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Effects of Building Information Modeling During Construction

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Abstract

Building information modelling (BIM) and 4D modelling have both recently received widespread attention from the architectural, engineering and construction (AEC) industries. Research efforts to date have demonstrated that BIM and 4D technologies are able to provide faster and more effective communication of information between interested project parties and yield improved and innovative solutions stemming from better design along with other benefits. This paper describes the results of research focused on capturing the effects of BIM during the construction phase of the project. Four factors including requests for information, rework, change orders, and schedule compliance are discussed based on personal interviews with contractor employees experienced in the use of BIM. Eight case studies were conducted to explore the effect of BIM during the construction phase with respect of these four factors.

Key Words: Construction Productivity, Requests for Information, Rework, Change Orders, Project Scheduling

1. Introduction

Building information modelling (BIM) and related issues have been a subject of intense research and development, as reported in the recent scholarly literature. Improvements in the efficiency of the planning and design processes [1−3], construction planning and control [4,5], design-construction integration [6,7], and facilities management [8,9] have been analysed. Additionally, benefits derived from BIM implementation have been defined based on improvements achieved throughout building-related processes [10−12].

It is widely accepted by experts and evidenced by prior research that BIM and 4D approaches are able to provide faster and more effective communication of information between interested project parties and yield improved and innovative solutions stemming from better design, along with many other benefits [13−15].

This paper describes the results of research focused on capturing the effects of BIM during the construction phase of the project. Four factors: requests for information (RFI), rework, change orders, and schedule compliance are discussed by personal interviews with the participation of contractor employees most knowledgeable in use of BIM. Eight case studies are done to explore the effect of BIM during construction phase with respects of these four factors.

2. Methodology

At first, a pilot survey was conducted to determine the levels of BIM usage by firms in the AEC industry. Managers and representatives of 26 companies based on the west coast of the United States, most in the range of

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$250 million to $1 billion in annual revenues, chosen from active Design-Build Institute of America (DBIA) members, and Fully Integrated Automated Technologies for Capital Projects (www.fiatech.org) annual conference participants were asked in personal interviews questions related to their usage of BIM technologies.

Secondly, managers and representatives of companies in the target audience were asked questions in informal interviews rather than filling out a questionnaire because more reliable results could be obtained. The newness of the process means that precise numbers were not known by the users so that perceptions of usage benefits needed to be evaluated.

The interviewed contractors were asked specifically which of their projects were being performed with the use of BIM in order to focus on the effects of BIM. A general survey of these projects based on the findings from the pilot survey was performed. A survey involving a personal interview was performed with the participation of contractor employees most knowledgeable in the use of BIM to determine the extent of BIM usage in the project and the relevant effects of BIM.

Finally, as shown in Table 1, eight case studies were performed. These primarily focused on contractors who are more aware than others of the effects of BIM in the field and fully familiar with implications of BIM processes.

3. Results of Pilot Survey

The results of pilot survey reported are shown as below:

1. Obtaining reliable data concerning construction field productivity was difficult, because accurate reporting of productivity values was rare in most contractor firms and because designers were not providing the contractors with sufficiently accurate BIM documentation. Many large subcontractors were not able to identify their productivity or rework rates also on projects with no BIM usage. There appears to be a systemic lack of understanding among contractors of the cause and effect relationships related to field productivity rates.
2. Some contractor field personnel (predominantly in unionized firms) reported a perception that BIM was merely a less-than-necessary communication tool mainly for information technology (IT) savvy engineers for coordinating tasks that could otherwise be

Table 1. Description of the 8 case studies in the states

No.	Company	Key contact and brief description
1.	COMPANY-1 (owner)	Project development manager of a retail giant, COMPANY-1. His experience and comments represent the owner's perspective in this case study.
2.	COMPANY-2 general contractor (GC)	BIM manager for COMPANY-2. It is one of the top 100 companies in revenue in the USA and in the top 20 in the hospital construction sector.
3.	COMPANY-3 (GC)	A regional manager in the San Francisco bay area of COMPANY-3. It is a $2 billion/year general contractor with several regional offices.
4.	COMPANY-4 (GC)	COMPANY-4 is a general contractor with a high of $180 million in revenues. The firm specializes in concrete tilt and warehouses but also perform a fair amount of projects in the public sector.
5.	COMPANY-5 (electrical subcontractor)	The electrical contractor's superintendent of COMPANY-5 which has been an electrical contractor on an airport project.
6.	COMPANY-6 (mechanical subcontractor)	A Senior Vice President of COMPANY-6 which is one of the largest U.S. mechanical contractors, headquartered in southern California and performing projects nationwide.
7.	COMPANY-7 (mechanical subcontractor)	A project manager that oversees projects in the high-tech sector of COMPANY-7. It is a large mechanical firm with different groups running various types of projects for diverse clients.
8.	COMPANY-8 (framing subcontractor)	Vice President of operations for COMPANY-8, a framing and drywall contractor which performs work in the commercial sector, including hospitals and other high-visibility projects

accomplished with equal success by experienced project site managers and construction foremen.

3. Construction drawing coordination in the field is being performed directly by the lower tier subcontractors, independently of the architect's models, and these contractors appear to be driving the adoption of the IT solutions at the construction level.
4. General contractors are driving the construction process planning, but they are assigning this work to specialty contractors – usually to mechanical contractors who coordinate the mechanical, electrical and plumbing (MEP) work.
5. The project owners need to be convinced to consistently support BIM usage. Many contractors will use BIM even if the owner does not require it, but most will not invest substantial resources if the owner is not willing to pay for the service. This research reveals that the owners lag behind the contractors in their desire to use this technology.
6. The architectural and structural designers utilizing BIM are often not providing reliable models for direct use on project sites. Contractors report that architects and their consultants using BIM often provide general models for orientation purposes only, but the contractors themselves need to produce their own detailed working models from 2-D contract documents provided by the architects.
7. Lastly, the creation of BIM-based detailed design documentation by contractors causes them to look more closely at the design details specific to their trade and allows them to understand how their detailed design decisions fit into the overall design of the project. This seems to be an effective approach to the distributed design process. These factors enable contractors to produce plans that will facilitate higher rates of productivity by reducing design conflicts and increasing the likelihood of having a project site layout and/or a work system setup that reflects their preferred operating style.

4. Results of General Survey

With face-to-face interviews with managers and representatives of companies, the survey was directed toward the leading indicators of field efficiency: RFI's, rework, change orders and schedule compliance.

4.1 RFI's

As shown in Table 2, the findings from this research indicate an arithmetic average of only 10 RFI's/$10 million (M) on projects that utilized BIM to any degree. The range was from 0.4 to 35 RFI's/$10M on projects that ranged from $8 to $231 million with an average of $85 million.

4.2 Rework

Rework due to field work scheduling conflicts: during this study 79% (37 of 47) of the respondents stated there was "very little rework and waiting time" when BIM was used for coordination of construction work on site. 13% (6 of 47) stated that there was improvement but could not express its value in quantitative terms. The remainder of the responders stated that they did not know or could not say whether there was any improvement attributable to BIM. This data is shown in Table 2.

4.3 Change Orders

Change orders (CO) due to errors and omissions and to field conflict based on incomplete plans were reduced dramatically. As shown in Table 3, change order reduced to less than 10 in ten projects completed using BIM for coordination.

In addition to the changes eliminated by reducing the design conflicts, the contractors and owners claimed that change orders were drastically reduced because the owner's intent was better represented in three dimensions so that the owners (building users) and builders

Table 2. Number of RFI's per $10 million

	Project type	Size ($M)	# RFI	RFI/$10M
1	Educational	15	52	35
2	Office	32	28	9
3	Hospital	107	300	28
4	Hospital	231	291	13
5	Office	120	32	3
6	Med. Proc.	145	137	9
7	Educational	61	21	3
8	Hospital	8	25	31
9	Educational	78	17	2
10	Educational	42	11	3
11	Hospital	96	4	0.4

communicated more efficiently and thus created models that represented the project outcome as needed. Owners in the survey believed that they saved 4–7% of project cost because of the non-issuance of CO's. This data is shown in Table 3.

4.4 Schedule Compliance

The exact value of schedule acceleration or reliability was not determined, but six out of the seven contractors and the owners included in the case studies stated that the projects were completed with the use of BIM. Eight of the nine interviewed contractors also indicated that the project schedule improved as a result of BIM. The principal schedule benefits gained by using the BIM process are less rework, quicker project layout, increased prefabrication and detailed scheduling capabilities. Contractors that commented on the amount of schedule change felt that there were savings of 5% to 10% based on the advantages listed above.

5. Results of Case Studies

Case studies characterize typical samples of the BIM managerial practices and the stakeholder's perceived productivity increases. The following eight case studies include the perspectives of the owner, the general contractor, and the trade subcontractor.

5.1 COMPANY-1 (Owner)

COMPANY-1 is making an effort to pioneer BIM usage in property development and portfolio management. COMPANY-1 employs internal BIM-capable architects and engineers, but also outsources some design to third party architects and engineers as needed. Conceptual design is performed with the aid of modelling tools on new projects. Some projects have been fully modelled in 3-D. Time scheduling (4-D) has been performed on some projects and manufacturing data for maintenance (6-D) has been included in some of the firm's models. As an organization, the firm keeps records of various practices and results that they are creating on their continuing experimentation with BIM.

From the smallest $2 million remodelling to the largest $200 million construction project, clear advantages in terms of reduced RFI's, change orders and rework were gained by the use of BIM during the construction and design process. COMPANY-1 is continuing to collect data on key cost and schedule indicators in relation to their BIM and construction management practices to determine the most effective manner of BIM expenditure. The ROI of BIM implementation is clearly positive since they are increasing BIM usage after completing 10 projects.

Table 3. Change orders

No.	Project type	Project size ($M)	No. of change orders
1	Educational	15	7
2	Office	32	2
3	Hospital	231	9
4	Office	120	1
5	Med. Proc.	145	2
6	Educational	61	3
7	Hospital	8	1
8	Educational	78	3
9	Educational	42	2
10	Hospital	96	0

The productivity changes on BIM projects compared to non-BIM project experienced by COMPANY-1 with respect of the four factors are as below:

1. RFI: A typical reduction in RFI's of approx. 90% on BIM related projects.
2. Rework: The quality of the work is improved due to fewer modifications and compromises on the project site.
3. Change orders: There is less rework and significantly fewer change orders.
4. Schedule compliance: The schedule is more accurate and of shorter duration.

5.2 COMPANY-2 (General Contractor)

COMPANY-2 is one of the top 100 companies in revenue in the USA and in the top 20 in the hospital sector. COMPANY-2 has five different divisions housed under the holding company, but this study involves the primary construction firm which performs most types of commercial construction nationwide. To manage their BIM dynamics, COMPANY-2 employs a corporate BIM manager, two BIM project managers in the office, and two BIM operators in the field.

Currently, COMPANY-2 fully models each healthcare facility construction project in BIM. Commercial projects generally use some aspect of BIM to a significant extent, utilizing BIM in coordination of work in about 75% of these projects. Tenant improvements and smaller construction projects do not usually have any BIM usage.

The overall result of COMPANY-2's BIM management style has proven to be such an increase in effectiveness that they have moved toward implementing BIM on most of their projects. They do not know the exact increase in productivity, but believe that it is well worth it to spend the 1/2 to 1% of the project cost on the BIM process because it solves many problems in the field.

The productivity changes on BIM projects compared to non-BIM project experienced by COMPANY-2 with respect of the four factors are as below:

1. RFI: Reductions in RFIs approaching 90% when compared to typical non-BIM projects are common. On a recent fully BIM-modelled 85,000 square feet (SF) (8,400 m^2) hospital project, COMPANY-2 experienced only 15 RFI's from the field. A typical project of this type without the benefit of BIM would be expected to have hundreds of RFI's.
2. Rework: The process of completing shop drawings principally from the model is 60% faster than with using 2-D clash detection. This planning and clash detection reduces field confusion and rework. Field rework is nearly eliminated.
3. Change order: On 85,000 SF (8,400 m^2) hospital construction project, 10−15 thousand real collisions or conflicts were discovered on each floor of this hospital. These were locations where different construction trades would be colliding with one another, and because it was determined that these collisions would have happened in the field based on 2-D drawings provided, the company saved $750,000 to $1 million in change orders.
4. Schedule compliance: COMPANY-2 simultaneously constructed two similar hospital projects in California; each approximately 250,000 SF (24,000 m^2). One hospital project was fully modelled with the use of BIM while the other had no modelling. The BIM-related project was two months ahead of schedule compared to the non-BIM project which was two months behind schedule.

5.3 COMPANY-3 (General Contractor)

COMPANY-3 is a $2 billion/year general contractor with several regional offices that are free to adapt operating procedures based on local conditions and needs. As a company policy, COMPANY-3 now utilizes BIM on all hospital projects. COMPANY-3 recently completed a hospital construction project in which the contractors began to implement BIM after the engineers had already completed their design work, and because of the results of that effort, the firm decided that all such projects should be modelled.

The productivity changes on BIM projects compared to non-BIM projects experienced by COMPANY-3 with respect of the four factors are as below:

1. RFI: An estimated 50% reduction in the number of RFI's. Few of the RFIs were field generated.
2. Rework: There was almost no rework and only a limited amount of unproductive field time for subcontractor labourers.
3. Change orders: Only 10% of the change orders were related to design changes and scope.
4. Schedule compliance: Pre-fabrication of electrical components before final assembly on the site contributed to shortening the schedule. BIM was helpful in coordinating the work and running a better schedule based on the more detailed planning.

5.4 COMPANY-4 (General Contractor)

COMPANY-4 is a general contractor with up to $180 million in annual revenues. They specialize in concrete tilt-up and warehouse construction but also perform projects in the public construction sector. The majority of their work is delivered by design-bid-build (DBB) project delivery, but the firm also engages in professional construction management (CM) and are venturing progressively into the design-build (DB) project delivery. Concrete installation is self-performed by efficient unionized forces. Due to market forces and the excitement about getting involved in BIM, COMPANY-4 decided to attempt BIM implementation. To perform a good effort experiment with BIM, they hired an in-house BIM expert for coordination and modelling, and performed several projects using BIM to a varying extent.

The productivity changes on BIM projects compared to non-BIM project experienced by COMPANY-4 with respect of the four factors are as below:

1. RFI: The RFIs were reduced to about half of what would be experienced on non-BIM projects.
2. Rework: Reduces rework when plans are coordinated.
3. Change orders: Grater clash detection abilities for the mechanical-electrical-plumbing (MEP) trades decreases conflict between trades. However, no consequences regarding clash detection were observed.
4. Schedule compliance: Productivity rates for the firm's field workforce did not change significantly on BIM projects. No particular consequences were observed in this regard.

5.5 COMPANY-5 (Electrical Subcontractor)

COMPANY-5 is the electrical contractor on an Airport project. COMPANY-5 is not new to modelling, but this is the first fully modelled project for the superintendent. The construction manager company has modelled many of their large projects as well, but there may be differences in the way in which the projects are managed.

Increased productivity followed on the airport construction project with respect of the four factors in which COMPANY-5 is the electrical contractor:

1. RFI: Marked reduction in RFI's.
2. Rework: Much less rework due to reduced conflicts.
3. Change orders: In a typical clash run, a very large amount of clashes are discovered – on one run 48,000 were identified by the program. However, no particular consequences were observed in this regard.
4. Schedule compliance: BIM is making the project more efficient because components are fabricated in their own shop or ready-made components are ordered from vendors. Prefabrication of components makes them meet specific requirements so that the fieldwork is more precise and the finished product is of better quality. This also speeds field installation. However, no particular consequences were observed in this regard.

5.6 COMPANY-6 (Mechanical Contractor)

COMPANY-6 is a large mechanical contractor, headquartered in southern California, but that performs work nationwide. Their capabilities in design and modelling and attitude toward collaboration attract projects that are almost exclusively design build. The Senior Vice President, reports that COMPANY-6 prefers to be brought in early in the project where they can have a better opportunity to participate in design coordination. Because fabrication of sheet metal used in their installation is based on 3-D representations, COMPANY-6 has been modelling in 3-D their own ductwork since the 1980's. The profit centre involves ductwork and heating-air conditioning-ventilating (HVAC) systems, and BIM is one tool that enables more efficient fabrication and installation. Because the firm had been modelling in 3-D for their own operations, they were poised to begin BIM coordination with other members of the design-construction team when the software became readily available in the 1990's.

The productivity changes on BIM projects compared to non-BIM project experienced by COMPANY-6 with respect of the four factors are given below:

1. RFI: Virtual elimination of field-generated RFI.
2. Rework: Rework is reduced dramatically. On BIM projects rework amounts to a fraction of 1% which is remarkable when compared to industry average of 14% of the cost of the project attributed to rework. The reduction is attributed mainly to the increased coordination between other trades and the increased accuracy. Rather than being within a 1/2″ with paper planning, tolerances are generally within a 1/16 of an inch – limited primarily by human ability rather than by the software.
3. Change orders: No particular consequences were observed in this regard.
4. Schedule compliance: Field installation time is reduced. The larger pieces are assembled more quickly and inspections are faster. The time spent on fieldwork was cut by 75% but the modelling took additional time. The field layout is on the critical path while the preparation work in the office may be able to be accomplished off of critical path. Therefore overall layout time in the field can be reduced if properly scheduled with the general contractor. Because mechanical work is generally on the critical path, this could reduce project schedule duration.

5.7 COMPANY-7 (Mechanical Subcontractor)

COMPANY-7 is a large mechanical firm with different groups running various types of projects for diverse clients. BIM is not used on most projects unless the owner requests and sponsors the work. The firm has an in-house BIM department that models work on large, multi-story projects in which the ductwork will be repetitive and should be coordinated with structural design and other design components. However, on high-tech, fast track projects common in Company-7 portfolio, there is not enough time to model the project with BIM. The foremen on the projects can visualize sufficiently the fit of the materials and equipment to be installed because of their experience with installation.

There are no real advantages experienced by COMPANY-7 with respect of the four factors on its small and fast-track fit-out projects.

5.8 COMPANY-8 (Framing Subcontractor)

COMPANY-8 is a framing and drywall contractor working in the commercial construction sector, including hospitals and other high-visibility public projects. They perform BIM services using company's in-house operators when requested by owners or general contractors to do so but do not utilize BIM on all of the firm's projects. BIM is part of the company's service package, not as a stand-alone profit centre.

Productivity changes on BIM projects compared to non-BIM project experienced by COMPANY-8 with respect of the four factors were as described below:

1. RFI: When COMPANY-8 is involved in BIM coordination, RFI's in the field are greatly reduced and usually eliminated. RFI's that do occur happen in earlier stages of the project and rather informally during the design phase. The requests for clarification are issued before field personnel are situated in the field attempting to install materials and/or equipment based on an imperfect plan.
2. Rework: Rework is reduced on projects that employ BIM. COMPANY-8 keeps records concerning the amount of time wasted in the field due to rework and plan conflicts, but only when the delay or extra work results in a change order. If loss of productivity does not appear to be billable to the project owner, the time spent waiting for directions or attempting to determine what to do due to poor planning is not recorded by the field labour management.
3. Change orders: Most of the rework and non-productive time is a result of MEP conflicts in the field. The firm feels that the more significant benefit may be for the other project participants, although even reducing MEP conflicts helps COMPANY-8 to be more efficient because the firm does not have to demolish installed work nor do they have to proceed from one area of the project to another in a suboptimal manner due to jobsite scheduling or physical conflicts. Any coordination accomplished prior to field work reduces RFIs, rework and change orders.
4. Schedule compliance: Although COMPANY-8 does not know precisely how much time is spent in non-productive activities as a result of the lack of proper coordination or scheduling, they know that amount is significant and preliminary experience indicate that BIM usage decreases the non-productive field time.

6. BIM Management Key Choices that Optimize Field Productivity Increases

According to the responses received from the construction firms surveyed, although BIM application almost always has a positive impact on productivity in the field, some key decision in regard to BIM usage will likely make productivity advantages even higher. The following section will describe these decisions and their effect on field productivity.

6.1 Effects of Project Delivery Method on BIM Effectiveness

The DBB project delivery method (PDM) will not likely exhibit the same levels of productivity increases due to the use of BIM as the other PDM's. The value adding feature of BIM in regard to field productivity is error elimination, and competitive bid contracting culture rewards contractors who are set on identifying conflicts and issuing claims for extra work and/or managing productivity despite confusion caused by erroneous design documents. Merely modifying DBB contracting approach will not rectify the problem because the BIM process is only marginally effective without an open collaborative environment in the project. Value can still be gained if project owners define their BIM requirements and reward lower tier contractors and suppliers for following them by sharing the resulting savings or at least paying for their BIM related efforts directly. There are a few cases of past projects where the project owner has modelled the project using BIM software, and subsequently provided that model to all competing contractors prior to the bid to obtain more favourable pricing. Increasing the quality of information contained in the design documentation and confidence in the building plans is an effective way of reducing construction field costs by up to 10%. Research reported herein has not identified any cases of the project owner believing that BIM application has not provided any savings to the cost of construction, but this research has identified three DBB project cases in which the contractors felt that there was no appreciable savings awarded to them. No other PDM's experienced a lack of savings due to the application of BIM.

Cost savings are evident for both the contractor and the owner on CM and DB projects. DB projects experience nearly half of the RFI's experienced by comparable CM projects. Two factors which are likely to cause this difference are that on the DB projects there has been typically more involvement and support by the owner, and the subcontractors were involved at the earlier stages (at least by the 50% completion point) of the design process. The trade subcontractors were selected primarily based on their technical qualifications in the case of DB projects, and based on their lowest bid in CM projects. These factors result in more collaboration among project team members in DB projects. Few DB or other projects are implementing an integrated project delivery (IPD) approach, but in the projects that were claimed to be such the project owner was actively involved in bringing the entire project team together in the early design stages, and contractually relating team member profitability to the progress in the project tasks based on the BIM based design. In terms of overall satisfaction and savings to the project owner, the savings resulting from the use of BIM in various PDM environments have been reported in the following order (from the lowest to the highest savings): DBB, CM, CM design-assist, DB, IPD.

6.2 When to Select Design Team

It was found in this research that contractors should be involved at the design stage of a project at the latest when the design documentation is 50% complete, but preferably earlier. By so doing the contractors can have a greater influence on the way the structural components are arranged and coordinated. In such cases the need for subsequent constructability reviews of completed project plans is not as compelling. In addition to the improvement in the design process itself, plan coordination and clash detection with construction contractor input significantly and directly affects field productivity. However, bringing the contractor into the design process before a clear definition of the entire project is articulated by the architect would yield a diminished effect. This research showed a weak positive relationship between the modellers beginning their work by the 50% mark of the completion of project design activity to the number of RFI's and rework. Clash detection with the use of BIM caused a significant reduction in RFI's on all surveyed projects.

6.3 Coordination Meetings Management

Design coordination meetings for the purpose of clash detection should be held weekly. Most surveyed contractors used a teleconferencing software environment (e.g. GoToMeeting®) because such software allows meeting participants to attend from their home office, and they are not interrupted in their other work when they need not be involved in the conversation at hand. Discussing only major or important conflicts at these meetings is important lest they become a waste of time for contractors. The productivity level in a meeting does not have a significant impact on field productivity, but it does affect overall project costs. Co-location is not critical to project success and unless the project is particularly large and complex, a physical "big room" meeting environment may be detrimental to designer satisfaction. Field productivity increases due to rework elimination and cooperation on prefabrication between specialty trade contractors were evident when the modellers knew and trusted their counterparts from other trades. Mechanical contractors are frequently called upon to perform coordination between the models from all the contractors, but it was found that it is more effective for the general contractor or the architect to manage the meetings. There was little effect on field productivity based on who managed the BIM related process, but the effectiveness of the design process was dependent on the approach to meeting management.

6.4 BIM Software and Modeller's Experience

In the surveyed projects no relationship was discovered between the brand of BIM software used and field productivity. Many contractors urge the use of the most dominant BIM software on the market, but according to the findings of this research the quality of the design coordination as measured by the number of RFI's originating from the project site and rework does not appear to be dependent on all contractors using the same modelling software. Some improvement in design process efficiency has been noted in several cases where all members used the same BIM software. Another opportunity to use common BIM software is when the owner requires a comprehensive as-built model delivered by the design team at the end of the project.

There is a relationship between the skill level of an individual engaged in design modelling with BIM software and project field productivity based on rework and number of RFI's. If the modeller does not understand the intricacies of the field operations for the specialty trade for which modelling is performed, the model may not include all of the components that should be included, or will depict these components improperly. Inexperienced modellers were cited as a significant cause of BIM failure causing rework in the field. The steep portion of the "learning curve" by field modellers knowledgeable about relevant field aspects of construction in regard to the technical aspects of BIM corresponds to approx. 3 to 4 projects. The "learning curve" for managing the modelling process (e.g. deciding correctly what to model) corresponds to 2 to 3 projects. If the modeller is not knowledgeable about relevant field operations, the "learning curve" is as long as it takes to learn the relevant details of the field operations in the project. At the field operations level, the contracting firm that will perform the relevant field work should also be the one to create the virtual model of the project documentation. Similarly, there is a strong correlation between the BIM competency of the contractor asked to generate the model of its field work and the amount of rework performed that was associated with the model. Lack of a high degree of such a competency has the effect of reducing field productivity. Contractors in this study found that the best method to make the BIM modeller effective was to train him/her directly in the field in the relevant aspects of the work to be performed. In this way, the modeller is able to see the real practical implications of his/her modelling details.

6.5 Level of Detail

The level of detail to be modelled is determined by prior experience. Some contractors specify minimum sizes of components to model while others let the specialty trade contractors decide what to model, but hold them responsible if their components clash with another trade's work that was also modelled. Too little modelling can be a cause for lower field productivity, but too much modelling does not negatively affect field operations. The most common complaint about what was modelled was that too little was being modelled, thus increasing waste and decreasing productivity.

7. Conclusions

The relative newness of BIM allows contractors the opportunity to increase profits by improving productivity while using pre-BIM productivity rates. This productivity is gained by clear visualization of the component assembly and elimination of conflicts in the field. Labour does not stand idle waiting to determine how to install material because it was coordinated in the model. There is little rework done because of conflicts. Larger, prefabricated building components make it easier to perform more work in off site where working conditions are more amenable to higher production rates. These causes contribute to the reduction in the amount of time spent to erect the structure. Until more contractors are able to manage the coordination process and realize lower costs, there will continue to be an opportunity to gain BIM early adopters' profits. As more contractors learn how to increase their productivity through the use of BIM, the amount of money that can be charged as premium will begin to decrease.

After completing BIM related construction projects, over 90% of surveyed contractors claimed to not want to perform another project without the use of BIM. BIM's evolution is not yet complete and it has not reached its full potential. The advancement of BIM from a construction tool to a project performance culture can be seen as the gradual construction of a new cooperative team attitude. Productivity gains in the field will only be one symptom of the advent of the BIM "Cultural Revolution," but they are one of the first that has already been realized.

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