SOFTWARE INTEROPERABILITY AS THE FUTURE STANDARD FOR DESIGN AND CONSTRUCTION

By

AYESH LAUREN BHAGVAT

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE IN BUILDING CONSTRUCTION

UNIVERSITY OF FLORIDA

2009

To my wife, for her constant support, strength, sacrifices and belief in myself and my ability to be all that I can be

ACKNOWLEDGEMENTS

I would like to thank the M.E. Rinker Sr. School of Building Construction for accepting me into their prestigious program and in doing so, imbuing me with a level of expertise and professionalism that I will forever be grateful for. I would also like to thank Dr. R. Raymond Issa, Dr. Svetlana Olbina, and Dr. Douglas Lucas for participating as my committee members on this endeavor, without whose help this thesis would have been unattainable.

Finally, to my helpmate, playmate, soulmate, wife and best friend, Erin, whose love during all the years has been the strong wind that, constant and true, has given my life direction.

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of the University of Florida in Partial Fulfillment of the
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Ayesh Lauren Bhagvat

August 2009

Chair: R. Raymond Issa
Cochair: Svetlana Olbina
Major: Building Constructon

Construction efficiency is the most sought after factor in the industry today. The ability to maximize profit while maintaining a defined schedule and meeting set deadlines are key aspects sought after in the construction industry. Of these aspects, maintaining steady lines of communication between the three major participants in the construction industry, (Architectural, Engineering and Construction) are paramount to delivering the standard of efficiency required today. In this regard, the development and propagation of common, multi–faceted Building Information Modeling (BIM) programs that have been used effectively by the design, project and construction management enterprises has been an endeavor that has reaped major dividends in the industry today.

The amount of effort it would require to enhance the compatibility between BIM and design software and increase efficiency and understanding between the design and construction sections of the industry is fairly minimal when one considers the rewards that can be obtained in the process. More importantly, adding the owner into the tried and tested equation will only allow for a better understanding of the intricacies of design and construction on the owners part as well as a unique perspective into the needs of the owner from the design and construction

arenas. Exploring the options available for the integration of certain malleable software into the symbiotic relationship of the Owner, Architect, Engineer and Construction Manager, while analyzing and estimating the increase in efficiency as a result of it show that the need for software compatibility in today's evolving industry is incontrovertible.

CHAPTER 1
INTRODUCTION

Efficiency in construction is the most sought after factor in the industry today. The ability to maximize profit while maintaining a proliferate schedule and meeting set deadlines are key aspects sought after in this industry. Of these aspects, maintaining steady and knowledgeable lines of communication between the three major sections of the construction industry (Architecture, engineering and construction) are paramount to delivering the standard of efficiency required today. In this mien, developing and propagating a common, multi–faceted program that can be used effectively by the design, project and construction management enterprises is an endeavor that would reap major dividends in the future of this industry.

One of the major issues faced by the construction industry is the inability of the different areas of the industry to understand what the workings of the other areas entail. The design industry, for example, has different priorities when it comes to construction. Aesthetic qualities, innovative design and user comfort are a few of the primary ideals emphasized in the architectural facet. Construction deadlines, material cost and labor issues are some of the subjects that are not as dire to the design department as it would be to the construction/project management department. The Owner, arguably the most important link in the chain, is often left out of important decisions due to their lack of knowledge or comprehension of the workings of the industry. This shift in prioritization reflects on the work performed by those individual groups and often lead to miscommunications and fallouts between them.

Software based programs and BIM technology is the most widespread and developing technology in the construction industry today. Designers use three dimensional modeling programs such as 3DS Max to add aesthetic values, materiality, lighting, texture and animations to the projects they work on. First person walkthroughs of the projects can be animated and developed for the lay person or owner to understand a design in its entirety before construction. Project and construction managers, on the other hand, are quickly adopting the use of software such as Autodesk Revit as an industry standard of categorizing materials, estimates and schedules for a desired project. What the industry fails to realize is that most of these technologies are a few software issues apart from being completely compatible with each other.

1.1 Statement of Purpose

The amount of effort it would require to disseminate the compatibility between BIM tools and traditional design software while increasing efficiency and understanding between the design and construction departments of the industry is fairly minimal when one considers the rewards that can be obtained in the process. More importantly, adding the owner into the tried and tested equation will only allow for a better understanding of the intricacies of design and construction on the owners part as well as give the designers and contractors a unique perspective into the needs of the owner from the design and construction aspects. It is the intent of this study to explore and identify the options available for the integration of certain malleable software into the symbiotic relationship of the owner, architect, engineer and construction manager. Analyzing and estimating the increase in efficiency as a result of these integrations illustrates the incontrovertible need for software compatibility in today's evolving industry.

1.2 Objective of the Study

The objective of this thesis is to evaluate the positive and negative attributes of implementing a collaborative BIM program into the construction process while prioritizing the commonly ignored owner involvement. This objective is broadly divided into four sections:

- Collect, analyze and prioritize the benefits of BIM and design software compatibility that have been cited to date.
- Use the preceding findings to perform interviews with national (2) and international (4) design and construction companies. These results were used to gauge the viability of

integrating software to help the owner perform a more active role in the construction process.

- Analyze the results of the interviews while documenting the advantages and limitations of implementing BIM with regards to broader compatibility.
- Summarize these findings into a decisive conclusion with weighted recommendations with regards to the viability of owner-prioritized software integration in the AEC industry.

1.3 Scope and Limitations

The scope of this study revolves around the latest research on the merits and advantages of aggressive implementation of collaborative BIM software into medium to large scale companies as compared to the traditional segregated, parallel processes followed by the designer, the contractor and the owner. Particular attention was paid to the possible improvement of the construction process by the greater involvement of the owner in BIM development.

Research was also conducted on the effect of implementing collaborative software on the overall productivity of a construction enterprise, by following certain fundamentals of construction productivity. In today's industry, BIM is more strongly accepted as a construction standard due to it increasing compatibility with estimating and scheduling software, thereby bridging the gap between the architectural, engineering and construction fields. It therefore stands to reason that extending that compatibility to incorporate the owner into the collaboration would augment the efficiency and productivity of any construction endeavor.

CHAPTER 2
LITERATURE REVIEW

The concept of Building Information Modeling in this study focuses on the significant impacts associated with its implementation on all the affiliates of a project team. Every passing day, planning, building and operating structures with BIM diverge from practicing the same processes in the traditional segmented format. This chapter discusses a variety of research done on the effect of BIM utilization on existing construction practices, productivity enhancements due to effective implementation and the possible disadvantages of implementing BIM technology. All these point to the fact that Building Information Modeling is not a software or set of programs, but a conceptual shift in the thinking process of the construction industry.

2.1 Building Information Modeling In Today's Industry

Current tradition involves a majority of firms designing a project by hand. These designs, being their own entity, are then analyzed by the engineering department. Structural feasibility, estimates, simulations, energy analysis, GIS integration and fabrication are some of the factors that are then added and assessed before a complete and feasible design is produced. Once in production, the project and construction management team would then have to use these specs to form their own series of information involving items such as scheduling, energy analysis, erection, and facilities management.

By using collaborative and compatible software, a number of the aforementioned steps can be combined into one efficient and all encompassing system in which information cannot only be accessible to all the facets of the industry, but also understood by them. This reduction in the general construction time would result in a reduction in the ultimate cost for the project as a whole.

2.1.1 Presently Used Architectural, Engineering and Construction Business Processes

In today's AEC industry, the traditional delivery processes, although logistically sound, remain relatively disjointed. Heavy reliance on paper based forms of interaction frequently results in unaccounted loss of information, unintended omissions and other such delays. Efforts have been made to seek out alternative methods of delivery processes, such as shared websites with commonly accessible databases and the implementation of basic 2D and 3D CAD utilities. These methods, although marginally successful, still do not provide a comprehensive solution to the traditional delivery format. Although there are many variations to the contracting methodology, the two prevailing processes in the U.S. are the Design-Bid-Build and Design-Build methods (Warne and Beard 2005).

The Design-Bid-Build contracting method (DBB) is arguably the most traditional approach when it comes to business models in the U.S. This is usually the case because of the system's lack of demand to select any given contractor as well as its ability to result in a substantial amount of competitive bidding to attain the lowest possible cost for the owner. These reasons would explain why approximately 90% of public buildings and 40% of private buildings in the year 2002 were constructed using the DBB method (DBIA 2007). In this method, the owner employs an architect who forms a program that constitutes the project's design goals. These designs are recorded on drawings that have enough specific detail to aid forthcoming construction bids. At this stage, the architect may decide to incorporate a lesser amount of detail in the drawings to prevent any potential liability. These exclusions and inaccuracies frequently lead to disputes with the contractor, as the responsibility and extra expenditure have to be reassigned.

Following this process, the owner and architect determine which general contractor may bid for the project. The winning contractor frequently has to redraw and detail the architects work to reflect the priorities of the construction process, as well create their own shop drawings to articulate the finer details. If there are inconsistencies in any of the aforementioned drawings, the cost and time to resolve the conflicts on-site can be substantial.

The concluding phase, which is the commissioning of the building, involves checking all the building systems to verify functionality. The final drawings are then created to reflect all as-built changes, concluding the DBB process. The process of transferring all information to the maintenance departments is another time consuming process fraught with errors.

The Design-Build (DB) process was eventually created to abridge the management of tasks for the owner by combining the responsibility of design and construction into a single contracting entity (Beard et al. 2005). In this process, the owner deals directly with the Design-Build team to create a properly classified building program and graphical design. The in house contractor then estimates the total time and cost required to complete construction of the building. Following the implementation of the requested owner modifications, the concluding cost estimate for the project is set. The DB process allocates certain leeway for changes to be made to the building's design during the earlier stages of the project and in this way, curtails the amount of extraneous money spent on change orders and so on. In this process, it is not always necessary for comprehensive detailed drawings to be complete prior to the start of construction. This generally allows for the building to be completed at a shorter time period, with a lesser total cost and fewer legal ramifications. The drawback to this method however, is that due to the inherent nature of the DB process, there is a curtailed ability for the owner to incorporate changes after the preliminary design is approved and a contract amount if finalized. Figure 2-1 shows the difference in process between the DBB and DB methods of construction.

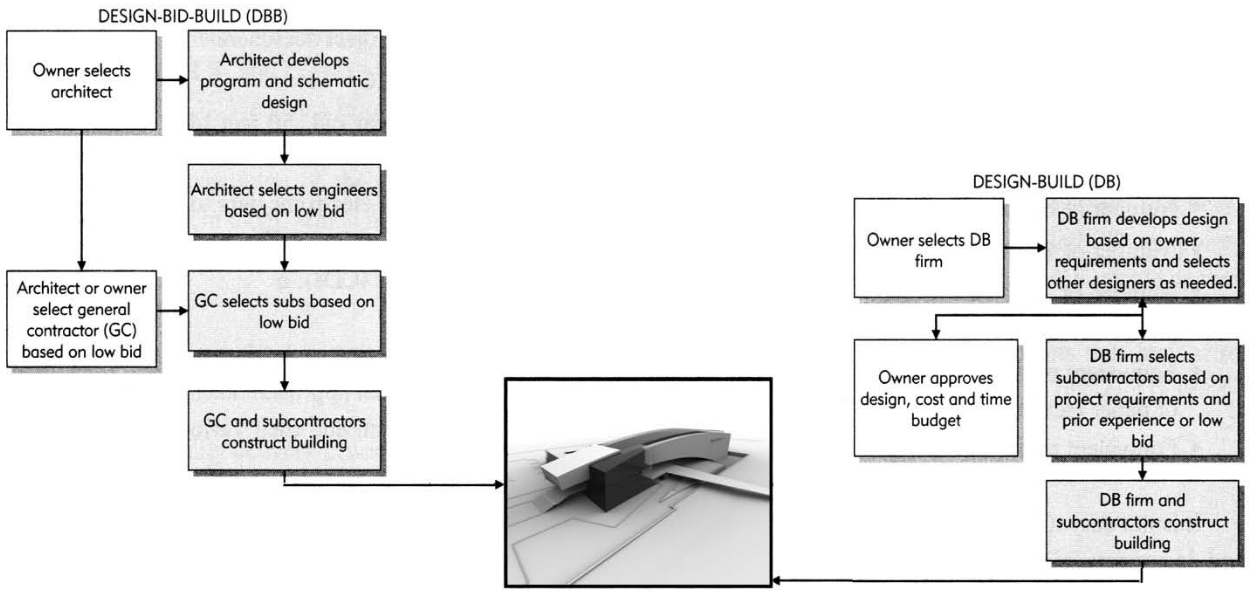

Figure 2-1. Schematic diagram of DBB and DB processes

The Design-Build method is gradually taking precedence in the international market as well as in the U.S. According to surveys conducted by the Design Build Institute of America (DBIA), in 2006, approximately 40% of construction endeavors in the U.S were based on a deviation of the DB format.

2.1.2 Inefficiency in the Construction Industry due to Insufficient Interoperability

In 2004, the National Institute of Standards and Technology (NIST) completed a study of all supplementary costs sustained by building owners due to insufficient interoperability (Gallaher at al. 2004). This analysis included the management and exchange of information, particularly instances when individual systems were incapable of accessing and employing data imported from a variety of other systems. The study focused on new construction during the year 2002 and comprised of institutional, commercial and industrial buildings. As mentioned before, incompatibility between software often leads to a plethora of problems including loss of information and additional costs. Calculated results showed that inefficient collaboration was responsible for the construction costs to be raised by $6.12 per square foot for newer construction. This resulted in a cumulative added cost of $15.8 billion. Please refer to Table 2-1 for a more detailed breakdown of costs.

Table 2-1. Costs of Inadequate Interoperability by Stakeholder Group, by Life-Cycle Phase (in $Millions)

Stakeholder Group	Planning, Engineering, and Design Phase	Construction Phase	Operations and Maintenance Phase	Total
Architects and Engineers	1,007.2	147.0	15.7	1,169.8
General Contractors	485.9	1,265.3	50.4	1,801.6
Specialty Fabricators and Suppliers	442.4	1,762.2	0.0	2,204.6
Owners and Operators	722.8	898.0	9,027.2	10,648.0
Total	2,658.3	4,072.4	9,093.3	15,824.0

Source: Table 6-1 NIST study

Hypothetical scenarios were created in which there was a flawless flow of information with no superfluous data entry and these results were compared to the current business costs and activities. Of these results, three major areas were recognized as items that cause additional costs due to insufficient collaboration:

- Mitigation (management of Requests For Information (R.F.I's), data reentry)
- Avoidance (incompetent business process administration, redundant computer systems)
- Delay (expenses incurred from idle employees)

Of these aforementioned expenses, approximately 68% (10.6 billion) were sustained by the owners. In addition to these findings, research conducted by the McGraw-Hill Construction Research Group identified similar factors as Drivers of Non-Interoperability Costs (McGraw-Hill 2007). Data re-entry, duplicate software use and unnecessary version checkouts were some of the redundant hindrances that were caused by lack of collaboration among construction companies (Figure 2-2).

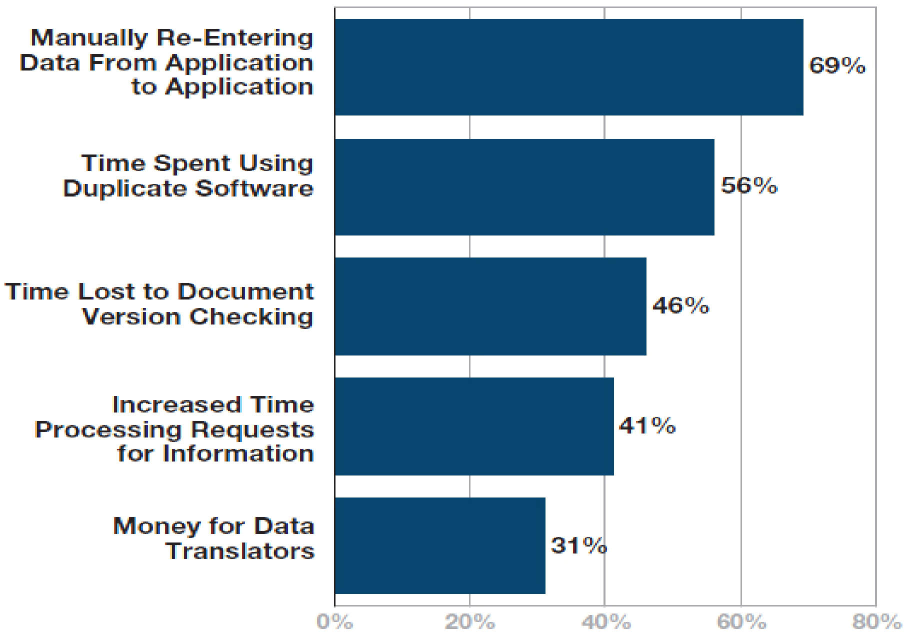

Figure 2-2. Drivers of Non-Interoperability Costs in the AEC Industry (McGraw-Hill Construction Research and Analytics 2007)

2.1.3 Adopting BIM Processes and Tools in the Construction Industry

Extensive adoption of Building Information Modeling while using comprehensive digital models from the initial stages and through the entire construction process is the first step towards purging all extraneous costs resulting from insufficient connectivity of data.

Since its inception, every CAD system and platform has generated digital records. These files, mostly in the form of drawings, were composed of layers, vectors and weighted line formats. Constant evolutions of this format lead to the addition of pertinent information and segments of data to be attached to these files. Adding another dimension in the form of 3D modeling allowed the use of complex surfacing tools along with advanced definition. As these systems grew in their ability to retain more information, CAD users shifted their priorities from 3D imaging to the actual categorization of attached data. This resulted in the eventual creation of BIM models and the tools supporting it.

BIM has been described as a modeling technology and associated set of processes to produce, communicate and analyze building models, i.e., an intelligent simulation of architecture (Eastman et al. 2008). There are also six vital characteristics that a model must exhibit to be able to achieve integrated delivery. These are:

- Spatiality (3D)
- Accessibility (through a collaborative interface)
- Comprehensiveness
- Digitalism
- Measurability (dimension-able and quantifiable)
- Durability (have the ability to be used through all the stages of a facility's existence)

These characteristics are imbued into what is commonly known as parametric modeling, which is the heart of BIM technology in today's industry. Parametric models are the culmination of years of evolution of virtual modeling and are central to recognizing its separation from traditional 2D models. They are comprised of associated data that is integrated non-redundantly into a project, automatically eliminating the possibility of inconsistencies throughout the course of a project. More importantly, parametric modeling is a dynamic system which automatically adjusts associated geometries to match each other, while staying within design standards. What this means is that when a wall switch is inserted into a wall it automatically aligns itself to the appropriate position beside a door, or when a roof is designed, it automatically levels itself out to the proper position on a wall. Since parametric modeling with BIM provides itself with a set of standards that can be modified at the user's will, it recognizes when an inserted object contravenes the feasibility norm set down by those standards. Conventional delivery methods have often promoted a divide between build team members, as work is handed off from one member to the next throughout the process and in order to reap the full benefits of BIM's ability to promote integrated project delivery, construction team members will increasingly need to have interoperable solutions (McGraw-Hill 2007). By adopting BIM processes and tools in today's construction industry, there will be a viable shift in the amount of extraneous effort spent on a project from the later stages of re-documentation and correction to the initial stages of preconstruction and design (Figure 2-3). This would allow for a more efficient and productive construction process.

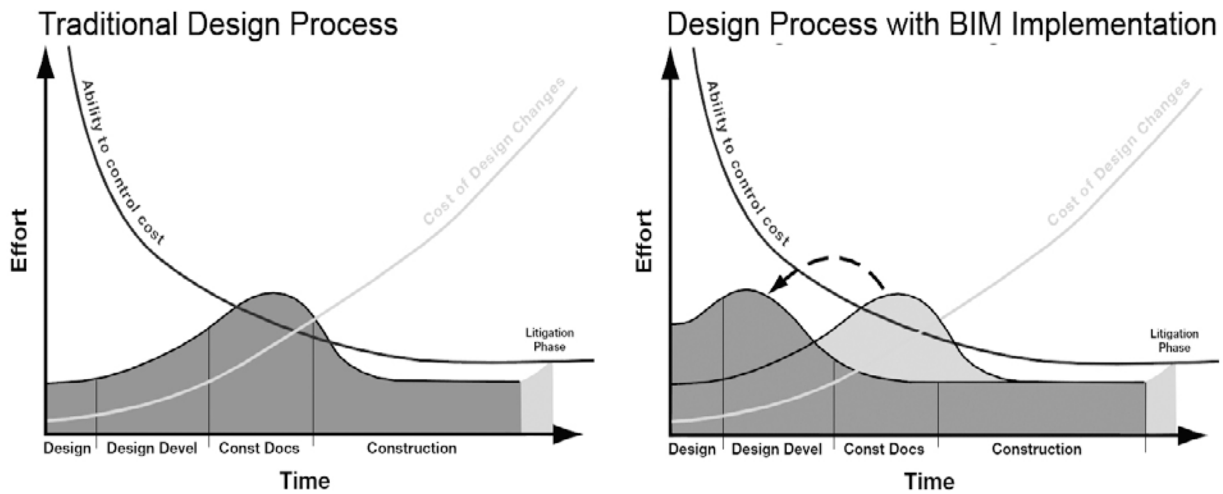

Figure 2-3. Earlier Decision Making Improving Ability To Control Costs (McGraw-Hill 2007)

The most important factor when it comes to implementation of BIM into all the facets of the construction industry is the concept of open interfaces allowing for collaborative interoperability between the owner, architect, engineer and construction manager. Although efforts have been made to do so, at the present moment a single computer application cannot support every task associated with building design and construction. Collaboration articulates the need to transfer data between applications, thus allowing a variety of professionals in their respective fields to contribute to the work at hand. Open interfaces allow for the import of pertinent data for the creation of a design as well as the ability to export that data into formats accessible by other standard construction software. Companies like Autodesk have taken significant steps towards propagating this compatibility by creating interoperable programs like

3DS Max, Revit and AutoCAD. These programs have concise integrations that provide the needed flexibility between the AEC components of the industry.

The aforementioned factors have resulted in a slow but steady acceptance and demand for the use of BIM in firms today. This quick integration of BIM is expected to have an exponential increase in the industry as its full potential is realized. Moreover, not only the firm, but also the owners are projected to have an increased demand for the use of BIM (Figure 2-8). As a considerable section of owners in the construction industry begin to take up BIM, there will be a natural tendency to have doubts over the collaborative aspect of these programs. Owners are the one facet in the industry that will enjoy the most benefits of proper collaboration. The total value of any investment will significantly increase if projects can be delivered faster and cheaper by eliminating waste through better interoperability. At present, the primary software program used by owners other than basic CAD software is scheduling. Scheduling software is frequently used by owners (57%) and many use project management programs (40%), but owners are frustrated by a lack of interoperability between these applications and other software used by the construction team (McGraw-Hill 2007).

2.2 BIM and Productivity

The construction industry is an entity that thrives on innovation and improvement. Since the dawn of the industrial age, advancements in development techniques and approaches have reaped substantial dividends. Essential functionality coupled with advancing ideals and a drive towards betterment is what distinguishes successful enterprises from their mediocre counterparts. All of these improvements could be fundamentally linked to productivity, or rather, its betterment. The clinical description of productivity as defined by the United States Department of Commerce is dollars of output per person–hour of labor input (Adrian 2004) and that description, although accurate, fails to encompass the scope development that this ideal embodies.

2.2.1 Obstacles to Construction Productivity

Despite the enormous size and significance of the construction industry to the U.S. economy, construction productivity is one of its most contentious and least understood factors. Much of construction industry policies in the U.S. are based on the premise that construction productivity has been gradually declining since the late 1960's (U.S. Department of Commerce 2002) (Figure 2-4).

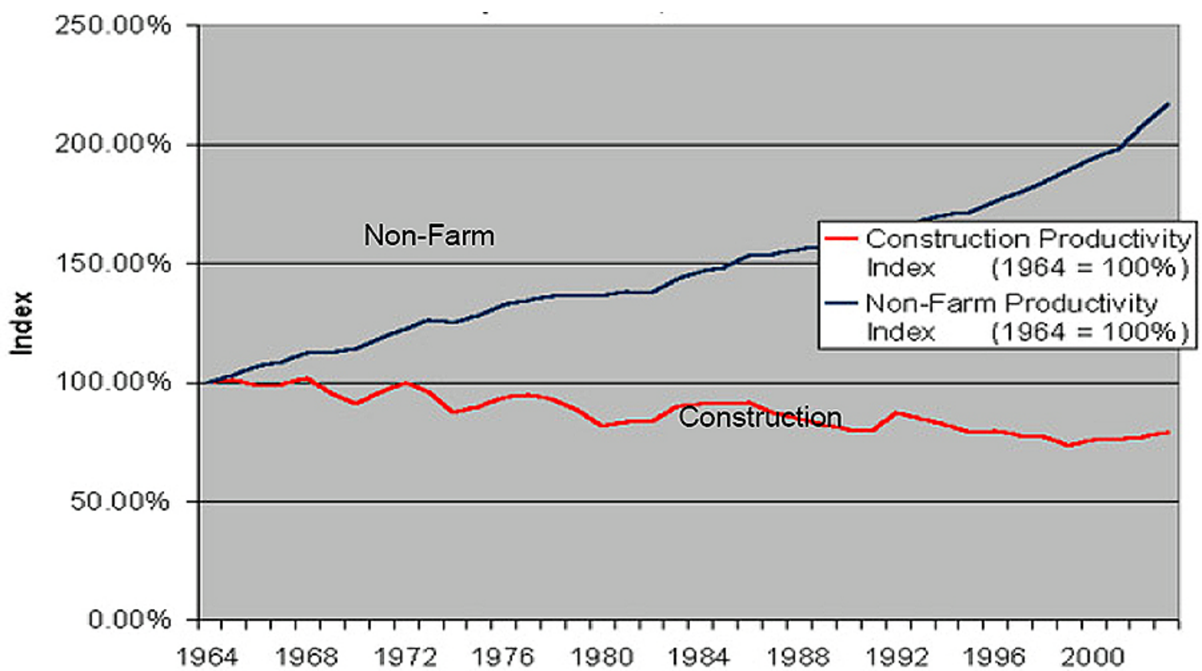

Figure 2-4. Constant $ of contracts / work hours of hourly workers (U.S. Department of Commerce, Bureau of Labor Statistics 2002)

Improvement in productivity will not be achieved without keeping in mind that there is an enormous number of factors that affect productivity and that it is necessary to locate the most influential ones among them. This approach helps determine the areas where the most effort is to be directed in order to reach optimum productivity. Using the Department of Commerce's definition of productivity, it becomes apparent that one could include a variety of resources such as materials, equipment, fuel, management etc. into this equation, all of which are relatively tricky to quantify. Adrian (2004) categorizes reasons for low productivity into three major groups, namely industry related factors, labor related causes, and management related factors.

In Industry Related Factors, the uniqueness of construction projects often concedes reasons for low productivity. When one considers the desirability of a unique design that project owners and design companies strive for, there is not much scope for contractors or project designers to make the most out of what was learnt from prior projects. The benefits from the use of a learning curve model or technique used by other industries would not be applicable to a project that thrives on its uniqueness. Exclusive projects do lead to artistically varied and innovative construction but its detrimental effect on the overall cost of construction projects and productivity cannot be ignored. Location variance is another aspect worth considering. Construction projects will mostly have decentralized aspects about them due to distance of resources, organization involving receiving those resources timely, accounting and also control problems arising because of this. The difference in the locations of various projects will regularly create a timing issue which will adversely affect the job productivity at that site. Construction is one of the rare industries that is subject to acts of nature, weather and seasonality. These factors significantly affect labor as well as equipment productivity. The construction industry is also directly affected by the state of the national economy. Dramatic swings in social policy, fiscal policies, tax laws and interest affect the individual contractor as well as the construction firm as a whole, leading to an eventual loss in productivity (Figure 2-5).

The size of the firm alone dictates the level of productivity that can be expected and obtained from it. Small, underfinanced firms may not be able to afford the latest or most appropriate equipped required for the particular job at hand and the optimum workload and productivity level would decline as a result. Research and development is an aspect that is often overlooked because of the limited budgets construction companies have at their disposal. The industry's lack of funding for research and development projects stop progressive ideas to better the industry and in its own way hinders construction productivity as a whole. Building codes, in an effort to maintain quality also have a hindering affect on construction productivity. They also vary from city to city, creating a problem for construction managers to draw experience from. Outdated codes also prove a tiresome burden for contractors and consumers to overcome, thus lowering construction productivity. Finally, the government can hamper the industry productivity by passing a variety of controversial regulations and laws that are not worth the benefits they confer relative to their cost.

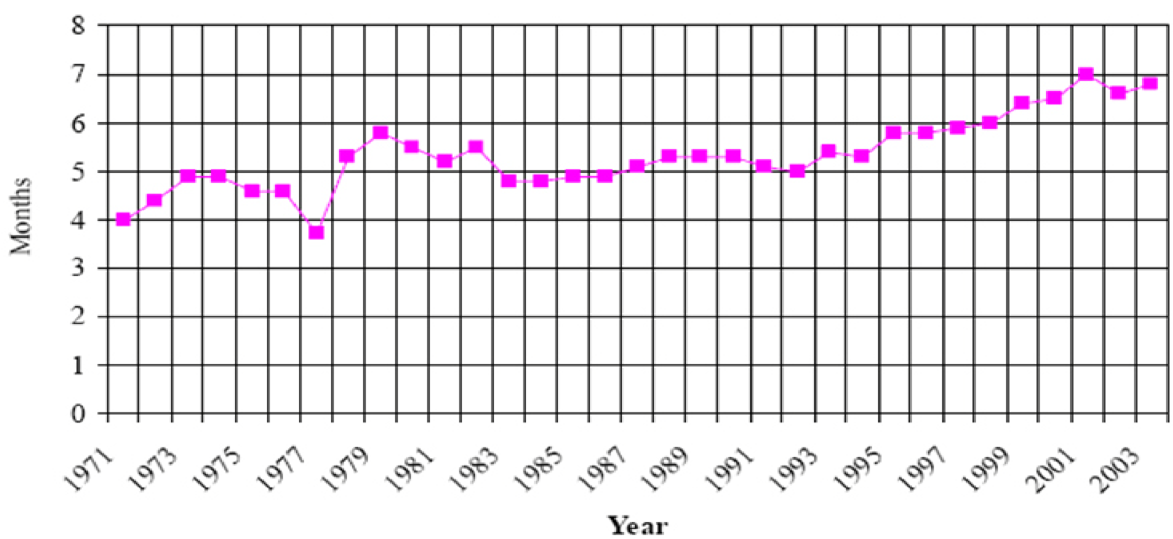

Figure 2-5. Average Number of Months from Start to Completion of New Privately Owned Residential Buildings (U.S. Census Bureau's Survey of Construction 2004)

In terms of labor- related causes, one of the major detriments to productivity is the high percentage of labor cost. The construction industry is highly labor-intensive. Its dependence on a significant amount of labor creates problems of high cost, adequate skills, worker attitude and supervision, all of which directly affect productivity levels. Labor productivity is a potentially risky factor that makes project cost estimates complicated. The supply-demand factor, in which the available resources have the most say when the resource exceeds the supply, is a characteristic that cannot be ignored. Due to the declining number of people entering the crafts, the availability of specialized labor is usually less than the demand, and this leverage give the laborers cause for decreasing productivity by working at a pace far below what they can actually accomplish. As mentioned before, every construction project is unique with regard to its construction methods and design. This in turn requires laborers to have to adapt to different projects, unlike the repetitive works most other industries expect from their laborers. Although this aspect prevents worker boredom and other such hindrances while providing new challenges, this challenge also affects labor productivity negatively by constraining the learning process. This industry is one that will always be injury prone. It has the worst disability frequency rate of all industries. It is, therefore, not surprising to find that workers tend to protect themselves from injury by working at a rate less than that which produces optimal productivity. This may seem counter-productive because an accident at the job site would prove more costly in terms of time and efforts to remedy it but in the end, righteous albeit over cautious behavior from the construction labor force is detrimental to productivity as a whole. Work rules often associated with union labor can prove harmful to the construction timeline at times. Historically, some work rules have dampened productivity with no offsetting benefit. Finally, lack of motivation for the worker is one of the most important causes for a decline in productivity. The individual worker rarely has the same goals or ideals as the management team and as such, would not have the proportional drive to complete the task in the most efficient or timely manner.

When it comes to management related factors, its lack of existence is responsible for a significant portion of the nonproductive time that characterizes the construction process. On many occasions, and excessive amount of attention is focused on labor without the management being included as contributing agent in productivity issues.

2.2.2 Total Quality Management

The aforementioned factors point out some of the consistent flaws that are prevalent in the construction industry today. There are a number of solutions that have been offered to counter the plethora of problems that hamper smooth and efficient productivity in the construction industry today. The method the author considers the most effective due to its comprehensive span and immediate effectiveness is the Total Quality Management approach.

Adrian (2004) defines Total Quality Management as a management philosophy that strives to involve every member of the workforce in controlling and continuously improving how work or a service is done with the objective of meeting customer expectations of quality. Quality means the freedom from errors or deficiencies, conformance or lack of variation through the commitment to improvements (Adrian 2004). Adrian (2004) simplified Total Quality management into a triad of philosophies: Customer Satisfaction, the Involvement of Everyone and Continuous Improvement (Figure 2-6). His description of this triad more than adequately articulates this approach:

> "The new wave of business, focused on the employees, while empowering employees, often resulted in slow decision making and a free reign type of work environment. In the TQM process, the focus or organizational entity shifts to the "customer". Attention is centered on identifying the needs of the customer. This includes the use of surveys and follow-up customer input. From the project owner of public agency perspective, there may be conflicting objectives and communication in regard to the project owner, designer and the contractor team. Often, these conflicting objectives end in a dispute, delays, or even law suits. In the TQM process, "involvement of everyone" is at the center of the program of improvement. Finally, the most important component of TQM is the emphasis of continuous and ongoing improvement." (Adrian 2004)

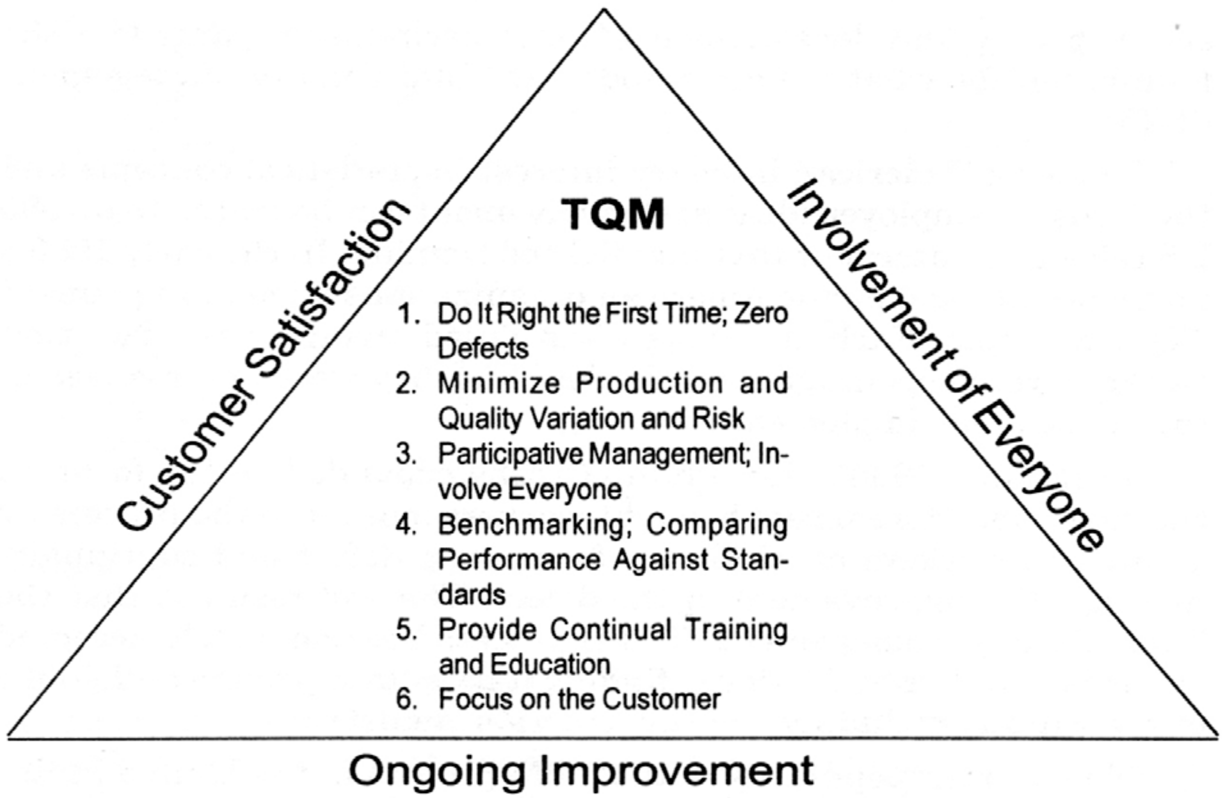

Figure 2-6. Three Key Components of Total Quality Management (Adrian 2004)

2.3 Benefits and Challenges of BIM Implementation

The AEC as well as the Facility Management industry could be considered to be in the early days of BIM use, even though it is a fact that BIM technology can maintain and advance most business practices. When it comes to the design industry, the immediate benefits are multifold. Earlier and significantly more accurate 3D visualizations of a design are created directly as opposed to being generated from multiple 2D views. Progressive software allows for visualizing the design at any stage of the construction process with the knowledge that every visualization will be dimensionally sound in any view. BIM also provides earlier 3D articulations that quantify the area of spaces and materials, making an initial accurate cost estimate a reality. For buildings defined by their technical aspect (factories, hospitals, etc.) quantitative design aspects are a norm, allowing a building model to be used appropriately to check all requirements.

If the building is more favorable to the qualitative aspect, the 3D model can be used to support automatic evaluations and requirements, i.e., making it easier to check against the design intent. BIM also allows for the linking of the building model to plug-ins such as energy analysis tools whereby an evaluation of energy use can be conducted during the early design phase. A process like this would not be possible using traditional 2D software that would necessitate an individual energy analysis to be performed after the design process. Most possibilities for alteration that would improve any energy performance would be severely curtailed at that point. This ability to tie the building model to different forms of analysis tools can significantly improve sustainability and energy efficiency.

When it comes to the construction phase, the ability to symbiotically orchestrate construction and design planning is invaluable. Construction planning using 4D software consists of linking construction plans to the 3D objects in a design, allowing the construction process to be simulated. This process could portray what the building would look like at any point during the construction phases, providing invaluable insight into day by day construction as well as the ability to foresee sources of potential problems and methods of solving them. Safety issues, equipment, area conflicts and site work are a few of the areas that could be worked on through this synchronization. This form of analysis would not be possible with physical bid documents and the like. Because BIM is a dynamic system, the effect of a change in design can be effortlessly entered into the building model which will automatically update the respective changes needed to other parts of the design. The inclusion of parametric rules allows for these automatic updates whose changes can be easily resolved because all alterations can be visualized, shared, estimated and resolved without the use of archaic paper transactions. Finally, if the completed design model is transmitted to a BIM fabrication tool and imbued with a level of detail comparable to that of shop models, it will have a precise representation of the construction objects required for fabrication. Being that the objects defined in 3D, the possibility of mechanized fabrication becomes extremely viable. Vendors could therefore detail any model needed for fabrication digitally.

For the post construction phase, the implementation of BIM would drastically help manage and operate facilities. As the building model is a source of graphical and specification-based information for all the systems used in a building, previously conducted analyses of control systems and mechanical equipment could be provided to the owner as a method of clarifying design decisions when the building is in full use. The model will also be updated with all the modifications made during the construction process which would make it an ideal starting point for operating and managing the building.

2.2.1 Benefits of BIM Implementation for Owners

From a traditional standpoint, owners have rarely taken the initiative to change the status quo of the construction industry format and are often prepared to accept problems such as cost overruns, schedule delays and quality issues (Jackson 2002). To owners, operational and lifecycle costs are considered a larger capital expenditure and generally take precedence over construction. The industry, however, is evolving from its linear processes and in doing so is forcing owners to rethink their views and place greater emphasis on the building delivery process and its impact on their business (Gaddie 2003). This risk of ignoring these advancements in the industry is now too ominous for owners to ignore. Digital modeling in the early nineties revolutionized the manufacturing industry. Early adopters of these production processes and tools, such as Toyota, have achieved a great deal of commercial success due to their developmental efficiencies (Laurenzo 2005). By taking advantage of all that BIM has to offer, owners are in a position to do the same.

When it comes to the preconstruction phase, the largest priority for the owner is to determine whether a building quality level, design parameters and size can be constructed within a specified cost and time constraint. Having the ability to answer these questions allow the owner to move forward with the belief that their goals are attainable. If a design is later discovered to be considerably over budget, the time and effort lost in the design process is extraneous when it comes to the owner. Using BIM, a properly tabulated and designed building model linked to a cost database can be of remarkable value to the owner.

Schematic model development done prior to generating a detailed building model would allow the owner to conduct a significantly more precise evaluation of the proposal scheme to establish whether it meets the building's sustainable and functional requirements. This early assessment of design options using simulation tools would augment the overall performance and quality of the building and satisfy the owner's demands as well.

As mentioned earlier, the design-bid-build and design-build methods are the two main facility delivery processes employed in the U.S today (DBIA 2007). The traditional organization of a project team involves contracts between the owner and primary architect and builder, who in turn retain contracts between sub contractors and the like. This form of contracting frequently thwarts the transfer of information and ultimately curtails the ability to effectively use BIM tools and processes. A collaborative process would lead to a more streamlined construction process and significantly reduce the cumulative time and expenditure of construction projects.

As we can see in Figure 2-8, the traditional single-stage involves the completion of each phase prior to the initiation of the next, often involving a different group performing each phase in a non-integrative fashion. The design build process induces an overlap of the developmental phases leading to a shortened overall schedule, but there is still a need for integration between designers and builders. A symbiotically collaborative process, on the other hand, involves participation by all key participants through every facet of the construction process (Figure 2-7). This also saves a significant amount of time and expenditure, leading to lower project overheads on the part of the owner.

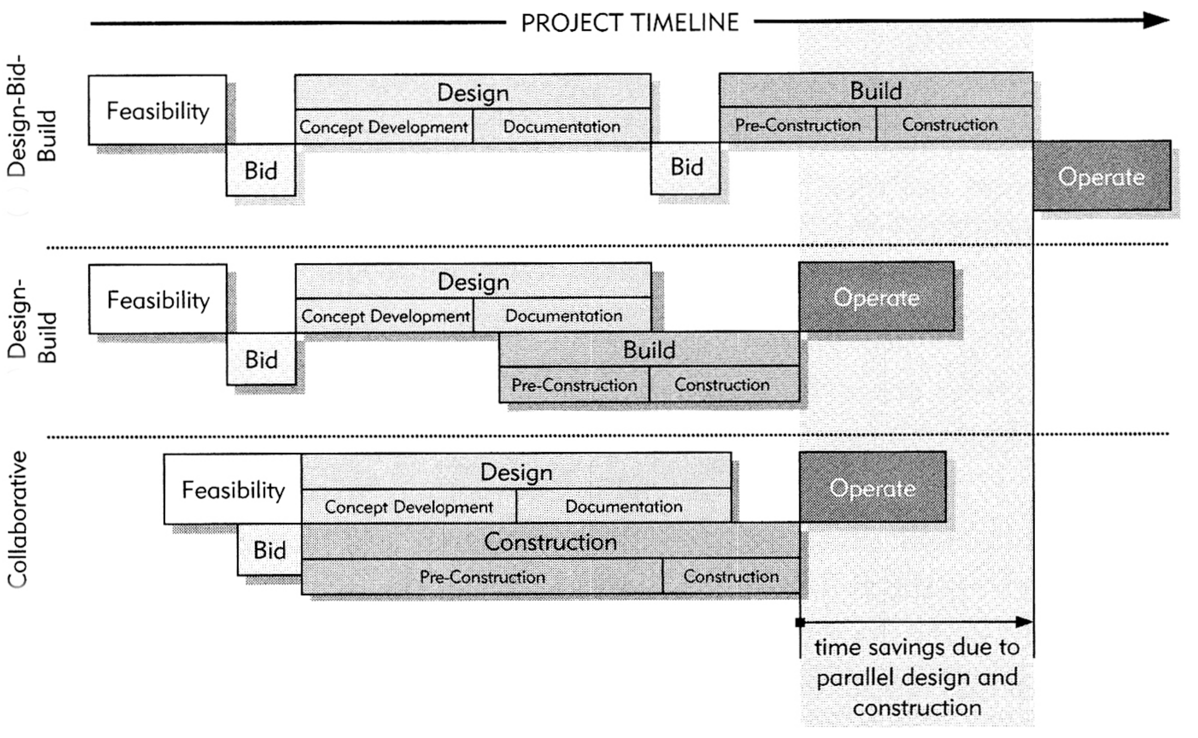

Figure 2-7. Comparison of Construction Processes (Gallaher et al. 2004)

2.2.2 Challenges to BIM Implementation

Improving processes in each phase of design and construction will lessen the severity of problems associated with conventional practices. The adaptation of BIM, however, will significantly change the relationships between all the members of a project as well as the contractual agreements between them. BIM offers new processes of collaboration, but while doing so introduces a few issues with respect to the formation of effective teams. Architects, for example, could be rooted in the traditional paper- based drawing system which would mean the contractor would have to create a model in its entirety before being able to implement it efficiently. These conditions add unforeseen complexities to the environment and could lead to the formation of potential errors as well.

Another major concern would be the legal challenges that adopting BIM successfully would entail. Questions will arise as to which particular component of the construction process owns the complete database of multiple design, analyses and fabrications. Segmented changes in the construction process are bound to create issues like these which can only be avoided if there is a complete overhaul of the Construction process.

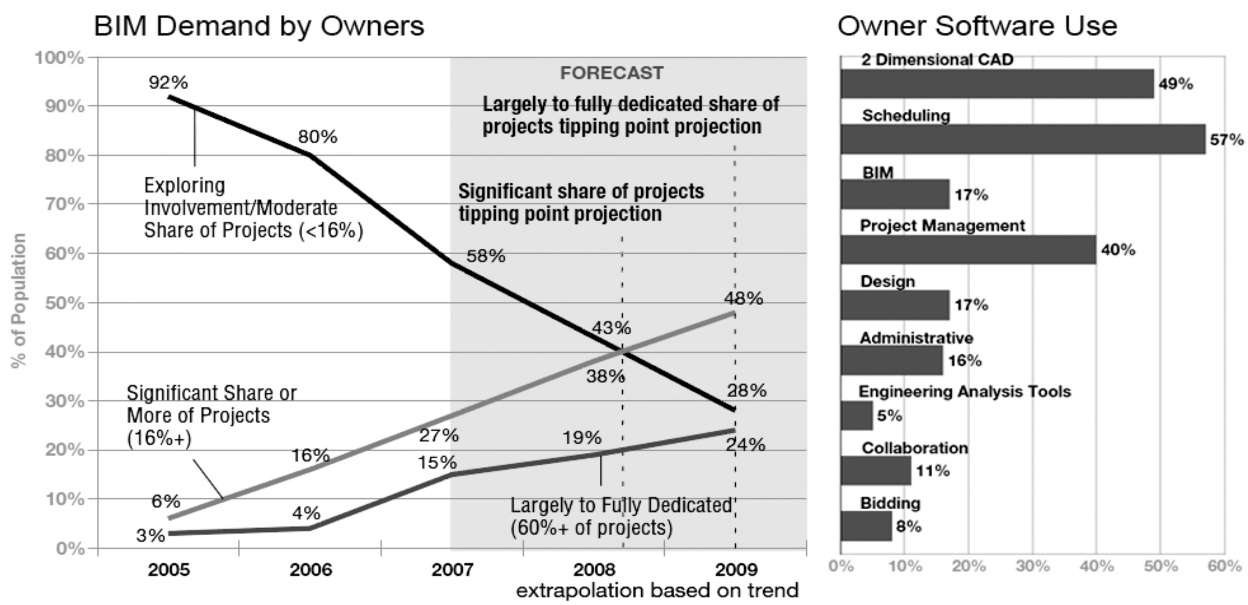

Figure 2-8. Building Information Management Demand by Owners and Current Owner Software Use (McGraw-Hill Construction Research and Analytics 2007)

CHAPTER 3
METHODOLOGY

As previously stated, the objective of this study is to analyze the possible adopation of the BIM processes into the construction industry, as well as the resulting benefit to the owners. Owners control the choosing of design service providers, the requirements and specifications of a facility, and the type of delivery processes. Due to the significant prospective impact that BIM can have addressing these options, as well as addressing a plethora of construction related problems, the owner is in a position to gain the most out of its implementation. It is, therefore, imperative that owners of all kinds realize how BIM applications allow for competitive benefits and enable their organizations to appropriately respond to constantly fluctuating market demands, as well as yield better returns on their capital investments. Using the attributes available to them, owners can better influence the proficiency and knowledge of their design and construction team.

At present, Autodesk® is the largest software provider for the AEC industry. The success of this provider is largely due to their developing and propagating of common, multi – faceted and vertically, as well as horizontally, interoperable programs that are used effectively by the design, project and construction management enterprises. This unilateral effort has reaped major dividends in the present and future of the construction industry. Programs such as Autodesk Revit and AutoCAD offer adaptable estimating benefits, planning and drafting capability, life cycle cost analyses and a variety of structural and energy simulations. Employing similar programs, such as Autodesk® 3DS MAX®, to develop interactive 3d modeling would help the lay owner have a better understanding of the processes in the AEC industry; making this the next logical step in achieving optimum collaboration with the final link of the industry's chain, i.e.: the owner. Having over seven years of experience with AutoCAD® and 3DS MAX®, the author will draw on this accumulated knowledge to siphon the attributes relative to the adaptability of these programs into the owner's involvement in the AEC process.

3.1 Interoperability, Productivity, Pros and Cons

As mentioned before, incompatibility between various systems prevents members on a construction project from sharing vital information accurately and efficiently. It goes without saying that the design and assembly of a structure is a team process. As a growing trend, each individual activity or specialty has its own support and enhancements in the form of individual computer applications. For example, rendering a 3D model with textures, lighting effects and motion can all be done through 3DS Max, but the addition of a plug-in, such as the Maxwell renderer, adds more options and enhances the visual range of the model. In addition to rendering, cost estimating, energy analyses, scheduling and fabrication issues are viable facets that retain a certain sense of individuality in the midst of constant endeavors toward compatibility. Interoperability recognizes the necessity to transfer information between applications, as well as encourages the allowance of multiple applications to jointly contribute to the entirety of the construction process. It also eliminates the need to duplicate redundant imputing of data. The move to develop a better collaboration between the owner, architect, engineer and construction manager should therefore be reflected by the instruments that support them.

When it comes to productivity, the author reviewed a variety of productivity improvement theories, such as value engineering and decreasing stress in the workplace. In the end, the Total Quality Management approach with the triad of philosophies: Customer Satisfaction, the Involvement of Everyone and Continuous Improvement (Adrian 2006) was found to be the most compatible with the BIM mentality. Adapting this or any productivity process into an enterprise, BIM or otherwise, is a must in today's competitive economy.

3.2 Interviews

The application of BIM methodology has had a significant impact on not only the national arena, but the international construction industry as well. For this reason, interviews were performed with a variety of design and construction firms located in various regions of the planet. A series of questions relating to BIM implementation, owner involvement and productivity were asked of representative of these companies with the hope that the answers would provide valuable insight into the need for increased use of BIM on projects and owner collaboration in today's projects. The set of questions asked were as follows:

- Please state the name and location of your office/firm/company.
- At present, is any form of Building Information Modeling being used at your office?
- If not, has there ever been an initiative or plan made to switch over to any of the variety of BIM software at your company?
- If so, have there been any hindrances encountered due to switching over from the traditional design method to the BIM practice?
- What is the average technical / construction expertise of the owners your company has worked with?
- How much time is spent interacting with the owner with respect to any given construction project?
- What is the average time taken to prepare a bid utilizing a traditional set of construction documents?
- Before commencement of any construction process, what is the average time assigned to analyze construction documents?
- On a standard construction/design project, what is the estimated number of RFI's submitted?
- How much time is generally taken to return/ wait for a return on an RFI?
- What is the average time taken to communicate with the engineers / construction managers about a standard construction/design project?

- Have any conventional or unconventional means of productivity enhancement been put into practice at your company? If so, please elaborate.

- What would your company consider to be the most significant hindrances to increasing productivity on and off the field?

The answers provided by all the representatives of the companies interviewed were documented and the results elaborated on in Chapter 4.

CHAPTER 4
INTERVIEW RESULTS

During the interview process, a substantial and varied amount of information was garnered from the national and international companies consulted. The intent of the interview questionnaire was to examine the respondent's perception towards BIM implementation, as well as the incorporation of the owner into their personal design/construction process. Company 1 and Company 2 were a relatively small national residential remodeling contractor and international (Australia) timber and frame contractor respectively. Company 3 and 4 were medium scale architectural design firms in India and the U.A.E. respectively. Company 5 was a large architectural design firm located in Cape Town, South Africa. All interviews were conducted during the months of May and June 2009. The questions put forth and tabulated results/answers of these conferences are found in Appendix B.

4.1 Construction Companies (Small Scale)

4.1.1 Construction Company 1 (Residential Remodeling Contractor)

As mentioned above, the first company interviewed was a local residential remodeling contractor specializing in constructing additions to preexisting homes. Before the commencement of the construction process, the scope of work and plans were considered to be the two major documents that needed analyzing. This process took an average of one to two days, depending on the size of the project. The documents were subsequently examined with the primary subcontractors and suppliers, a process that took another day on average when incorporating travel time and other such inconveniences. An additional amount of time (2-3 days) is taken to prepare the bid using a traditional set of construction documents. These traditional documents are used due to the need to incorporate and coordinate changes specified by the subcontractors and owners. It was noted that this was the phase in which errors often go unnoticed, resulting in future inconsistencies and RFI's. The estimated number of RFI's submitted per project were approximately fifteen to twenty, but those numbers were known to consistently rise when the subcontractor did not supply his own materials. The average time taken to wait for a return on an RFI was a day, with custom orders taking up to a week to be replied to. Since the nature of work performed by the company interviewed was relatively specialized, the amount of time taken to communicate with the engineers was fairly limited. More importantly, the average technical expertise of the owner they interacted with was minimal while the interaction level with them was practically on a daily basis. BIM was not being employed at the office, with the exception of basic CAD or layout software.

When asked what the company considered to be the most significant hindrance to increasing productivity on or off the field, the response was better communication between all the parties involved on the project. The need to plan and schedule different pieces of the project with minimum downtime was also addressed. The representative added that although BIM was not adapted in their company, the ability of all stakeholders, from the clients to the local building department, to interface with a form of BIM model would result in better communication, fewer errors and a more pleasing finished project for the client.

4.1.2 Construction Company 2 (Trussing and Framing Contractor)

Following the same process of consultation, the second company interviewed was a contractor located in Keith, Australia, specializing in timber trussing and framing systems. Since the work performed by this contractor was significantly specialized, the software utilized by the company aptly reflected the field of work. The only software used at the office was Pryda Build truss and wall design, a competent if not compatible program. The owners and clients for this company ranged from shop labor construction to government regulatory engineers and as such, the construction expertise of these clients differed accordingly. It was noted that the contractor preferred to spend as little time as possible with the owners due to the demands for changes in design that accompanied any interaction with them. Due to the specific nature of work performed by this contractor, the number of RFI's submitted was fairly minimal, with an estimated return date of one day. The contractor agreed upon the benefits of collaborative software integration to the owners, architects as well as themselves, but felt that other concerns such as labor training and competence were a higher priority.

4.3 Medium Scale Architectural Design Firm (Companies 3 and 4)

As mentioned earlier, the fourth and fifth companies interviewed were medium scale architectural design firms located in Mumbai, India and Abu-Dhabi, U.A.E. respectively. Both companies did not employ any advanced variety of BIM at the time, but had made earlier initiatives to employ 4D modeling. The biggest hindrances these companies came across during their attempt to transition over to the use of BIM were lack of skills and proficiencies displayed by not only their employees, but also the rest of the facets of the architectural, engineering and construction industry in India and the U.A.E. The average technical / construction expertise of the owners both companies worked with ranged from turn-key builders to lay individuals with no construction knowledge whatsoever.

It was the general opinion of both companies that the adaptation of BIM into the work process would have to be a comprehensive movement including all the components of the construction industry. Employing BIM into the architectural arena alone would not suffice when it came to increasing productivity and efficiency and the amount of time and resources it would take to make this option feasible was considered unrealistic.

4.3 Large Architectural Design Firm (Company 5)

The third company interviewed was a large and successful architecture and interior design firm located in Cape Town, South Africa. The significance of interviewing this particular firm lay in the fact that it had recently switched over from the traditional CAD design method to the employment of Autodesk Revit, arguably the most successful BIM tool to date. It had been three months since the changeover was undertaken, and there were a number of impediments that hindered the smooth transition between the two varieties of software. The primary issue that had to be dealt with was the training of staff, which was both costly and time consuming. The need to move staff off paying work to training for periods up to a week at different times caused an increase in workload and delays on multiple projects. All computer hardware in the firm had to be updated as Revit demands a highly performing computer to function effectively. Projects already started on conventional 2D software were not transitioned over to Revit due to time constraints, causing an inevitable delay in the BIM changeover. It was also observed that the number of cost consultants, building contractors and engineers using BIM methods in South Africa were limited and so the ability to expand on the collaborative aspect of Revit was severely curtailed. Most contractors were not up to date with BIM software. In the company's opinion, the main reason for the existence of BIM software was to cut out the issue of conventional drawings in plan / section / elevation / detail format by issuing a 3D computer software model to the contractor to build from. From there they could generate the required drawings after all the consultants provided their input on a service coordinated virtual building model, ideally also containing vital information such as vendors for specific materials, location of details and quantities required for estimation and tendering. The ability to construct in this manner was considered practically non-existent in South-Africa as only a few contractors were equipped to build this way.

In the firm's experience, the contractor was normally given a month to prepare their tender or bid, after which the professional team took an average of two weeks to analyze the different tenders and prepare an adjudication of tendered documentation for the client. An average period of 2 to 3 months was considered to be the norm for preparing a bid utilizing a traditional set of construction documents. When it came to the average time taken to communicate between the engineers and construction managers about a standard project, an example of a two hundred bedroom hotel was provided. It was considered fair to allow for bi-monthly two or three hour coordination meetings for six months before construction, followed by monthly project site meetings during a construction period of twelve to eighteen months, with weekly technical meetings during construction. This average excluded all telephone calls and email correspondence, which also took up a significant period of extraneous time and effort.

All the hindrances mentioned above were considered to be comprehensively addressed by the implementation of Revit into the firm's design process. The amount of RFI's generated were halved on every new project using BIM technology. The use of Revit software was considered to be a productivity enhancer, allowing for intelligent, 3D and parametric object-based design providing full bi-directional associativity. A change anywhere was a change everywhere, instantly, with no user interaction needed to manually update any view, specification or schedule. This method saved time and fees, especially with regards to client changes.

Finally, when asked what the company considered to be the most significant hindrance to increasing productivity, client indecisiveness was chosen. The client's lack of understanding their needs often led to delays and frustration when it came time to formulate an appropriate brief for the project. A considerable amount of time was consistently lost due to redesign work, until the client realized what route should be taken with the project. Client changes during construction, especially after all services have been coordinated, all details drawn and schedules issued, led to costly delays and decreased productivity. In the company's opinion, BIM adaptation would aid the visualization process (to explain a project to a client), as it was 3D based. The company felt that the further utilization of BIM, to allow the owner to have a better understanding of the design and construction process, was an avenue that deserved further research.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

Building Information Modeling is by far the most significant development in the architecture, engineering and construction industries in terms of potential and capability. Using this technology, a precise digital model of any building or structure can be created virtually. This computer-generated reproduction, when properly completed, includes all the data and exact geometry needed to sustain the fabrication, the construction and the acquisition activities required to complete the structure. BIM also incorporates several of the components required to develop the lifecycle of a structure. This assimilation defines the starting point of new construction capabilities as well as alters the responsibilities and relationships within a project team. The most important factor, which cannot be ignored, is that when appropriately applied, BIM ensures a more integrated design, construction and engineering process that, in turn, results in better quality buildings with abridged project duration and lower costs.

5.1 Adaptation of Total Quality Management through BIM Proclivities

Total Quality Management (TQM) is a widely adopted management philosophy for incorporating everyone in a firm towards continuously improving how a service is rendered while maintaining the owner's expectations of quality. As previously mentioned, Adrian (2004) has differentiated this process into three major components which, when adopted into BIM, would help harness and proliferate the efficiency and productivity both genres have to offer.

5.1.1 Customer/Owner Satisfaction

The propensity of TQM to involve the owner and prioritize their satisfaction is a philosophy that is commonly shared with traditional BIM methodology. In this process, attention is centered on recognizing the needs of the owner by changing the focus of the organizational entity. Companies 3, 4 and 5 all agree on the need to improve the involvement of the owner in every step of the design and construction process. Using rendering capabilities with Autodesk software such as 3DS Max, 3D models created in Revit will have the ability to display photorealistic materiality, texture, lighting effects and animations. Designers use three dimensional modeling programs, such as 3DS Max, to add these aesthetic values and animations to the projects they work on. First person walkthroughs of projects can be symbiotically constructed alongside the construction process and be dynamically updated and developed for the owner to comprehend. Figure 5-1 shows how potent photorealistic renderings are when it comes to articulating the interior and exterior of a structure.

Figure 5-1. Interior/Exterior design renderings. Images courtesy of Pure Render (Pure Render 2009).

These renderings were created as standalone entities using 3DS Max, which is an Autodesk product. The amount of effort it would require to propagate the compatibility between BIM modeling such as Revit, which is also an Autodesk product, and this 3D design software, while increasing efficiency and understanding between the owner and AEC departments of the industry, is practically nonexistent when one considers the rewards that can be obtained in the process.

5.1.2 Involvement of Everyone

BIM, by its very nature, is an entity that strives to create connections and collaborations between all the members of the AEC industry. In most organizations, including the construction industry, decision making is characteristically centralized within the upper management. The owner supplies demands to the designer, who mandates instructions to the project manager, who relays the information to the superintendent. This staccato method of linear information exchange and lack of involvement is extremely detrimental to the construction process as a whole. In the TQM process, communication and involvement is paramount to the process of improvement. BIM reflects this ideology in the need for team building and team solving within all the separate construction groups. As per the information received during the interview with Company 5, most contractors are not up to date with BIM software. The main reason for BIM software to exist is to cut out the issue of conventional drawings in plan / section / elevation / detail format and rather issue a 3D computer software model to the contractor to build from. From there they could generate the required drawings, including the consultants' input, on a service coordinated virtual building model, which ideally would also contain vital information such as specific material vendors, location of details and quantities required for estimation and tendering. Unfortunately, only a few contractors world-wide are currently equipped to build in this new way. In general, BIM should increase delivery speed and reduce cost, but will only be successful once all members of the professional team and contractors use the same virtual model, and most probably the same software. The move to involving everyone by incorporating TQM principles will therefore help increase productivity by allowing BIM to function in the way it was intended to: an all encompassing design and construction entity.

5.1.3 Continuous Improvement

The importance placed on ongoing and continuous improvement is arguably the most important component of TQM. Instead of using a result based system, effort is taken early on in the analytical process by addressing causes of known problems. This process places less emphasis on time spent for examination and more emphasis on time applied in problem solving and elimination of causes leading to the need for reexamination. BIM stands to gain much by adopting this preemptive practice, the foundations of which have already begun in today's market. Major BIM tools add integrating potential and functionality of other products, thereby providing even richer platforms for use. Automated checks for code conformance and constructability while employing BIM is becoming increasingly available. BIM is also promoting the globalization of prefabrication for progressively complex building sub-assemblies. All these factors and more suggest that BIM will remain a dynamic process that continually learns, adapts and improves to meet the needs of the construction industry of the future.

5.2 Recommendations

Building Information Modeling (BIM) cannot be considered a facet of software, but rather an organic activity that will inevitably result in an extensive change of processes in the AEC industry. From the interviews conducted, it is apparent that the existing restrictions to general implementation of BIM practices do not exist in the technology itself, but in the lack of properly trained professional staff. There has been a viable shift in the way in which owners are insisting on BIM and modifying contract terms to allow for its use. With the early adoption of collaborative BIM software into the design and construction process, owners can expect additional 3D visualizations and conceptual models complete with programmatic analysis. This early adoption would make three-dimensional models, as well as 4D simulations extrapolated from those models, increasingly expansive and edifying to the lay person as compared to technical schematics. Owners will now have the potential to not only view project models, but also successfully use them for sales, marketing, and design viability evaluations. Finally, BIM creates designs that are significantly more educational and adaptable than simplistic computer rendered CAD designs. These models would therefore aid owners in comparing design alternatives early on in the project and enable them to make significant decisions that would positively affect the project and life-cycle costs.

APPENDIX A
LIST OF TERMINOLOGY AND ABBREVIATIONS

- 2D. A drawing that exists in only the X and Y planes
- 3D. A drawing that exists in the X, Y, and Z planes
- 4D. A BIM that can also be shown in a time stamp sequence, to show progress
- AEC. Architecture / Engineering / Construction
- BIM. Building Information Modeling
- CAD. Computer Aided Drafting
- CM. Construction Management Firm
- DBB. Design Bid Build, which is a project delivery method in which the agency or owner contracts with separate entities for each the design and construction of a project.
- DB. Design Build, which is a construction project delivery system where the design and construction aspects are contracted for with a single entity known as the design-builder or design-build contractor.
- GIS. Geographical Information System, which captures, stores, analyzes, manages, and presents data that is linked to location.
- MODELING. The model that houses, maintains, and controls the flow of information needed to manage the building
- NIST. National Institute of Standards and Technology
- RFI. Request for Information
- TQM. Total Quality Management, which is a business management strategy aimed at embedding awareness of quality in all organizational processes.

APPENDIX B
INTERVIEW QUESTIONNAIRE (SMALL RESIDENTIAL REMODELING CONTRACTOR)

- **At present, is any form of Building Information Modeling being employed at your office?**
    1. No. We will, on occasion, work directly with basic architectural or layout software.
- **If not, has there ever been an initiative or plan made to switch over to any variety of BIM at your company?**
    1. I don't see current movement toward BIM in my segment of the industry. However I can see it as the future direction of all levels of construction particularly in places like Florida where so much attention is being placed on structurally sound building. If all stakeholders from clients to the local Building Dept were plugged into some form of BIM the likely result would be better communication, fewer errors and a more pleasing finished project for the client.
- **If so, have there been any hindrances encountered due to switching over from the traditional design method to the BIM practice?**
    1. -
- **What is the average technical / construction expertise of the owners your company has worked with?**
    1. As a rule, minimal. They are typical residential homeowners.
- **How much time is spent interacting with the owner about any given construction project?**
    1. Usually on a daily basis from conceptualizing to the final punch list.
- **What is the average time taken to prepare a bid utilizing a traditional set of construction documents?**
    1. Depends on the size of the project. A major addition could take 2-3 days or more.
- **Before commencement of any construction process, what is the average time assigned to analyze construction documents?**
    1. Two main documents we use are the scope of the work and the plans. On a large project both are studied carefully before the start of the project, maybe a couple of hours. Then they're analyzed with primary subs and suppliers, probably a few more hours and often travel time as well. As the project progresses they're used regularly by many parties.
- **On a standard construction/ design project, what is the estimated number of RFI's submitted?**
    1. Assuming we're talking about getting quotes, etc., a large project would likely involve at least 15-20. More if the sub contractor doesn't supply his own materials.
- **How much time is generally taken to return/ wait for a return on an RFI?**
    1. Normally a few hours to a day. Some custom orders like cabinetry or trusses could take a week.
- **What is the average time taken to communicate with the engineers / construction managers about a standard construction/design project?**
    1. We are more likely to be dealing with subs and partners. And so many different factors make that a tough question to answer. Probably a minimum of an hour or so a day. But there are times it could be ongoing throughout the entire day.

- **Have any conventional or unconventional means of productivity enhancement been put into practice at your company? If so, please elaborate.**
    1. No.
- **What would your company consider to be the most significant hindrances to increasing productivity on and off the field?**
    1. With so many parties involved in a large project, communication is a big factor; getting everyone on the same page. Planning and scheduling different pieces of the project with minimal downtime can also an interesting challenge.

APPENDIX C
INTERVIEW QUESTIONNAIRE: COMPANY 2 (SMALL TRUSSING AND FRAMING CONTRACTOR)

- **At present, is any form of Building Information Modeling being employed at your office?**
    2. We use Pryda Build truss & wall design software.
- **If not, has there ever been an initiative or plan made to switch over to any variety of BIM at your company?**
    2. Not at this time; we prefer to remain with Pryda.
- **If so, have there been any hindrances encountered due to switching over from the traditional design method to the BIM practice?**
    2. It would be difficult to switch from one software provider to another, as all previous designs would have to be re-entered into the new software or discarded.
- **What is the average technical / construction expertise of the owners your company has worked with?**
    2. Expertise spans from shop labor to government regulatory engineers and everything in between.
- **How much time is spent interacting with the owner about any given construction project?**
    2. As minimal as can be possibly spent.
- **What is the average time taken to prepare a bid utilizing a traditional set of construction documents?**
    2. That depends on the size of the project. Usually a day, but it can be a great deal more.
- **Before commencement of any construction process, what is the average time assigned to analyze construction documents?**
    2. Refer to question above.
- **On a standard construction/ design project, what is the estimated number of RFI's submitted?**
    2. We aim to have as few RFI's as possible.
- **How much time is generally taken to return/ wait for a return on an RFI?**
    2. One day.
- **What is the average time taken to communicate with the engineers / construction managers about a standard construction/design project?**
    2. Usually done in real-time, using email and phone calls..
- **Have any conventional or unconventional means of productivity enhancement been put into practice at your company? If so, please elaborate.**
    2. No.
- **What would your company consider to be the most significant hindrances to increasing productivity on and off the field?**
    2. Training.

APPENDIX D
INTERVIEW QUESTIONNAIRE: COMPANY 3 (MEDIUM SCALE ARCHITECTURAL DESIGN FIRM)

- **At present, is any form of Building Information Modeling being employed at your office?**
    3. No.
- **If not, has there ever been an initiative or plan made to switch over to any variety of BIM at your company?**
    3. Yes.
- **If so, have there been any hindrances encountered due to switching over from the traditional design method to the BIM practice?**
    3. Fear of lag to convert office from ACAD/3DMAX to Revit, skills and proficiencies currently strong with latter platforms
- **What is the average technical / construction expertise of the owners your company has worked with?**
    3. Turn-key builders.
- **How much time is spent interacting with the owner about any given construction project?**
    3. Two hours a week.
- **What is the average time taken to prepare a bid utilizing a traditional set of construction documents?**
    3. One to two weeks.
- **Before commencement of any construction process, what is the average time assigned to analyze construction documents?**
    3. 2-3 days.
- **On a standard construction/ design project, what is the estimated number of RFI's submitted?**
    3. 10-15 on average.
- **How much time is generally taken to return/ wait for a return on an RFI?**
    3. It ranges from day to a week.
- **What is the average time taken to communicate with the engineers / construction managers about a standard construction/design project?**
    3. It ranges from day to a week.
- **Have any conventional or unconventional means of productivity enhancement been put into practice at your company? If so, please elaborate.**
    3. No.
- **What would your company consider to be the most significant hindrances to increasing productivity on and off the field?**
    3. General delays.

APPENDIX E
INTERVIEW QUESTIONNAIRE: COMPANY 4 (MEDIUM SCALE ARCHITECTURAL DESIGN FIRM)

- **At present, is any form of Building Information Modeling being employed at your office?**
    4. No.
- **If not, has there ever been an initiative or plan made to switch over to any variety of BIM at your company?**
    4. Yes, about 10 years ago.
- **If so, have there been any hindrances encountered due to switching over from the traditional design method to the BIM practice?**
    4. Lack of training and interoperability between employees, engineers, comtractors and owners.
- **What is the average technical / construction expertise of the owners your company has worked with?**
    4. Minimal to nonexistent.
- **How much time is spent interacting with the owner about any given construction project?**
    4. Two to four hours a week.
- **What is the average time taken to prepare a bid utilizing a traditional set of construction documents?**
    4. One to two weeks, but this depends on the scope of the project.
- **Before commencement of any construction process, what is the average time assigned to analyze construction documents?**
    4. This also depends on the scope of the project.
- **On a standard construction/ design project, what is the estimated number of RFI's submitted?**
    4. 20-30 on average.
- **How much time is generally taken to return/ wait for a return on an RFI?**
    4. Anywhere between a day to two weeks..
- **What is the average time taken to communicate with the engineers / construction managers about a standard construction/design project?**
    4. Anywhere between a day to two weeks.
- **Have any conventional or unconventional means of productivity enhancement been put into practice at your company? If so, please elaborate.**
    4. Bonus/incentive system.
- **What would your company consider to be the most significant hindrances to increasing productivity on and off the field?**
    4. Proper edification and feasibility challenges.

APPENDIX F
INTERVIEW QUESTIONNAIRE (LARGE ARCHITECTURAL DESIGN FIRM)

- **At present, is any form of Building Information Modeling being employed at your office?**
    5. We have recently (3 months) ago, made the decision to gradually move all CAD functions in the office over from AutoCAD to Autodesk Revit.
- **If not, has there ever been an initiative or plan made to switch over to any variety of BIM at your company?**
    5. -
- **If so, have there been any hindrances encountered due to switching over from the traditional design method to the BIM practice?**
    5. As we are still in the process of switching over to BIM, the following hindrances can be reported:
        - Training of staff, which is both costly and time consuming – especially to move staff off paying work to training for periods up to a week at different times.
        - Updating of computer hardware, as the new software requires the latest high-performance pc's
        - It is impossible due to time constraints, to move projects already started on conventional 2d software over to Revit, and as such only new projects are being started on it, which will also delay the switch to BIM
        - Very few consultants (Engineers / Cost Consultants), especially in South Africa, have moved to BIM. It is mainly used by architects.
        - Very few Building Contractors in South Africa have moved to BIM.
- **What is the average technical / construction expertise of the owners your company has worked with?**
    5. Varies per project.
- **How much time is spent interacting with the owner about any given construction project?**
    5. Two to four hours a week, but we expect that number to increase after the implementation of BIM.
- **What is the average time taken to prepare a bid utilizing a traditional set of construction documents?**
    5. It is difficult to answer as it depends greatly on the size of the project, but an average period of 2 to 3 months is the norm.
- **Before commencement of any construction process, what is the average time assigned to analyze construction documents?**
    5. The contractor is normally given a month to prepare his tender or bid, and the professional team takes two weeks after that to analyze the different tenders and prepare an adjudication of tenders document for the client.
- **On a standard construction/ design project, what is the estimated number of RFI's submitted?**
    5. It depends on the size of the project, the complexity of the building, and the level of detail agreed to be drawn by ourselves. For instance, on turnkey / design-build contracts there will be many more RFI's than a project with a full architectural appointment.
- **How much time is generally taken to return/ wait for a return on an RFI?**

5. It depends on the urgency of the request, and the detail level of information requested – anything from 1 day to 2 weeks.

- **What is the average time taken to communicate with the engineers / construction managers about a standard construction/design project?**
    5. With an example: on a 200 bedroom hotel, it would be fair to allow for bi-monthly 2-3 hour coordination meetings for 6 months before construction, and then monthly project site meetings during a construction period of 12 to 18 months, with weekly technical meetings during construction. This excludes all telephone calls and email correspondence, which take up many hours.
- **Have any conventional or unconventional means of productivity enhancement been put into practice at your company? If so, please elaborate.**
    5. Weekly timesheets to monitor staff productivity and to correlate overhead expenses with fees earned. Revit Architecture software, that allows for intelligent, 3D and parametric object-based design. In this way, Revit provides full bi-directional associativity. A change anywhere is a change everywhere, instantly, with no user interaction to manually update any view, specification or schedule. This saves time and fees, especially with regards to client changes. Custom Specification-writing software, we had written for our Interior Design FF&E Specifications, that establishes a central database with all information entered, so that the information can be used by all staff members on future specifications.
- **What would your company consider to be the most significant hindrances to increasing productivity on and off the field?**
    5. Client indecisiveness and the client's lack of understanding of their needs often lead to delays and frustrations to formulate an appropriate brief. A lot of time is lost due to redesign work, until the client realizes what route should be taken with the project. BIM should aid the visualization process (to explain a project to a client), as it is 3d based. In South Africa, time is often wasted on getting Authority approval from Government Authorities required for Environmental Approval Applications or Rezoning Applications. One would hope BIM models would one day include the whole built and natural environment, to easier study the effect of a proposed project and make approvals a speedier process. Client changes during construction, especially after all services have been coordinated and all details drawn and schedules issued, lead to costly delays and decreased productivity. The claimed ease of BIM software to effect changes will hopefully help to minimize this. Most Contractors are not up to date with BIM software – the main reason for BIM software to exist is to cut out the issue of conventional drawings in plan / section / elevation / detail format and rather issue a 3d computer software model to the Contractor to build from. From there they can generate the required drawings after all the consultants gave their input on a service coordinated virtual building model, ideally also containing vital information such as vendors for specific materials, location of details and quantities required for estimation and tendering. Only a few contractors world-wide are currently equipped to build this new way, and it is practically non-existent in South-Africa. In general, BIM should increase delivery speed and reduce cost, but will only be successful once all members of the professional team

and contractors use the same virtual model, and most probably the same software, which is highly unlikely.

APPENDIX G
INTERVIEW QUESTIONS AND ANSWERS

1. Company 1 (small residential remodeling contractor)
2. Company 2 (small trussing and framing contractor)
3. Company 3 (medium scale architectural design firm)
4. Company 4 (medium scale architectural design firm)
5. Company 5 (large architectural design firm)

Table G-1.

Questions	Company 1	Company 2	Company 3	Company 4	Company 5
Is any form of BIM being employed?	No	Yes	No	No	Yes
If not, has there ever been a plan made to switch over to any form BIM?	No	No	Yes	Yes	N/A
If so, have there been any hindrances encountered due to switching from the traditional design method to BIM?	N/A	Yes	Yes	Yes	Yes
What is the average techincal / construction expertise of the owners your company has worked with?	Minimal	Varies	Turn-Key	Minimal	Varies
How much time is spent interacting with owners?	Daily	The least possible	2 hrs per week	2-4 hrs per week	2-4 hrs per week
Average time is takes to prepare a bid using traditional contruction documents?	Varies	1+ days	1-2 weeks	1-2 weeks	Varies
Average time assigned to analyze construction documents before commencement of any construction process?	Varies	Varies	2-3 days	Varies	1.5 months
Estimated number of RFI's submitted on a standard project?	15-20	The least possible	10-15 on average	20-30	Varies
How much time is taken to return / wait for a return on a RFI?	A few hrs - 1 day	1 day	1 day - 1 week	1 day - 2 weeks	1 day - 2 weeks

Table G-1. (continued)

Questions	Company 1	Company 2	Company 3	Company 4	Company 5
Average time taken to communicate with engineers / construction managers about a standard project?	Varies	Daily	1 day - 1 week	1 day - 2 weeks	Varies
Have any means of productivity enhancements been put into practice at your company? If so, please elaborate.	No	No	No	Yes	Yes
Most significant hindrances to increasing productivity on and off the field?	Communication	Training	General	Feasibility	Client Indecision

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BIOGRAPHICAL SKETCH

Ayesh L. Bhagvat earned his master's degree from the M.E. Rinker, Sr. School of Building Construction at the University of Florida in Gainesville. He interned for Ghazi Awad Architects and Engineers in Abu-Dhabi, U.A.E. where he developed 3D presentations using 3DS Max, including walkthroughs and lighting previews. While pursuing his master's in building construction, he interned at the Project Management department at Walt Disney Imagineering, where he supervised and organized construction activities for a variety of WDI projects. Prior to earning his master's degree, he attended the University of Florida's School of Architecture, where he earned a bachelor's of design in architecture. During this time, he interned at the Florida Community Design Center in Gainesville, Florida, where he prepared cost/benefit analyses and materials/project estimates for the Florida Steering Committee as well as proposed and designed a multimodal transportation infrastructure for Gainesville's growing population.

Ayesh's research interests are in the area of design and construction technology, with emphasis on symbiotic integration of compatible software technology into all the facets of the construction industry. He looks forward to using his versatile proclivity in the Project Management arena along with his developed interest in Digital Design within the construction field to maintain substantial proficiency in a variety of construction fundamentals.