first identified that a choice of building system was needed. One group selected a panelized approach, another chose a completely modular system, and the third elected to create an enclosed, onsite factory. Importantly, each team began with dedicated construction planning with a goal of reducing cost. As depicted in Figure 2, the winning group focused on maximizing ROI by both minimizing cost and maximizing the potential sales price of each unit. They figured out that the best design would be one that optimized the cost of transport, labor, and materials for their particular site. Without the construction means and methods knowledge inherent to each team, such planning would likely not have occurred. For each team, this knowledge drove the design and BIM implementation, ultimately resulting in unexpected, yet favorable, outcomes. Interestingly, the groups' resolve to use building systems technologies is supported by industry data as one third of housing starts in 2005 were projected to use these types of construction[5].

The inadequacy in an underlying process that is taken for granted

There are huge gaps in the existing process of construction through which information and understanding are lost at great cost. In fact, the annual cost of sub-optimal interoperability in the construction process has been estimated at $16 Billion[6]. This level of inefficiency and transactional cost is truly taken for granted, resulting in an adversarial situation where decision making is complex and bounded by numerous constraints. Fortunately, BIM provides numerous opportunities to remedy such inadequacy by streamlining communication and the transfer of technical content. BIM also can lead to new forms of collaboration, especially amongst architects, contractors, product engineers and materials scientists. The interaction amongst these groups can be seen in Figure 3. This diagram is based on the work of Kieran and Timberlake (2004) and has been modified to highlight the role of the master builder. Certainly, BIM can assist the master builder in their task of coordinating the engineering, procurement, and construction of a project. However, the authors contend that construction engineers, and not architects, are ideally suited for this role. This is because of their broad educational background that facilitates communication with materials scientists and product engineers.

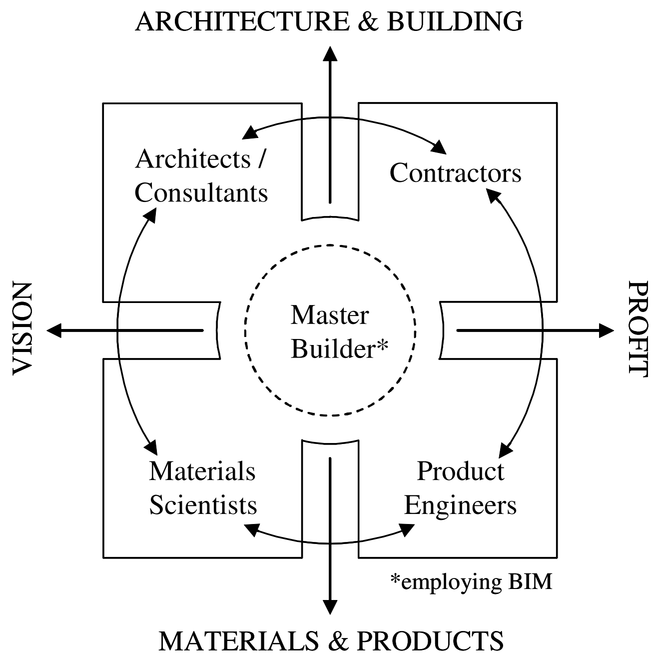

Figure 3. BIM-Enabled Construction Process.

Estimating was one aspect of the Texas State competition enabled through BIM. Instead of producing estimates of construction cost at the conclusion of design activity, BIM allowed student teams the ability to continuously forecast construction cost given new materials, methods, and building systems. As stated previously, graduate students were employed to assist in estimating. These students continuously converted the BIM bill of materials (BOM) into appropriate assemblies for construction and then pricing them given certain project constraints. For each group, the pricing activity took different forms. One group used real-time contractor cost data, another national cost data modified by local pricing, and the third used local bidding websites to effectively 'shop' the materials and labor involved. All three strategies proved valuable not because they provided relevant data, but rather because they informed each design on a daily basis thereby enabling decisions on how to proceed. Certainly, BIM-empowered estimating greatly redefined today's outmoded processes.

The changes in an industry or market structure that catch everyone by surprise

The advent of BIM occurs contemporaneously with the rise of design-build as a project delivery system. By 2010 design-build will be the leading method of project delivery in North America[7]. Consequently, the argument exists for one contract instead of two. Owners often believe that design-build saves time and money while reducing conflict. Having one contract also helps accommodate the increasing complexity inherent to modern buildings. By one estimate[4], 50% of the cost of today's building is systems-related (e.g., HVAC, electrical, etc.) whereas it was closer to 5% of construction cost a century ago. These changes in the A/E/C industry point towards an expanded role for the use of BIM – thereby empowering the design-builder and accommodating ever-increasing systems complexity.

In the construction engineering educational environment, these changes in market structure point toward an expanded focus on design-build as well. The School of Architecture at the University of Kansas (Lawrence) has long been a proponent of active design-build education, offering a senior studio since 1995 and actually constructing several affordable homes using prefabrication. However, instead of educating architects about building, Texas State has approached the changes in industry by educating construction students in design. In fact, the university's program has evolved a four course sequence in Architectural design with the final two courses being taught exclusively using BIM. The tool is also used effectively to teach planning, scheduling, and productivity concepts[8] in other courses in the curriculum. Indeed, the authors strongly advocate that construction programs should be at the forefront of changes in industry, conducting research, and educating tomorrow's leaders.

The demographic changes caused by wars, medical improvements and even superstition

Worldwide, the construction industry employs approximately 111 million people[6]. While most are engaged in good, exciting, and creative pursuits, keeping up with the diverse and turbulent environment in which the industry operates can be difficult. For example, it is estimated that between 8 and 20% of total installed cost of a project is tied to transactional cost between parties[6]. Add to this superstition about the 'housing bubble', changing development patterns favoring urban regeneration, and the shifting needs of the information age, and it is easy to see why innovation in the construction process is needed.

Speed of execution is critical. The result of demographic change, this factor is mandating innovation through the use of BIM. In the competition at Texas State to develop student housing, time to market ahead of the Fall 2007 semester became a constant concern. BIM aided the design process by managing schedule through means of construction as opposed to a contract. Long lead items were identified early and parameters for their inclusion were frozen. Moreover, BIM streamlined the analysis of building the project because the process was inherent to the design of the project. As a result, constructability review was unnecessary – a focus on innovation in both design and execution was all that was required.

Changes in perception, mood and fashion brought on by the ups and downs of the economy

Currently in the United States, the A/E/C industry accounts for 20% of the national GDP[6]. Through the ups and downs of the dotcom era, the trends of offshoring and outsourcing, and the internet economy, the need for 'bricks and mortar' remained. Certainly, these times brought about changes in the A/E/C industry, in its practices, technologies, and financing strategies. However, more than anything else, the continued prevalence of inexpensive financing has only continued to fuel expansion in the construction industry. As a result, U.S. construction programs continue to expand at a rapid pace to accommodate demand. Plus, unlike other products and services, the built environment cannot be exported. The net effect is growing interest in building amongst students who have grown up with computers, e-mail, video games, and the like. Connectivity is nothing new to these students. For them, BIM makes complete sense and is easily learned – leaving them to wonder why older processes are still in use.

Leading A/E/C firms have perceived economic advantage through BIM. Dallas, Texas-based Beck Group has invested millions in developing a proprietary rule-based BIM software suite called DESTINI (for design and estimating integration initiative). This innovation groups building assemblies with production cost data so that real-time estimates can be generated with 3D visualization. The main advantage of this BIM implementation is that it allows developers to quickly explore numerous strategies to improve their real estate and ascertain with greater accuracy whether or not to go forward with a project[9]. In most cases, Beck Group can use its systems to help reach a go/no go decision within 24 hours as opposed to weeks or months. Under these circumstances, Beck can reduce design costs, lock in subcontractor pricing, and accelerate schedule through advanced planning and purchasing.

For students, BIM is understood as reality, not merely a representation of it. Skills related to the representation of design ideas such as drafting and rendering become much less important than the understanding of the actual creation of a building in the BIM environment. Technical issues regarding structure, engineering analyses, fabrication means, and thermal control take priority in modeling. As in the competition at Texas State, the authors' students realized that a part-for-part digital model of a building was a reality in similar terms as actual construction. Certainly this realization places increased emphasis on the construction engineer as a master builder. It also makes the product a lot more precise. Given BIM software, students understand that a high level of complexity in systems and materials can be created in the field with a high degree of confidence in its execution. Until now, such understanding was rarely achieved.

The changes in awareness caused by new knowledge

In its most basic form, BIM is the catalyst that will move construction engineering education from the analog to the digital realm. As an innovation, BIM is poised to fundamentally change the way projects are built and the way stakeholders communicate with each other. Moreover, it will spawn new processes, services, and products for improving the built environment. Indeed, BIM represents new knowledge and a path forward for construction education, thereby changing how students perceive construction's body of knowledge. Increased use of BIM will help:

- Enhance pre-project planning through predictive cost capability
- Formalize and communicate project scope in understandable terms
- Systematize constructability via rapid assessment of project alternatives
- Revolutionize project controls by monitoring progress to plan
- Facilitate improved decision making
- Engender new forms of project finance for capital facilities
- Create new project delivery systems and contract types

Innovations in construction engineering inevitably put pressure on construction education. To many, the business of education seems similar to a supply and demand system. That is, skills should be taught at the university to meet the needs of the profession. In the case of BIM, the whole is greater than the sum of its parts. Creating and understanding all its nuances takes time. Indeed, the maturing process for most construction engineers can be slow due to the fact that expertise is hard-earned and occurring over a large timeframe. Therefore, it is appropriate to consider a construction education as the starting point of a lifelong process of discovery. Viewed from this perspective, the role of the educator is to merely establish the vector for exploration after graduation, thereby founding the future of the profession[10].

Finally, BIM has created awareness of the next new innovation in construction: building directly from the three dimensional models themselves. Interestingly, at the advent of 3D CAD representation in 1988, the authors are aware one industrial sector engineering, procurement, and construction (EPC) firm that attempted to build a $400 million polymers plant directly from the engineers' computer screens. After several months of hard work, the EPC contractor abandoned the experiment and spent the next few months modifying their work to two dimensional working drawings. The project owner was dismayed: how could this disconnect occur since the plant was to be built in three dimensions? The short answer is that neither the technology nor the construction culture had progressed enough by 1988 to make this transition. Today, however, we are ready. The students at Texas State have demonstrated the understanding to actually build from BIM. The attributes and information regarding each component and assembly in the project are truly present. But, who will first venture to build directly from BIM?

Conclusions

"There is a way to use building information modeling (BIM) that works…and a way to use it that goes nowhere[11]." Indeed, given the amount of information in BIM, the pitfall of 'analysis paralysis' is ever-present. The challenge is twofold: implementation and execution. By examining seven sources of opportunity for those in search of innovation through implementing BIM, many openings for advancement in construction engineering education and practice have been illustrated. The case study of Texas State's competition validates the hypothesis that BIM is indeed a new frontier for construction education. Important innovations regarding planning, estimating, and project management were discovered through this experiment. However, no discovery was more visceral than the establishment of a new project delivery system. By working with the student groups, the developer of the student housing project was able to produce three conceptual designs and prices as quickly and inexpensively as possible. To the authors' knowledge, this was the first instance of a constrution program providing 'bridging' documents to a design-build project using BIM. One outcome of this delivery system was that it facilitated reductions in consultant billings for specific civil, structural, and MEP design services. Certainly, this particular implementation of BIM produced results.

Educationally, there is ample evidence that BIM produces meaningful learning outcomes. Texas State students involved with the competition used BIM to plan their projects by simultaneously designing both the activity precedence relationships and the organizational resources in the model. Remarkably, the students reported the process to be both simple and intuitive. Moreover, the activity of designing a project using BIM lead to excellent questions being asked by the students about project execution whilst in a laboratory setting. Once their models possessed enabling data, the students received immediate feedback regarding the potential time and cost impact of their design. This form of feedback allowed each student to make adjustments to improve their team's project planning and execution. If their design were subsequently used for construction, they would be able to see their projections of performance relative to actual experience onsite – one benefit of an integrated construction education.

This paper justifies the use of Building Information Modeling (BIM) as an integrated format for construction education. It demonstrates the advantage which a comprehensive interface can provide to an engineering student; one which depicts the integration between design and construction services. As a result, students are able to comprehend both how a building is designed and how it will be constructed. The extended impact is student understanding of how their work affects execution resources and performance parameters such as time, cost, scope and quality. Given such advanced technology, engineering students readily realize the link between planning and the attainment of project goals and objectives. Certainly this type of understanding points towards an increasing role for BIM in construction engineering in the future.

References

1. American Institute of Architects (AIA) (2006). *AIA Document A201: General Conditions of the Contract for Construction*. AIA, Washington, DC.
2. Drucker, P. (1985). *Innovation and Entrepreneurship.* HarperCollins, New York, NY.
3. Workman, R. (2001). *Personal Interview.* Chairman, BSW International, Tulsa, OK.
4. Kieran, S. and Timberlake, J. (2004). *Refabricating Architecture.* McGraw-Hill, New York, NY.
5. O'Keefe, C. (2002). Strength in Systems. *Builder*, 5, 176-180.
6. Barrett, P. and Lee, A. (2005). *Revaluing Construction: A CIB Priority Theme*. CIB, The Netherlands.
7. Solomon, N. (2005). The Hopes and Fears of Design-Build. *Architectural Record*, 193(11), 167-174.
8. Gier, D., Loftin, E. and Coogan, K. (2006). Are Building Information Models Effective for Teaching Productivity Analysis? ASC, *Proc. 42nd Annual Conference*, ASC, Fort Collins, CO, 300-308.
9. Frink, M. (2006). Costing and Visualization? [WWW document]. URL http://www.thebeckgroup.com/content/about/features/WhitePapers/CostingandVisualization.pdf
10. Cheng, R. (2006). Questioning the role of BIM in Architectural Education. [WWW document]. URL http://www.aecbytes.com/viewpoint/2006/issue_26.html
11. Sawyer, T. (2005). Build It First Digitally. *Engineering News Record (ENR),* 255(14), 28-32.