AC 2012-4587: THE INTEGRATION OF BUILDING INFORMATION MODELING AND INTEGRATED PROJECT DELIVERY INTO THE CONSTRUCTION MANAGEMENT CURRICULUM

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The Integration of Building Information Modeling and Integrated Project Delivery into the Construction Management Curriculum

Introduction

The requirements of a construction program accredited by the American Council for Construction Education (ACCE) encourages the inclusion of the latest best practice in the construction industry through the integration of the construction process throughout the curriculum. The purpose of this paper is to explore the current best practice of Building Information Modeling (BIM) and Integrated Project Delivery (IPD), to discuss avenues for the integration of such knowledge into an undergraduate program in construction, and to explore ways in which BIM and IPD may be further developed for the improvement of knowledge management in the constructed project.

An exploration of BIM as an enabling tool for IPD requires an investigation into the current state of practice of both BIM and IPD. In recent years BIM has expanded to becoming the normal tool for coordinating all data on the constructed project through the use of 4D and 5D models which also embed details on schedules, cost and product data. This coordination may be enhanced by early involvement of the major parties to the construction process through collaborative contracts such as IPD. This paper provides definitions of BIM and IPD and then explores the enabling relationship between these in order to enhance Owner satisfaction through less adversarial construction team relationships. It also explored ways in which such examples of latest practice in construction may be integrated in the curriculum of an undergraduate curriculum for construction management programs. It concludes by providing examples of good practice through the presentation of case studies.

A Definition of BIM

BIM has been defined as “the process of creating and using digital models for design, construction and/or operations of projects.”¹ This definition is interesting in that it does not restrict BIM to just geo-spatial images representing the geometry of the project as would normally be associated with CAD packages. This definition also includes all digital information related to the project from its inception through construction and into operations. As such it becomes a management and communications tool for all participants in the project. At present there appears to be little progress in the education community to present BIM as anything more than a 3D modeling tool, perhaps because the construction industry is still in the early stages of addressing this.

Prior to the 1990s Computer Aided Design packages were little more than an electronic drafting board that was used to produce 2D drawings which became, in hard copy, part of the Contract Documents. In the mid-1990s large software houses such as Autodesk and Bentley began developing 3D packages as a design tool chiefly to allow designers to communicate with clients more clearly. They were not necessarily aids that would facilitate a systematic plan of action with a global scope for a project. Rather, they were aids that would facilitate the arrangement of built elements in three dimensions, with some quantitative outcomes related to quantities. At this
stage such packages did not proactively take into account issues related to financing, cost control, energy control, and other controlling aspects of the construction process. At present there are a number of software developments that integrate BIM/CAD packages which can produce analysis of designed elements of the built project. However, they do not proactively inform the user or optimize possible solutions before the design is produced. The iterative process of decision making still relies upon the end user rather than the computer.

At that stage there have been a series of advancements in various directions but not in an integrated or easily integratable manner. Files could be imported or exported from one specific program to another, usually with a significant loss of important data, and most of the time with unavoidable transformations that would render the process of transfer marginally efficient. In a fashion similar to the operating systems wars of the late 80s and early 90s, products of one company would be formulated to function well with the allied products. It was left to the end user to apply the strength of every available program and reach a point where the information would be transferred to another.

The current state of best practice in BIM utilization to integrate all project information still relies on an array of software packages which are improving in terms of their ability to transfer information without loss of data. This range of packages is illustrated in Figure 1 below. This includes design software 3D BIM modeling software, scheduling software to produce 4D models, and digital document control software to track changes in information during the construction phase.

There is a general consensus that greater adoption of BIM technology can lead to better than expected value, higher competitive advantage, improved productivity, greater investment in the team, and greater client satisfaction. Better than expected value, measured in terms of increased return on investment (ROI) has been reported by over two-thirds of respondents in a recent McGraw-Hill SmartMarket Report. Similarly, respondents reported that BIM offers competitive advantage in marketing new business to new clients, offering new services, and maintaining repeat business with past clients. Improved productivity is seen by the reduction in rework and reduced conflicts and changes during construction. Investment in the team emanates from better multi-party communication and understanding from the 3D visualization. Clients are more satisfied because of improved ROI and better project outcomes.

The development of a more integrated approach to BIM in a construction curriculum will require more than its use in Engineering and Architectural design courses. It would need to find ways of using the broader capabilities for time and cost management, and the increasing use of electronic data storage and retrieval.
A Definition of IPD

The development of IPD is hardly modern. Most of the principles underlying the integration of the project team are derived from W. Edwards Deming’s work with Toyota in the 1950s. His work on productivity improvement and optimization in management through the use of systems thinking is in contrast to the current practice of fragmentation of construction disciplines. The continued fragmentation of the construction process which often leads to adversarial relationships has lead to significant customer dissatisfaction and contributed to the development of more cooperative relationships including IPD.

Owners are becoming more definitive in their demands for more reliable outcomes of the construction process. These demands include: improved decision-making to reduce poor design decisions, improved contract documentation to eliminate the extensive use of RFI’s in the building process, improved preconstruction estimating, improved procurement, expediting and scheduling, improved coordination between design and construction, improved cost-efficiency through a value-based approach, and improved closeout documentation.

A working definition of IPD as a project delivery approach is that it “integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste, and maximize efficiency through all phases of design, fabrication, and construction.” In its most effective form IPD should go well beyond just a more collaborative agreement between Owner, Designer and Constructor to include other
consultants, subcontractors and vendors who become stakeholders of the entire project process, rather than just their traditional limited role. However, it must be acknowledged that, as yet, no clear single definition of IPD exists. It is unclear whether IPD is to be considered as either a philosophy of project delivery or a required multi-party contract. It has been defined as operating at one of three levels of collaboration:

- Collaboration Level One or “Typical” where collaboration is not contractually required,
- Collaboration Level Two or “Enhanced” where some contractual collaboration is required, and
- Collaboration Level Three or “Required” where collaboration is required through multi-party contract.

The first two levels may be regarded as more philosophical than contractual in nature. Indeed, some opponents of the use of IPD as a contracting method argue that integrated delivery is a process and operational framework which may be achieved under other better tested forms of contract such as design-build and at-risk construction management. At a minimum, Level Three IPD requires that the Owner, Designer and Constructor all sign the multi-party agreement, and often, other project team members considered critical to the project success are also brought into the agreement. However, there exist problems with such arrangements in that there are few insurance products to cover multi-party contracts, and those being developed are project specific and expensive. The waiving of one’s right to make claims against other team members will likely render any liability insurance inoperative.

Some have suggested that IPD should be regarded as a process that does not include the client in order to maintain the ability to make claims against the team’s liability insurance. In such arrangements, one of the primary team members enacts a conventional contract for the total package with the client and forms an IPD relational pact with the other major team members, as defined in Figure 2 below. This pact includes an open book approach between the team and sharing of the “pain or gain” of the project success via the use of a target style of agreement. It would seem that such an approach, while having some merit, is at best Level Two IPD as defined above.

Contractual IPD has been posited as having three elements: a multi-party agreement a shared risk and reward component, and the early involvement of all parties. IPD is generally entered into via a multi-party agreement for the entire project. It is entered into by the owner, the architect/engineer, the contractor and other parties who have a significant role in the project. The main goal is to maximize collaboration and coordination from the project inception to its completion. Such relationships are articulated by multi-party agreements such as ConsensusDocs 300 “Standard Form of Tri-party Agreement for Collaborative Project Delivery” as articulated in Figure 3 below.
Figure 2: IPD Relationship without Client

Figure 3 Tri-Party Agreement
Most IPD contracts include a shared risk and reward component that is designed to encourage teamwork and enhance communication to promote the success of the project. Usually this is associated with cost, schedule and quality performance indicators used to measure project success. Such measures may include a value-based system to provide an incentive to the project team by offering a bonus linked to added project value, an incentive pool that can change up or down based on various agreed criteria and then distributed to the team, an innovation and outstanding performance bonuses to provide rewards based on quality and creativity, and/or a profit sharing scheme.

Perhaps the most fundamental advantage of IPD is the ability of all parties to be involved with the project from the project inception. Such early collaboration can mitigate the problem of fragmentation between design and construction professionals typical of standard forms of agreement that results in inefficient work practices and costly changes late in the construction phase. Such early involvement can be enhanced by the use of information technology tools such as BIM to increase the efficiency of collaboration throughout the project.

There are examples in education of the introduction of multi-party agreements such as ConsensusDocs 300 into a contract course, including the addressing of such issues as liability and other such risks. But the provision of this alone does not address the potential effects on other aspects of the project process from inception to completion, the integration of which may provide the greatest benefit of IPD.

In the United Kingdom, the use of what is called third generation partnering has become common, even among public sector clients. In such arrangements an Owner uses the services of a preselected group successful of Designers and Constructors for all of their work. Over time this limited pool of resources develops strong collaborative working relationships that encourage innovation and efficiency. Successful performance is measured through the establishment of Key Performance Indicators (KPIs) which allow the client to benchmark the team’s performance. If the team maintains good scores on the KPIs, then their services are retained. Such arrangements use conventional contracting instruments, though often they will involve target pricing to encourage greater attention to the bottom line.

Care must be taken, though, in not overstating the power of partnering agreements, including IPD. Such agreements are not necessarily a panacea to solve all problems in construction relationships: they can fail. There are four main reasons why partnering alliances are unsuccessful, their success depending on the ability to effectively mitigate these problems:

- the failure to establish clear goals, operating procedures or responsibilities with no concrete measures of success;
- a clash of management styles or business cultures, or the emergence of internal interpersonal problems which frustrate the progress of the alliance;
- a lack of trust or mutuality where one partner perceives that the other is gaining an unfair advantage through the alliance; and
- changes in one of the partner organizations which reduce its commitment to the success of the alliance.
However, if the above concerns are handled professionally, IPD is proving itself to provide fewer errors in the design and construction phase, fewer RFIs and Change Orders during construction, and greater client satisfaction with the project outcomes. This greater collaboration may be greatly enhanced by the extensive use of BIM to handle and control the project documentation.

**How BIM Enables IPD**

The foregoing sections already illustrate the compatibility of BIM ad IPD for producing a more coordinated and integrated approach to project development and delivery. While it is certainly true that IPD could be used without BIM technology, the enabling benefits of BIM are significant.

In many ways the drive towards the greater use of BIM and IPD has been forced on the industry by Owners’ demand. Owners are becoming more demanding of the construction industry, including the heed for improved decision-making using digital models; improved contract documentation to eliminate the use of the RFIs during construction; improved preconstruction estimating; improved procurement, expediting and scheduling; improved coordination of the design and construction phases of the project; improved cost-efficiency trough a value-based approach; and improved closeout documentation through the use of laser scanning and digital models. Drivers for the increased use of BIM and IPD include: a shift toward globalization of the product supply chain in the construction industry, the need for increased productivity in construction and the consequent low profit margins, the demand for greater sustainability and the need to reduce the environmental impacts of construction, and the increasing complexity of the building process.

BIM and IPD are complementary tools: BIM facilitates the integration of information and provides a single platform for the storage and retrieval of data, and IPD provides a framework to integrate the shared goals and values of the project participants. The basic principle of both BIM and IPD is the provision of knowledge integration. Since IPD relies on the collective expertise of all project stakeholders particularly in the early stages of design, the consequences of design decisions can be understood earlier in the process and thus such decisions can more readily ensure project success. The use of BIM to capture this project knowledge can create a better, more integrated understanding of the project, enabling Clients and their IPD team to more effectively assess how project options align themselves to the desired business goals. Satisfying Owner demands is at the heart of the both the use of BIM and IPD process.

Architects, Engineers and Constructors are responding to Owners’ demands by adopting new processes, including collaborative partnerships, and utilizing new technologies. New tools and technologies are key enablers of the integration of design and construction. These include:

- BIM design tools to provide platforms for integrated processes built on coordinated reliable information and resulting in enhanced coordination, fewer RFIs and change orders, and less rework;
- 3D and 4D visualization for enhancing scope definition, stakeholder engagement, and decision making;
• model-based analysis using BIM-based data and digital analytical tools to understand project energy consumption, structural performance, cost estimates and other inferential reasoning from the design while it is underway;
• 4D modeling for coordinating construction and increasing the reliability of schedules;
• fabrication from 3D models resulting in elimination of shop drawings; better tolerance, lead time, and safety, and faster field assembly;
• model-based bills of materials providing faster, more accurate takeoffs for cost estimating, energy analysis, etc.; and
• laser scanning to capture existing (as-built) conditions that can be combined with BIM to provide reliable as-built models.

It is clear that this integration of BIM technology and IPD is being fuelled by increased Owner demands for a product where the design and construction process is typified by a more cooperative and non-adversarial relationship among the members of the project team. This is being enhanced as Owners realize that the industry now has better tools to achieve this harmony. They demand better value for money and less wastage of resources as the new norm for the construction industry.

The Integration of BIM and IPD into the Construction Curriculum

The curriculum of an ACCE accredited program includes the two content areas of construction and construction science, both of which offer potential areas of integration of BIM and IPD. In the construction content area, the emphasis on the effective management of personnel, materials, equipment, costs, and time may be significantly enhanced through the use of BIM. Additionally, an analysis of the various roles and responsibilities of project participants throughout a project’s life may be broadened through the introduction of IPD, particularly as it relates to alternate and creative ways to structure the owner-designer-constructor team relationships. In the construction science content area, the emphasis is to provide an understanding of the contribution of the design disciplines and processes to the constructed project. Three issues arise regarding the integration of BIM and IPD into the construction management curriculum:
• how construction educational objectives may be met though such integration,
• how BIM and IPD may be integrated into the construction curriculum, and
• the data which may be available to measure the success of such integration

There is a sense in which the integration of BIM and IPD may be regarded as a desirable educational objective in itself. A criticism of the traditional approach to education is the tendency to treat each course on a program as a “silo,” considering each subject area in isolation from other areas. The introduction of BIM and IPD requires a more integrative and holistic approach, leading to a more cohesive educational experience. The second enhanced educational objective of BIM is the ability to better simulate the 3D project in a virtual platform. While the engineering and construction industries have traditionally relied on the ability of its participants to “translate” 2D drawings into a 3D final project, the ability to build a virtual model allows for early detection of potential construction problems and the need for rework. Other educational objectives include the ability to more definitively link a project schedule to the activities needed to undertake a particular project, and the ability to perform more accurate material take-offs for construction estimating. Care must be taken, though, to not overstate these benefits given the
current limitations of the software. BIM and scheduling software are still not totally compatible, and a material take-off provides only one-third of the requirements of a good estimate. Indeed, a critical evaluation of the current state of practice would be more educationally beneficial than an uncritical adoption of the software and contractual relationships, especially for more senior courses.

The obvious courses in a construction curriculum for the introduction of BIM and IPD are courses in engineering/architectural graphics and in construction law/contracts, respectively. Such an approach, though, would potentially reinforce the “silo” mentality discussed above. A more integrative approach would be to use a BIM model developed in, for example, a graphics and/or an engineering/architectural technology course and apply this to scheduling, estimating and cost control courses in addition to a construction law/contracts course to explore the benefits and limitations of the current best practice. This could then be brought together in a capstone or senior-level management course to provide the critically evaluative aspect of learning. Such an approach would allow for higher learning aspects identified by ACCE, including project development, feasibility studies, value analysis, site planning and logistics.

In terms of measures of determining the success of such integration of the curriculum, it is generally agreed that outcome-based assessment is a better determinant of success. Unfortunately, the ACCE accreditation process still relies heavily on dictating the curriculum content, paying only a scant acknowledgement that student learning outcomes are a better measure of success and leaving the determination of such measures to the individual institution. However, the development of learning outcomes from the content of an ACCE accredited course is possible based on the construction and construction science content areas.

Material to be evaluated in the construction area should include the creative use of owner-designer-constructor teams to provide the effective management of personnel, materials, equipment, costs, and time during the construction process. In addition to the contractual aspects of this it should also include an evaluation of how effectively the estimating and bidding process the project execution and project controls are integrated into the overall planning and execution phase of the project. In the construction science area this should include the analysis and design of construction systems related to structures, plumbing, mechanical, drainage and other utilities. It should also include the design of temporary facilities, formwork, scaffolding, and construction surveying. This may be translated into learning outcomes which are appropriate for the level of study. For courses at the freshman and sophomore levels, it would be appropriate to evaluate the degree to which a basic understanding of how the various aspects of the curriculum contribute to the successful integration of these tools to manage the project process, whereas at the junior and senior levels a more critically evaluative and comparative study of the use of BIM and IPD, as well as other design tools, software and early contractor involvement approaches may enhance the integration of the project process.

**Case Studies**

The benefits of combining BIM with IPD may be best illustrated by considering three case studies where such a strategy was used. In the first, a formal IPD contract was not used thought BIM was used extensively. However, the philosophy of IPD was very much in evidence during
the project development. In the second, a formal IPD agreement was enacted between the three primary parties and BIM was used extensively at the request of the Client. In the Third, a paradigm shift in the use of IPD was evident in that 11 partners were cosignatories of the agreement.

The use of such case studies in an educational setting is a strong mechanism for providing real-world examples of current best practice and therefore stimulating learning beyond just the rudiments of the construction management curriculum. Such case studies could be readily incorporated into a construction law/contracts class as a first instance to developing a more cross-curricular approach to integration. Most education institutions have Construction Advisory Board members who are willing to share their current experience in such areas. There are also many examples of industry literature containing critiques of current engineering and construction accomplishments.

Case Study 1: Research 2 (R2) project for the University of Colorado Denver Health Sciences Center, 2003 to 2008

The 11-story 540,000 square-feet biomedical facility was valued at $201 million. Prior to this project, the General Contractor had employed virtual design and construction on several projects, but lacked hard performance data on its true benefit.1 This project, however, would provide hard information as it was very similar to the R1 project built earlier. In order to better leverage the benefits of the technology, the General Contractor pursued an integrated approach, engaging early with the design team. The team worked together for nearly two years on the design and preconstruction phases to fine tune how data would be shared, how subcontractors would be procured, and how the models would be used throughout the project. In addition to focusing on construction coordination issues, the team brought in Owner’s representatives to ensure that the project would also be maintenance-friendly upon completion.

Because significant planning, coordination and verification took place up front, the team started to accrue significant time savings once the construction model took shape. The structural engineers were able to transfer the 3D structural steel design model to the steel subcontractor who then turned around 3D shop drawings for review in one package. The structural engineers were able to speed through review and approve it for fabrication, contributing to the structural steel being erected six weeks ahead of schedule.

Because R2 was very similar to R1 except for the use of BIM and IPD, the client decided to make a comparison between the two projects. The study spotlighted a range of savings and benefits on the R2 project compared to R1. Through use of BIM, more decisions were made early in the project, causing an increase in RFIs during preconstruction. But early review during design led to a reduction in construction RFIs of 74% during the foundation phase and 47% during the steel erection phase. Overall, R2 experienced a 37% reduction in coordination RFIs and a 32% reduction in coordination changes.

Additional benefits were realized in savings on the schedule. When completed the R2 project was two months ahead of schedule and six months ahead of R1. In addition to a reduction in rework enabled by early coordination efforts with BIM, credit is also given to the 4D simulation during the job for helping improve the schedule. The Mechanical Subcontractor estimated a 50%
reduction in labor and a 50% reduction in schedule thanks to the virtual design coordination approach.

Case Study 2: Autodesk One Market in San Francisco, 2007 to 2008
The construction of Autodesk One Market in San Francisco in 2007/08 was a prime example of the use of BIM as an enabling tool for IPD. The project, located at One Market Street, San Francisco, California, was a commercial interior renovation consisting of a roughly $10 million budget and an aggressive twenty-two week construction schedule. It comprised of approximately 25,800 square feet of renovated area. This project exemplified the incorporation of IPD as a multi-party contract with shared risks and rewards with the early involvement of some parties. Initially, a four-party agreement was entered into by the owner, the general contractor, and two architectural companies that bound together these parties, specifying their roles, the decision-making process and the compensation structure. Other subcontractors and subconsultants entered into contracts with one of the four parties, the conditions of which mirrored those of the main contract. The early involvement of the main parties ensured the establishment of common goals and objectives, including a protocol for handling the BIM data based on Autodesk’s software.

Three levels of management were organized to facilitate the decision-making process: the Project Implementation Team (PIT), Project Management Team (PMT) and Executive Committee. The PIT was the first level, managing daily technical activities and identifying issues in the field. When the PIT could not reach a unanimous decision, the issue was escalated to the PMT who managed broader concerns of program, budget and schedule. If the PMT could not reach a unanimous decision, the issue was ultimately referred to the Executive Committee, who required a majority vote to reach a final decision. During the course of the project, only one issue was elevated to the Executive Committee, the majority of issues being resolved at the PIT level. This is a clear example of how the involvement of all parties early in the project can result in better conflict resolution and a more cooperative management style.

The use of BIM also significantly enhanced the early identification and resolution of conflicts. Modeling was used for several functions including constructability reviews, energy modeling, day lighting analysis, MEP coordination, visualization, prefabrication, just-in-time delivery and model-based layout. The project required the re-use of 60% of the HVAC infrastructure and the existing concrete columns and floor slab. Thus accurate preconstruction data, obtained by laser scanning was captured to eliminate the need for rework during construction. As a result, Change Orders amounted to only approximately 1% of the project costs and RFIs were kept to a total of 72, each with an average three-day turnaround.

Shared risks and reward was obtained by the establishment of a pool of funds to cover corporate overheads and profit, construction and project overhead costs being guaranteed to each party. The success of the project was determined independently to significantly exceed the project requirement. This resulted in a 20% increase in the pool, which was then distributed to the parties in proportion to their equity stake in the project.
Case Study 3: Castro Valley Sutter Health Clinic Hospital in San Francisco, 2007 to 2012

This project, scheduled to complete in November 2012, is a $320 million 164-bed hospital facility with an innovative approach to IPD. In 2007 eleven parties agree to enter into a multi-party contract to undertake the design and construction of the facility. The partners include the Owner, General Contractor, Architect, Structural Engineer, Mechanical and Electrical Contractors among others. This project has again relied on the extensive use of BIM since its inception. In addition to the main IPD agreement, trade subcontractors were engaged using an Integrated Form of Agreement (IFOA) as their subcontract, attempting to also engage them in the shared goals and values aspect of the project without exposing them to the risk sharing aspect of IPD.

Again, the early engagement of even some of the subcontractors during the preconstruction and design phases has resulted in a significant reduction in RFIs and Change Orders. Thus far, there have been only 26 Owner-initiated changes which is less than 1% of the project. It is scheduled to be completed six weeks ahead of the original schedule and within the target budget.

Conclusion

The above discussion has focused on the relationship between BIM and IPD in helping to deliver excellence for the constructed project in order to provide the level of Client satisfaction the industry has come to expect. It is clear that leading players in construction are realizing the benefits of early close collaboration between at least the major participants in construction during all phases of the project. While some limitations to BIM and IPD exist, including the lack of interchangeability between software packages and the fear of more collaborative risk sharing, many industry leaders are willing to work these problems through in order to improve the project process. The three case studies reveal some very innovative approaches to the collaborative use of BIM and IPD in moving the industry into a new era.

It should also be noted that the current best practice of integrating BIM and IPD provide excellent opportunities for undergraduate programs in construction management to engage in cross-curricular efforts to stimulate team building and a broader understanding of the interrelatedness of construction activities. A suggestion for further research would be the development of a pilot study to explore ways to further develop such integration.

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