Building Information Modeling: Value for Real Estate Developers and Owners

by

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ABSTRACT

The Architecture, Engineering, and Construction industry severely lags behind the manufacturing industry in terms of efficiency and productivity growth. This lag is a result of the fragmented nature of the industry and its resistance to adopting innovative technologies and processes that enable collaboration and efficiency. Building Information Modeling (BIM) is one of these innovations. Since building owners ultimately absorb every cost associated with a building project, they are in the best position to lead the AEC industry into an era of increased productivity through the adoption of collaborative practices and technologies such as BIM.

However, owners cannot be expected to venture down this path unless they are aware of the potential value that the proper use of BIM can create for them. Therefore, this paper provides evidence of the value created for owners and developers by the use of BIM, and conveys that evidence in a framework that follows the actual phases and tasks of a real development project. Those phases are as follows: Market Research, Feasibility Analysis, Design, Construction, and Operations. In addition to actual examples of value creation, theoretical examples of future applications are discussed.

The value created for owners and developers by implementing BIM on their projects is manifested primarily in the form of improved design quality and savings in time and money.

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1.0 INTRODUCTION

In 2006, the U.S. construction industry produced goods that accounted for over $646.9 billion, or 4.9% of the national Gross Domestic Product.[58,59] Despite this significant contribution to the U.S. economy, the Center for Integrated Facility Engineering (CIFE) at Stanford University reports that the productivity of all non-farm industries more than doubled from 1964 to 2003, while the U.S. construction industry experienced a slight decline during that same period.[46] This research suggests that construction productivity has not only trailed other sectors of the U.S. economy, but it has actually worsened over time.*

Two key questions arise from this conclusion. First, what enabled productivity growth in the other sectors, and second, what restricted productivity growth in construction? In regards to the first question, automotive, aerospace, electronics, and consumer goods manufacturing firms long ago adopted model-based digital design processes in order to remain competitive both domestically and globally. These digital models currently include data that supports cost modeling, bill-of-material generation, engineering analysis, supply-chain integration, production planning, and computer-controlled fabrication. The implementation of these technologies and processes has played a key role in the productivity growth of the above mentioned industries.[40]

In an effort to address the second question, the National Institute of Standards and Technology (NIST) conducted a study in 2002 that was based on surveys and interviews with 105 individuals from 70 organizations representing the key industry players: architects, engineers, contractors, fabricators, suppliers, and owners and operators. In August of 2004, the results of this study were released by the NIST in a report entitled "Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry." This report estimates that the annual cost of interoperability to the Architecture, Engineering, and Construction (AEC) industry in the United States is a staggering $15.8 billion.[47] While the term interoperability is frequently used to describe the ability of software applications to exchange data, the NIST report defines this term as "the ability to manage and communicate electronic product and project data between collaborating firms' and within individual companies' design, construction, maintenance, and business process systems."[47] The report basically views interoperability as the integration of the workflows and

* See Construction & Non-Farm Labor Productivity Index chart in Appendix B.

processes of each participant involved in the life cycle of a building.[39] According to the report, this inadequate interoperability is due to “the highly fragmented nature of the industry, the industry’s continued paper-based business practices, a lack of standardization, and inconsistent adoption among stakeholders.”[47]

The lessons learned from manufacturing are finally resonating with AEC practitioners, but that resonance is still very limited, as suggested by James Timberlake, partner at Philadelphia architecture firm KieranTimberlake Associates: “Architects haven't been trained to think collaboratively; they're only interested in handing off designs,” Timberlake said. “That's the way the automobile industry worked in the 1950s: The designer did everything down to the tail fins, they handed off the drawing and things would end up on the production floor not fitting. The automobile industry decided there was a better way to do it, but we're still working on it. So many opportunities for integration and coordination are missed in the building process today.”[44] The integrated supply chains of the manufacturing industry stand in stark contrast to the AEC industry, where building project teams rarely work together more than once. AEC Project teams are focused on the one-time delivery of a single, unique structure. Consequently, project delivery methods are optimized so that each participant incurs the lowest cost and exposure, thereby limiting the final outcome of the development. The costs of these inefficiencies are shouldered primarily by the building owner, since the owner is most affected by design and construction errors, broken schedules and budgets, and high operational and maintenance costs.[40]

According to the NIST report mentioned earlier, building owners and operators bear $10.6 billion of the total $15.8 billion annual interoperability cost, which is by far the highest of any stakeholder.[47] So why aren’t more owners demanding better integration on their project teams? Ian Howell, CEO of Newforma, a software development company, makes the following argument: “The majority of building owners do not realize that they have the power to eliminate this waste and its associated cost burden. By mandating the sharing of project information, collaborative project delivery, and the use of interoperable technology, building owners can drive the integration of the processes and business workflows of all project participants, across all phases of the lifecycle of a facility.”[38]

As stated earlier, a critical component to an owner's quest for increased collaboration and project efficiency is the implementation of interoperable technology and methodology during each phase of the development process. A term commonly used to denote such practices is *Building Information Modeling, or BIM*. For an owner to invest in or implement such technology and methodology in its projects, additional value must be created as a result. Therefore, the purpose of this paper is to determine how the use of Building Information Modeling can create value for the owner during the real estate development process.

The remainder of this introductory section will discuss the nomenclature associated with BIM and further refine its definition. Information describing the major developers of BIM software will also be provided.

1.1 Nomenclature and Definitions

Building Information Modeling, or BIM, is one of the most overused and misunderstood terms in the AEC industry.[42] Part of the reason for this misuse is that BIM is an evolving concept that will continue to change as technology gets better along with our ability to apply that technology. The primary difference between BIM and CAD (Computer Aided Design) is the "I" in BIM – "Information."[42]

There are three categories of information that can be associated with a BIM model, with the first being object-based geometry.[42] For example, in BIM a window isn't simply a collection of points, lines, and surfaces arranged to *look* like a window – it is an object that knows it's a window, and displays many of the qualities and behaviors of a real window within the context of a model. When that window is inserted into a wall, the wall "receives" the window by automatically adjusting its geometry to accommodate the window placement. Also, the wall will only allow the window to be placed in "reasonable" locations as defined by pre-programmed parameters. Another feature of BIM geometry is parametric integrity, meaning that relationships between elements are consistently maintained as the model is manipulated.[28] For example, if a window was dimensioned to be four feet away from a door and that door was moved, the window would automatically move to maintain the four foot distance from the door.

The second type of information associated with a BIM model is non-graphical information. This information further defines the function and structure of the model, along with any associated properties assigned to it such as cost, fire rating, materials content, reflectivity, conductivity, etc.[42] The potential list of these properties is enormous, and is only limited by the use for such information and the computing power needed to process it.

The third type is linked information, or information that is related to but not contained directly in the model. Examples include fabricator's shop drawings and Gantt charts for construction scheduling.[42]

One common misconception is that BIM is for 3D design and CAD is for 2D design. This is clearly not true, since 3D designs can easily be created with CAD technology.[45] The critical question for any "BIM" solution is whether the model produced by the solution is computable.[7] Referring to the lack of computability with CAD, Professor Chuck Eastman at Georgia Tech said "one of the limitations of 2D drawings is that only people can read them."[14] If a model is computable, then information about that model can be understood by a computer in a way appropriate to the model's purpose. For instance, a wall described in a 3D CAD model may look right, but the computer doesn't know it's a wall. There's no way the wall can accept a window or a door, and it can't be quantified as a wall made of real materials.[7]

One term closely related to BIM is Virtual Design and Construction (VDC), which, according to CIFE, is "the use of multi-disciplinary performance models of design-construction projects."[43] CIFE views BIM as a tool to support product design, which is a subset of the broader application of VDC. That broader application represents the product (the physical building), organization, and processes of the design-construction-operation team.[43] Some argue that BIM isn't just design software, but also a methodology involving the entire project team.[4] Regardless of the scope of one's definition of BIM, a truly successful BIM or VDC implementation requires collaboration across all project teams, as will be discussed in later sections of this paper.

1.2 Major BIM Vendors

There are currently several major players in the BIM software market. Autodesk is the maker of REVIT, which focuses on having all building elements in one database, thus providing users the ability to immediately see the results of design modifications and detect any interference issues. Bentley Systems takes a different approach by producing a family of application modules that coordinate easily with one another. Those modules include Bentley Architecture, Bentley Structural, Bentley Building Mechanical Systems, and Bentley Building Electrical Systems. Another major provider is Graphisoft, which was acquired by German firm Nemetschek in 2006. Graphisoft's BIM approach is to create a virtual building model, around which their flagship product ArchiCAD will orbit along with other satellite applications.[25] Finally, Dassault Systemes' CATIA, originally produced for use in the aerospace industry, is being adapted by Gehry Technologies for use in the AEC industry.

1.3 Contribution

A common theme in BIM-related publications is that building information modeling potentially carries the most value for building owners and developers. What seems to be lacking, however, is a comprehensive framework of evidence showing how that value is created in the context of the full lifecycle of a building. This paper helps to fill that gap by providing numerous case examples for each development phase, and analyzes those examples from the perspective of the owner/developer to determine the resulting value of BIM methodologies.

The publications referenced by this paper typically focused on fairly narrow, BIM-related topics. For example, "The Contractors' Guide to BIM," produced by The Associated General Contractors of America, is a very thorough and informative document, but it understandably focuses on BIM from the perspective of a contractor. Likewise, publications written by design or fabrication related entities provided the perspectives of those industries. This paper takes the position of owners and developers, which reside at the very core of the construction industry since these entities ultimately shoulder every expense associated with the lifecycle of a building.

2.0 METHODOLOGY

The majority of the data used in this paper was obtained from published information, which includes the following:

- Magazine and journal articles
- Trade organization publications
- White papers and marketing publications by software vendors
- Practitioner presentations
- Articles and commentaries by industry experts
- Academic research papers
- Surveys
- Case studies

Interviews were conducted with selected developers, architects, and researchers. Examples include Gerding Edlen Development, LLC, and Sera Architects, both based out of Portland, Oregon. These firms were selected based on their experience with sustainable developments and BIM implementations. Researchers interviewed include Professors Martin Fischer and John Kunz at Stanford University, along with Professor Chuck Eastman at Georgia Tech. These individuals were selected due to their industry-leading expertise with architectural computing and BIM-related methodologies.

The primary criterion used to determine usability of the case data in particular was whether or not the project was actually built or nearly built. Since this paper focuses on the value of BIM from a developer's holistic perspective, using case data from a project that never emerged or has yet to emerge from the design phase would undermine this paper's credibility. However, for statements made in articles, online publications, and interviews that were not project-specific, this criterion was not used because those statements can refer to experiences on multiple projects.

The types of data obtained for this paper range from qualitative opinions to quantitative data about cost, time, and efficiency. Whenever possible, quantified case data about project performance was sought after in order to determine the degree of effectiveness a particular modeling strategy or implementation. Since BIM is relatively new to the AEC industry, practitioners often demand evidence of how BIM can add value to a project before they commit valuable time and resources. Case data from real projects provides this evidence, along with examples of mistakes made and lessons learned.

The majority of the quantified case data used in this paper is from larger-sized development projects, such as residential and office towers, hotels, schools, and event centers. This data bias is primarily due to the lack of data about BIM use on small projects. It is unclear whether this lack of data is a result of BIM not being used on small projects, or because smaller scale projects simply aren't as publicized. Regardless, additional data about BIM use on small development projects would help to formulate a more comprehensive argument.

3.0 ANALYSIS AND RESULTS

This section will present information about how BIM is being used in the development process, how that use adds value for developers and owners, and potential uses of BIM that could create additional value. This section is divided into sub-sections that discuss the major phases and tasks of a development project. Listed in approximate chronological order, those sub-sections are:

- Market Research
- Feasibility Analysis
- Design
- Construction
- Operations

In an actual development project, these phases usually overlap substantially, and sometimes even occur in parallel. Therefore, the BIM applications discussed in one phase may be just as applicable to one or more other phases. Future applications and the cost of BIM will also be discussed in this section.

The BIM tools discussed in this section can be classified as either micro or macro focused. Micro BIM addresses the downstream issues of constructability and coordination by providing accurate designs and drawings for a building. Macro BIM, on the other hand, is more focused on the holistic view of a project and is primarily used for early cost estimation and design optimization.[27]

The major findings of this section are as follows. First, using BIM processes can result in significant savings of time and money for owners and developers, especially during the design and construction phases of a project. Second, BIM is beginning to enhance sustainable design, although the full potential of BIM's sustainable design influence has yet to be realized. Third, the operations phase of a development offers many areas where BIM could feasibly be utilized, but it appears that technology has not progressed to the degree required for widespread application. Fourth, owners and developers, as the leaders of the AEC industry, are in the best position to push for BIM implementation and reap the majority of the resulting benefits.

3.1 Market Research

Typically, the first phase of a development project is measuring market demand for specific types of development. This type of research involves studying demographic trends, rent and sales cycles, current inventories, future supply, vacancy rates, and other related factors. Although there does not appear to be a way in which the use of BIM could influence research in the above mentioned areas, virtual building models are being used to create project "fly-throughs" for the marketing related tasks of public awareness and advertising. Virtual building models are also being used for marketing and customer feedback purposes in the online virtual reality world known as Second Life.

Project fly-throughs or animations are often created without BIM tools. However, case data suggests that fly-throughs can be cheaper and more effective when created using BIM. According to Scott Simpson, president and CEO of Stubbins Associates, an animation that would have cost his firm $55,000 to complete using traditional methods can be done for $18,000 using Autodesk Revit.[33] The Washington State Department of Transportation (WashDOT) used BIM tools to create fly-throughs of two alternatives for the proposed Alaskan Way Viaduct and Seawall Replacement project in Seattle, Washington. Due to the massive scope of the project ($4.63 billion at the project midpoint in 2013), WashDOT realized the difficulty of building public support and understanding of the alternatives. As an early step to address this challenge, two 4.5-minute fly-through "videos" of the landscape with the two alternatives were created. "We use this video as a communication tool with the public and elected officials," said Ron Paananen, project director for WashDOT. "It's all digitally based on mapping of the city. It looks like a photograph, it looks like the real thing, but it is also technically accurate from the drawings themselves. The dimensions are all there. It has been very effective."[57]

In addition to creating fly-throughs for marketing and public exposure, firms are using virtual modeling for marketing and feedback purposes in Second Life, an online virtual reality world created by Linden Labs of San Francisco.[†] As of July 2007, the total number of users or "residents" in Second Life was over 7.7 million and growing rapidly.[31] This flurry of virtual activity has prompted firms such as Toyota, Sun Microsystems, General Motors, Intel, Microsoft,

[†] See Appendix B for a more detailed description of Second Life.

Warner Bros. Records, 20th Century Fox, NBC, AOL, and Reuters to invest in virtual projects, some of which actually contribute to real world developments. In 2006, Starwood Hotels hired virtual design firm Electric Sheep Company to bring their new “aloft” hotel line into Second Life. Although the planned opening for the hotels is not until 2008, this project in Second Life allowed Starwood to give potential customers a sneak preview of the future hotel development and also get their feedback early in the design process. According to Starwood, changes were made to the hotel design based on customer feedback generated from the Second Life model.[32] Another real life application is from Crescendo Design, an architecture firm that builds virtual models of its design concepts in Second Life and encourages clients to explore the models and provide feedback.[31]

Examples of developers using Second Life for pre-leasing and pre-selling purposes were not found. Although such cases may in fact exist, the potential real estate marketing value of Second Life appears to be relatively untapped. A project in Second Life offers potential tenants and buyers the opportunity to go online and experience the project virtually as compared to simply looking at static 2D renderings and floor plans. This same model in Second Life could also assist in the entitlement process by allowing development officials and neighborhood residents to virtually experience a project prior to construction, thus greatly increasing their understanding of the project and how it interacts with the surrounding community. People tend to fear or resist what they don’t understand, so the entitlement process can be shortened if a developer can help neighborhood residents and development authorities better understand its project.

The virtual design services provided to the firms mentioned earlier are not cheap. The average cost of a project in Second Life for a major company is in the low six-figure range, along with recurring costs for support and event hosting. For such a project to be feasible for a developer, the aggregate value of the exposure, public feedback, and increased public understanding generated would have to be greater than the cost of creating the virtual project. Assigning a dollar value to those factors is difficult, so making the decision on a Second Life project may be based more on intuition and gut feel rather than financial value. For developers that place a high value on determining customer preferences and obtaining broad public exposure, a project in Second Life would be worth considering.

3.2 Feasibility Analysis

Once a developer has determined market conditions are favorable for new development, it must determine the financial feasibility of its project. Obtaining more accurate cost information early in a development project would benefit every developer, so any tool that would help to provide this information would add significant value. One such tool that claims to offer such capabilities is DProfiler by Beck Technologies. This section will present case data showing how this tool was successfully used to save money and make decisions, but questions remain regarding the accuracy of the tool's estimating capabilities and its lack of interoperability with other BIM solutions.

The primary difference between DProfiler and other BIM systems is that it integrates an object-based, 3D modeling system with a cost database from RSMeans that is updated quarterly and adjusted for location. This integration allows users to create project cost figures at the early stages of conceptual design. As the model is created in DProfiler, a project budget is generated by associating quantity take-offs with unit costs. As a result, the user can develop and communicate project scope, estimate the project budget based on that scope, and conduct optimization studies by reviewing design and cost alternatives. If a particular design concept is over budget, the user can change the model and receive instant cost and visual feedback. "Today the architect gets hired to dream big, while the general contractor gets hired to bring it in at a low cost," says Stewart Carroll, COO of Beck Technologies. "Those two things don't match, so you don't really know what it costs to build until you get much further downstream. Our view is that you have to coordinate the two to be realistic."[23]

One example of the value obtained by using DProfiler is the Two Alliance Center project in Atlanta. Developed by Trizec Properties Inc., the project is a 20-story, 485,000 sf office tower. Trizec stated that "within 24 hours of identifying a potential benefit to reconfiguring the parking deck, we were able to confirm both the design and cost implications without additional design time or cost. The process took a few hours. The savings we identified in excavation, construction and design costs are well into six figures."[18,19]

CG Schmidt, a construction management firm, has used DProfiler to determine costs in the conceptual design phases of two multi-million dollar buildings. "With DProfiler, we are able to provide customers with more accurate costing information at the earliest stages of pre-construction," says Dan Klancnik, Pre-Construction Technologist at CG Schmidt. "It also helps us do a better job of providing owners with intricate what-if scenarios. This helps them make more informed decisions about where money is being spent."[21] The firm is also using DProfiler to create templates for their niche building types, and according to Klancnik, this effort "really pays off by saving a tremendous amount of time, when starting a new project, that can be passed on to our customers in savings."[21] When considering client response to DProfiler, Klancnik stated that "whenever we bring a laptop to a customer site and use DProfiler for cost data and what-if scenarios, everyone is impressed. Our customers see real value in DProfiler and macro BIM technology."[21]

When considering the value of DProfiler, one must reflect upon the proclaimed accuracy of the tool's cost estimation capability, which is only as good as the RSMeans database it uses. For this application to create value for the developer, those estimations would have to be very close to the actual project costs. In December of 2005, a developer approached Beck Technologies with rough design sketches for a certain "Project X" and asked for a DProfiler cost estimate. A DProfiler estimate of $45,984,675 was produced in less than 5 hours. Unbeknownst to the technology group using DProfiler, this same developer also approached the Beck Group's conventional estimating team and made the same request. The estimating team produced a budget number of $46,000,000 by averaging several recent office tower projects similar in size and scope to the building shown on the submitted sketches. The $215,325 variance between the two independent estimates was .46% of the total project cost.[17] Although that result suggests DProfiler's rapidly produced estimates are in line with the more time consuming, conventionally produced estimates, the question of improved accuracy still remains. Project X's actual costs remain unknown, and more case data is needed to fully ascertain the accuracy of DProfiler's cost estimation capabilities.

While DProfiler's accuracy remains in question, one definite limitation of the software is interoperability. At its current state, DProfiler is unable to export models to micro BIM solutions.

According to Klancnik, the DProfiler models are no longer useful after the conceptual design and cost estimation phase. Consequently, the building model has to be re-created using another BIM package for the detailed design phase.[34] Beck Technologies is very aware of this limitation, and is currently working on an integrated bridge built into Revit. The firm is also in discussion with Graphisoft and Bentley, because, says Carroll, "we're trying to be BIM neutral."[23]

3.3 Design

Once a developer determines its proposed project is feasible and supported by sufficient market demand, the detailed design phase begins. This section will provide examples of how BIM enables Design Efficiency, Visualization, and Sustainability. In the Design Efficiency section, case data is provided showing how BIM can save time and money through associative modeling and documentation, optimization and automation, and interoperability. This section also addresses the challenges and recommendations associated with a BIM implementation in the design phase of project. Case data in the Visualization section demonstrates that BIM can help to obtain more timely client feedback, achieve real-time design understanding, and enable team members to rapidly locate critical information. Lastly, the Sustainability section discusses the relationship between BIM and green building, how BIM can enable sustainable design, and sustainability-related improvements needed in BIM tools.

3.3.1 Design Efficiency

In this context of this section, the term "efficiency" refers to a design team completing a design in less time or at lower cost or both. In February of 2006, the University of Minnesota hosted a BIM Symposium which was attended by Dr. Lachmi Khemlani, AEC technology consultant and founder of AECbytes.com. Dr. Khemlani noted the following: "Some audience members questioned the 'cheaper, faster, and better' marketing rhetoric behind BIM and asked if this was really true. The answer to this from those panelists such as NBBJ, Mortenson, and HGA, who were ahead of the curve in BIM implementation was a resounding 'yes.' They all agreed that BIM makes for a better design process and product and also provides more business opportunities. And while BIM may be an optional technology at the moment, it won't stay that way for too long—some of the panelists revealed that they already had clients coming in asking for BIM."[6] The following examples will demonstrate how the BIM characteristics of associative modeling and documentation, optimization and automation, and interoperability helped to save time and money during the design phases of actual projects.

3.3.1.1 Associative Modeling and Documentation

The Eureka Tower project in Melbourne, Australia, provides examples of design efficiency obtained through associative modeling and documentation. The project began in 1998, even before the term “Building Information Modeling” had been coined, making the Eureka Tower one of the earlier BIM projects. This high-rise apartment building includes a 10 story podium complex containing retail and office space, a 3-star hotel, a public viewing deck, and a parking lot. The project was designed by Fender Katsalidis Architects (FKA), and is one of the largest projects to be designed using the principles, methodology, and processes of building information modeling. Surprisingly, FKA made the firm-wide transition from 2D to 3D design on this project, with the intention of looking beyond traditional methods and aligning the design process with the modern and elegant nature of the project.[12]

FKA selected ArchiCAD for use on this project, primarily because of its ease of use compared to the only other BIM solution available at the time, MicroStation Triforma. ArchiCAD allowed for components and assemblies to be designed once and then reused across the project. The building models were all linked together according to hierarchy, and any change made in a sub-model was automatically reflected in all the parent-level models linked to the sub-model, thus avoiding redundant work. The building model was also used for interior design, allowing furniture layouts and material combinations to be explored. Once the interior designs were finalized, the model allowed the penetration documents to be automatically checked against fixture placements.[12]

Document generation was another task on this project that was completed in less time by utilizing the associative capabilities of BIM. Most of the construction documentation for the Eureka Tower project, estimated to be approximately 1000 A1 sized construction drawings, was derived directly from the 3D building model. Many of the detailing aspects of drawing creation were automated by the software, so relatively little drafting work was needed to complete the construction documents. Since every drawing was associated or “linked” to the model, any change in the model was automatically reflected in the drawing, thereby eliminating the divide between design and documentation. Since documentation was achieved as a byproduct on this project, employees were able to concentrate on the design, and were required to collaborate effectively with one another. Thus, according to FKA's David Sutherland, BIM enhanced cooperation rather than segregation between team members on this project.[12]

Time and labor savings resulting from modeling and documentation efficiencies realized on the Eureka Tower project were substantial. Table 1 shows the values of efficiency related criteria for two actual projects, the Eureka Tower which was designed with BIM methodology, and Project A (actual name not disclosed), designed with traditional 2D methodology. Both are residential towers of similar standard and complexity.[13]

Table 1: Design Efficiency Comparison[13]

	Project A	Eureka Tower
Size	45 stories	88 stories
Time to document	100%	50%
Number of staff	100%	66%
Working hours per week	72 hrs	51 hrs

3.3.1.2 Optimization and Automation

Other design efficiencies were realized during the Beijing National Swimming Centre project by using the optimization and automation functionality of a BIM system. The Beijing National Swimming Centre, also known as the "Water Cube," was designed by international engineering and design firm Arup, along with Australian architectural firm PTW. The structural design of the building was based on the most efficient sub-division of three-dimensional space: the basic arrangement of organic cells and the natural formation of soap bubbles. This naturally occurring arrangement results in a seemingly random structure generation, but is actually a very repetitive and highly buildable solution. The structure of the building is based on a repeating unit comprised of six 14-sided polyhedrons and two 12-sided polyhedrons. Arup created an optimization program to create a 3D array of these units from which the 175m x 175m x 35m building envelope was sculpted. The optimization program then conducted a structural analysis of the previously generated arrangement. The program repeated this process until the optimal size of each member was determined, resulting in the minimum structural self-weight. During this optimization process, 22,000 steel beam members were tested under 190 loading scenarios.

The automated optimization program allowed for many different design options to be evaluated quickly and accurately. To guarantee that the optimal structural analysis model was imported correctly into the 3D model, Arup created a conversion program within Microstation. The conversion program read the output data from the structural analysis optimization, and was able to model the entire structure in 25 minutes rather than months if done manually. From that 3D model, Arup was able to extract all of the elevations, sections, and details to produce the final documentation drawings.[26,30] The total budget estimate for the Water Cube project was $130 million, and Arup estimates that the optimization and automation programs used with the Bentley BIM solutions resulted in project savings of $4.25 million (3.3% of total project costs) and 14 months of schedule time.[26,48]

3.3.1.3 Interoperability

Interoperability, also known as Electronic Data Interchange (EDI), is proving to be another BIM capability that can increase efficiency during the design process. EDI is simply the exchange of information between multiple software programs, from one native format to another, without creating inaccuracies or requiring inefficient data re-entry.[35,50] The demand in the AEC industry for flawless and universal EDI is enormous, but many obstacles to achieving this goal still remain. Nevertheless, some forward-looking firms have learned to capitalize on existing EDI technology, and are enjoying the benefits.

International EPC (Engineering, Procurement, and Construction) firm Hatch was hired to expand and develop a 5,000 ton plant for Alcoa World Alumina, and implemented EDI to save money and time. Hatch engineers use Bentley's Structural Tri-Forma (STF) software to simultaneously design the pipe, architectural, electrical, and mechanical systems for the Alcoa plant. This integrated design approach helped to accurately model the structural steel frame which, upon completion, was delivered to the Hatch detailing team. "By cutting out 2D engineering drawings, we eliminated 20% of the conceptual work," said Timothy Kaiser, Senior Engineer for Hatch.[8] Hatch detailers used CIS/2 data transfer to export the STF structural model into Design Data's SDS/2 detailing package, which can automatically detail connections using a 3D model.[8] CIS/2 is essentially a translator, or a bridge that allows software programs to communicate. Once a component is defined in a CIS/2 compliant program, in essence it is also defined in a CIS/2 analysis program, thereby eliminating the need to manually recreate the model.[35] Hatch detailing manager Ivan Jivkov estimates that SDS/2 automatically designed 80% of the steel connections, leaving 20% to be designed manually by the detailers. Once the structural model was completed in SDS/2, it was transferred back to Structural Tri-Forma using CIS/2, where engineers tested it for interferences with plant mechanicals.[8]

Normally at this stage, detailers produce paper shop drawings. Once again, Hatch took a more integrated approach and utilized Virtual Reality Modeling Language (VRML) technologies developed by the National Institute of Standards and Technology (NIST) to enable a paperless process. "VRML provides a 3D visual representation of a CIS/2 file," says Bob Lipman, head of NIST's CIS/2 to VRML mapping initiative. "It allows users to visually verify a steel structure down to the bolts and welds to see what works and what doesn't. In this case, we linked electronic versions (PDF) of the shop drawings to the appropriate steel members. And because VRML is viewable through web browsers, all parties were able to view the 3D model and the shop drawings simultaneously, without the need for commercial software licenses." According to Michael Hebert, Project Manager for New Orleans based fabricator Manufab, Inc., the digital approach "worked so much easier and faster than the snail mail lag associated with paper drawings. Shop drawings were electronically transmitted in batches, saving us 3-5 days per transmission." Overall, Hatch estimates a project schedule savings of 4-8 weeks resulting from the use of EDI and VRML technologies.[8]

3.3.1.4 Design Efficiency Discussion

The increased design efficiency resulting from associative models, document generation, interoperability, and optimization and automation programs enable a shorter design phase, which is clearly valuable to the real estate developer. From the developer's perspective, several issues related to the implementation of a BIM system in the design phase of a project should be considered. First, there is a learning curve associated with implementing BIM, and with that learning curve comes a short-term decline in efficiency, essentially making things worse before they get better.[49] This decline has the potential to partially or completely offset any efficiency gains realized by the use of BIM at the project level. The developer must be aware of that possibility when selecting its design team.

Second, the more team members that use BIM and the earlier they get involved, the greater the overall efficiencies will be. For example, on the Eureka Tower project, BIM use did not extend beyond the design team because other disciplines were unwilling to give up their 2D CAD processes. Had these other disciplines been involved with BIM, "the benefits [to the project] would have been even more remarkable."[12] Starting the BIM process early across multiple project teams helps to create a collaborative environment and substantially increases the probability of identifying and resolving potentially expensive problems.[15]

Third, the developer will have to create and manage new forms of contracts to govern the flow of BIM data between members of its development team. Traditional contracts are based on 2D documentation, and many of those contracts simply aren't adequate for governing the transfer and use of electronic data. "We're talking about new contracts, new relationships between architects and contractors and owners," said Mario Guttman, vice president and CAD director at architectural firm HOK. Currently, he said, the transition to construction is "usually done in a traditional contract arrangement: two-dimensional documents are the contract. But the model is shared in information meetings so everybody in the room is better informed."[4] This issue also relates to new concerns about liability and data ownership on BIM projects, which could be an entire research topic of its own. Regardless of the ambiguity and lack of precedent, the developer must be prepared to grapple with this challenge.

Fourth, lack of interoperability is a significant roadblock to achieving an efficient workflow between architectural, structural, and building services design disciplines. Progress is being made in this area with the development of open standards such as IFC (Industry Foundation Classes) and CIS/2, but these standards have certain limitations.[51] For example, the export from a BIM model to IFC causes the loss of some important energy-related information, and IFC still lacks a sufficiently complete representation of structural engineering to be effectively used by structural engineers. In relationship to IFC, CIS/2 is smaller in scope and more focused on structural steel applications rather than the entire spectrum of tasks involved with the design, construction, and operation of buildings.[52,53] Based on numerous examples of interoperability issues identified, it seems likely that any developer who incorporates BIM into its project can expect to deal with interoperability issues of one form or another. These issues can be partially alleviated by using multiple applications produced by the same company, but no company has all of the solutions, so using 3rd party applications to some degree is to be expected.

Lastly, based on the competitive nature of the architectural design industry and the demands of owners, it seems likely that any reduction in schedule achieved by the design team would be passed on to the owner. It appears that cost savings, however, can either remain with the design team or be passed downstream to the owner, depending on the situation. David R. Scheer, associate professor at the College of Architecture and Planning at the University of Utah, commented on this issue from the perspective of an architect: "The productivity enhancements promised by BIM would seem to make it attractive to architects and other design professionals as well as to owners. However, the intensely competitive nature of our industry makes it likely that most if not all of any productivity gains realized by BIM will be passed through to our clients. This is what happened with CAD. Over the last 15 years, architects' fees have actually declined in real terms as our productivity has increased by automated drafting. Our clients will demand that we use BIM, but unless we are careful, adopting BIM may be no more than an additional cost that we will have to absorb within our present fee structure."[41]

3.3.2 Visualization

Based on the number of examples easily identified, visualization appears to be one of the more common benefits to firms utilizing BIM in the design phase of a project. The following case data will demonstrate how BIM can help to obtain more timely design feedback, enable real time design understanding, allow model information to be quickly located, and provide the electronic data required to easily produce complex physical models.

The Orcutt/Winslow Partnership, designer of the Willie and Coy Payne Junior High School in Gilbert, Arizona, noted that having a building model to review with owners and consulting engineers allows for more timely feedback.[10] Scott Simpson of Stubbins Associates said the following: "The unit of progress for BIM is the ability to make better decisions. 3D technology allows clients to finally understand in real time what architects are trying to communicate via their designs. 2D design to the client – much like a musical score to a nonmusician – is just notes on paper."[33] The Hong Kong housing authority noted that "with everyone looking at the same model, changes can be reflected immediately and all are notified at once. This will save time and reduce misunderstandings later in the process." The GSA (General Services Administration), which handles the development and operation of all federal buildings, said "the fire protection engineer, for example, instead of spending all of his/her time looking for information, knows where it is and can really bring knowledge and expertise to the team much more quickly and productively….the same with other team members. There is a huge amount of productivity gains for moving in the direction of BIM."[27]

Arup provides another example of visualization benefits through BIM, and stated that "the end users will see sooner and more clearly what they are getting…and can make sure they are getting what they really want."[27] For the Water Cube project, Arup was required to create a physical model of their proposal. As mentioned earlier, Arup's design for the structural portion of the building was very organic in nature, so manually constructing a representative model would have been expensive and time consuming. Instead, Arup used a rapid prototyping technique called stereolithography, which is commonly used in aerospace and other industries. After the 3D model of the building was created in MicroStation, the model file was exported to an STL file (stereolithography). Using a process know as SLA, liquid epoxy resin was solidified by a laser following the STL file information to make a semitransparent, solid model of the Water Cube. This time-saving process would not have been possible without an accurate 3D model of the building structure.[26,30]

3.3.3 Sustainability

Although the United States is by far the world's leading energy producer, it is also the world's leading energy consumer by an even wider margin. As a result, the US ranks number one in the world for net energy imports, presently consuming about 1.4 times as much energy as it produces.[36] Of this enormous amount of energy consumed, buildings account for the largest portion of that consumption.[3] This statistic presents both a challenge and an opportunity for the AEC industry. If buildings can be built and operated using less energy and natural resources, the benefits to society would be phenomenal. These benefits include reducing the United States' reliance on foreign energy sources, lower CO_2 emissions from power plants, lower consumption of raw materials, and a reduction in landfills. With reference to owners and developers, sustainable or “green” buildings are cheaper to operate and create positive publicity.

So what role does BIM play in the sustainable building movement? According to Dr. Khemlani, “one of the most significant aspects of BIM is its ability to capture the description of a building in a semantically intelligent format that can be analyzed to study different aspects of its performance, including those related to energy use. Thus, there is a natural correlation between BIM and green buildings; in fact, I would even go so far as to say that if there ever was a technology ‘in the right place, at the right time’ – at least in AEC – that has to be BIM in the context of sustainable design.”[3] Nadav Malin, vice president of BuildingGreen, Inc. and editor of Environmental Building News, says “with green building and building information modeling on geometric growth curves, their marriage is mutually supportive.”[4]

When viewed as individual tools, BIM software packages do not create value for the real estate developer. During the design phase, value is created when the developer’s design team uses these tools to economically design a sustainable project. The developer’s relationship to BIM software tools is similar to the relationship between an orchestra conductor and the instruments within that orchestra. Clearly the conductor doesn’t have to be an expert with each of the instruments in the orchestra. However he must be familiar with the capabilities of each instrument so that he can adjust, guide, and optimize the roles of the individual parts to produce a polished overall performance. Although the developer usually isn’t a direct Revit or ArchiCAD user, it is critical for the developer to understand the capabilities of such tools in order to effectively lead and optimize the functions of the development team. Therefore the purpose of this section is not only to examine how BIM enables sustainability, but also to discuss the functionality and limitations of these tools so they can be effectively leveraged by the developer and its project team.

Specifically, this section will discuss how BIM can help to streamline performance simulations, provide energy feedback during conceptual design, conduct energy analysis during design development, and track building materials and their associated properties. This section will also address the implications of BIM on obtaining LEED® certification (Leadership in Energy and

Environmental Design), a standard developed by the United States Green Building Council (USGBC) to evaluate building sustainability. Also, industry examples of how BIM is currently being used to enhance sustainability will be presented, along with suggested technological and process oriented improvements.

3.3.3.1 Streamlining Performance Simulations

Using traditional CAD solutions, producing a building performance simulation can be a painful and lengthy process. With a 2D solution, special 3D models are created or manual plan take-offs from the floor plans are conducted. With a non-BIM 3D solution, an input file is created by extracting building data from disparate CAD files and then merging that data. Typically, the data import must be manipulated for import into the analysis tool, and then the output has to be "deciphered" before it can be used by the designer.[5] With traditional CAD, "you had to do all this heroic behavior to create an environmentally sensitive design," said Jay Bhatt, vice president for AEC at Autodesk.[4] According to Vincent Murray, business development manager in the Boston office of simulation software company IES, "BIM opens up building-performance modeling to the entire building construction community."[4]

To create a building performance simulation, energy modelers use specialized software to create a virtual model of the building. Anticipated weather and usage patterns for the building are then applied to the model to predict energy use. The many hours required to create and analyze energy models built from traditional data sources causes many design firms to outsource their performance simulation tasks. With BIM, the "model is available as a given, representing the actual current state of the design, [so] we can shorten this amount of time dramatically," said Adam Rendek, of Ashen + Allen Architects in San Francisco. "We are taking advantage of the intelligence that is embedded in the model. That's what makes BIM different from 3D CAD." [4]

3.3.3.2 Energy Feedback During Conceptual Design

Just as early communication between designers, builders, and owners saves time and money on a project, early stage simulations from preliminary 3D and BIM models offer the greatest potential benefits on the quest for building sustainability. "A smart team working on sustainable design will start looking at energy models before even designing the building," said Mario Guttman of

HOK.[4] In a perfect world, each time a designer moved a window or changed the thickness of a wall, the building's predicted energy performance would be updated and displayed in real time. This type of instant feedback would dramatically increase designers' energy optimization skills, allowing new buildings to rapidly approach carbon neutrality. That world has obviously not yet arrived, but progress is being made.[4]

One application showing promise in this area is Green Building Studio (GBS), an early stage energy analysis tool produced by GeoPraxis, Inc. GBS is able to translate information from BIM software into a format readable by DOE-2, the industry standard energy simulation engine. Energy models typically require data that is not normally included in BIM files, let alone conventional 3D CAD files. GBS populates these "data gaps" with numerous default assumptions, which are based on a large network of relational databases containing weather data, design data, and information about building and energy codes. GBS plug-ins for Revit and ArchiCAD have been created that assist users in creating HVAC zones and validating the BIM model to increase the probability that the energy simulation results will be useful. The plug-in generates a gbXML formatted file (gbXML is an information exchange protocol developed by GBS) and uploads the file to GBS's server for analysis. Within minutes, the designer can download and view the results, which provide energy statistics for the building and recommendations for design improvements based on information in the relational databases mentioned earlier. This process can then be repeated to determine the optimal design for energy efficiency.[4,5]

The ubiquity of XML as a protocol for transferring "packets" of project data is a critical point of opportunity toward achieving interoperability across the large and fragmented AEC industry, and GBS's gbXML is one of the best examples of this.[25]

Another set of applications intended for use in the early energy modeling phase is SketchUp and EnergyPlus. While far from being a full-blown BIM tool, "a lot of designers prefer SketchUp early on because it's such a facile tool," said Chris Leary of design firm KlingStubbins.[4] In 2007 the U.S. Department of Energy (DOE) plans to release a SketchUp plug-in for the powerful EnergyPlus modeling engine which is intended to supersede DOE-2. This new plug-in will help designers define HVAC zones and assign thermal characteristics to model elements. It will then create an EnergyPlus input file for the user to run separately, although future releases of the plug-in will run the simulation within SketchUp.[4]

Although not an energy analysis tool, DProfiler now includes a “green” assembly to help evaluate the financial impact of using sustainable building methods and materials without adding to the cost of design. This new “green” assembly is a wall assembly using insulating concrete forms (ICF’s) to construct poured-in-place, reinforced concrete walls. Beck Technology claims “the resulting walls are durable, energy efficient, and soundproof walls” that use eco-friendly materials and contribute toward LEED certification along with other energy efficiency designations.[20] Beck also claims the pricing for this assembly is very competitive to traditional wall assemblies, and when used in a project, this assembly can very often result in up-front construction savings.[20] Case data substantiating these claims appears to be limited, but it should be noted that this new “green” assembly was just recently announced by Beck Technologies on June 21, 2007, therefore very little time has elapsed for actual use of this new assembly.

3.3.3.3 Analysis During Design Development

During design development, the more facile tools such as SketchUp are replaced by the full-blown BIM tools such as Revit, ArchiCAD, and Bentley Systems. Several efforts are currently ongoing to create links between these BIM tools and performance modeling platforms. In February 2007, Autodesk and simulation developer IES announced a collaborative effort to link their tools. As a result, Revit MEP now has the ability to calculate energy loads using a built in IES engine. Unfortunately, IES is currently only tied to Revit MEP and not Revit Architectural, which appears to be a limiting factor in producing sustainable building designs.[4]

Graphisoft is also pursuing a partnership with an integrated performance modeling package known as Ecotect, which is popular in academic settings and early design studies. According to Nadav Malin of Environmental Building News, Ecotect’s popularity results from its “intuitive” graphical interface and flexible connections to open source tools, such as Radiance for daylight modeling and EnergyPlus for energy.[4]

Bentley Systems has taken a different approach. Rather than trying to link to a specific energy modeling package, Bentley instead focuses on using the IFC (Industry Foundation Classes) framework to transfer data to third-party analysis tools. However, Malin claims that "support of the IFC standard has been spotty and the IFC definitions don't cover all building data exchange requirements."[4] For example, global architecture firm NBBJ uses IFC to send data to consultants, but the firm does not regard IFC import/export as an optimal process. The process is very involved and time consuming, and every exchange is case-specific and must be mapped and tested before being used on an actual project. One solution would be to have both the building modeling and analysis tools use IFC as their native file format so that the import/export fiascos and case-specific mappings could be avoided. This type of solution is not currently available, and it is not known whether any effort is being made to develop such a solution.[3,4]

3.3.3.4 Materials

In addition to energy efficiency, materials selection is another critical aspect of sustainable design. BIM models, if set up properly, can automatically track the materials used in a design, thereby eliminating the tedious and error-prone tasks of measuring surfaces and volumes to estimate material quantities. The resulting accuracy in materials take-offs reduces waste, but a potentially more significant benefit from BIM is the ability to track specific materials attributes. Most BIM models already link to cost information, so theoretically they could also store data such as environmental impact scores from life-cycle assessments and quantities of recycled content. Ultimately, according to Mara Baum of Anshen + Allen, "we'd like to make a change and be able to understand, in real time, the carbon impact of the change in terms of embodied energy of the materials."[4] Getting accurate life-cycle data on most products is difficult, but one solution is to have that information flow directly from the product manufacturers into the model. Many manufacturers currently provide CAD models of their products, and BIM-friendly models of those same products that incorporate properties data will likely be published in the future.[4]

3.3.3.5 LEED Certification Implications

As adoption of the LEED Green Building Rating System grows, many owner/operators are requiring their new projects achieve LEED certification. This rating system provides a total score for a project, and that score is based on site design, indoor environmental quality, and efficient use of materials, water, and energy. Projects with high LEED ratings qualify for certain state and local government financial incentives, which are obviously valuable to the owner and developer.[5]

BIM creates interesting LEED certification implications due to its ability to aggregate materials information and analyze other building information. LEED Online is the portal through which project staffers submit documentation that describes and quantifies the sustainable attributes of the project. Currently, these LEED submission documents are Adobe Acrobat PDF files, but according to Max Zahniser, the USGBC's certification manager for LEED New Construction, future submissions won't necessarily require a PDF submission at all. "LEED Online was originally built on XML technology, so our templates are submitting XML packets into our database," he says. "We went that route so that we could eventually capitalize on the ability for other tools to submit those packets, without users having to go through LEED Online themselves."[4] In theory, those data packets could come directly from BIM software. This arrangement appears likely due to the November 2006 announcement of a partnership between the USGBC and Autodesk. Streamlining innovations such as this will likely increase the confidence of design teams that they are submitting acceptable documentation. From the developer's point of view, the LEED certification process will be shortened, thereby hastening the arrival of the resulting financial and public image benefits.[4]

3.3.3.6 Industry Examples

The ambiguous cost implications of sustainable design are common obstacles to widespread sustainable development. "Before BIM, developers had no way to accurately predict the long-term cost savings of a green building," claims Jay Bhatt of Autodesk. "They had to go with their gut feeling that building green was better for the environment but they couldn't really measure the financial impact."[29] A BIM-based solution to this problem of predicting green cost savings was applied during the development of the Octagon, a 500-unit luxury residential apartment complex on Roosevelt Island in New York City. Bruce Becker, president of Becker + Becker Associates which designed and developed the Octagon, stated that "the software helps with the hundreds of decisions that you need to make to be green. It's a very important tool to determine the benefit and cost of each green strategy. With it, you can [add engineering value] to your project."[29] The Octagon project received a LEED Silver certification, and is comprised of two towers that have 250 solar panels, insulated windows, and recycled materials.[29] The quantified benefits of using BIM for predicting green cost savings on this project were unavailable.

3.3.3.7 Sustainability Discussion

In summary, substantial progress is being made to link BIM and sustainability, but several key improvements are needed to solidify their integration. First, BIM models should be able to contain the data required to perform meaningful energy calculations. An energy model needs location information like sun angles and climate data, along with schedules of operation and mapped HVAC zones. This capability is needed particularly at the preliminary design stage. That being said, too much data in a model can slow even the most capable simulation engine to a crawl, so model data must be compartmentalized in such a way that allows users to "stow" data not needed for the current application. Second, linking manufacturers' product data into BIM assemblies will allow for accurate material information analysis. Third, BIM should be able to calculate the financial implications of green building features such as reduced water usage, recycled materials, etc., both in terms of initial construction costs and recurring costs during operations. Fourth, BIM should be integrated with the LEED document submission process so that LEED certification can be automated. Fifth, the development of on-the-fly energy calculators would help to make sustainability a more significant part of the design process.[3,4]

Even with the above mentioned improvements, there will likely always be a need for specialists to obtain more sophisticated energy simulation results. "There is a lot of art to the science of energy modeling," said Kevin Pratt, director of research at architectural firm KieranTimberlake. "You can't just take an architectural model and run a thermal analysis on it. The real question is, do you understand what the [energy analysis] results mean?"[4] Developers should not rely on their architects alone to produce energy analyses, but should plan to include the appropriate energy experts and consultants on their projects. Energy consultants should also be familiar with the project location, since there are regional differences in what is considered "green," which is difficult for analysis tools to capture.[3,4]

After attending a recent "BIM For Green Buildings" summit, Dr. Lachmi Khemlani notes that "most of the discussions related to how BIM can help design greener buildings were very theoretical rather than based on the practical experience of using BIM in conjunction with energy analysis tools. The lack of real-world examples….in industry forums as a whole, may be a troubling indicator that the technology is not there yet. BIM certainly has the potential to help design more sustainable buildings, but this potential currently seems to be a long way from being fully exploited."[3]

3.4 Construction

After the design phase, the construction phase of a project offers the next opportunity to create value by implementing BIM methodology. Case examples in this section will demonstrate the value derived from using BIM for interference and design error detection, both prior to and during the construction process. This section will also discuss the cost estimation and quantity extraction capabilities of BIM, and how those capabilities can enable design optimization and better decision making. Case data will then be presented showing how BIM can help to verify construction integrity and the conditions of existing buildings by importing data from laser scanning devices. Lastly, case data from two of General Motor's recent plant construction projects will demonstrate how BIM can enable prefabrication and just-in-time delivery.

3.4.1 Interference and Design Error Detection

A common cause of construction budget overruns and schedule delays in development projects are caused by unresolved design errors that later surface as unpleasant surprises. The ability to virtually build a project prior to any shovel hitting the ground is invaluable – it gives constructors the chance for a "trial run" where the vast majority of the design errors can be resolved. This section will discuss two projects that successfully used BIM for this purpose along with the value derived as a result.

The first case example is from the 250,000 sf Camino Medical Office Building project in Mountain View, CA, built by DPR Construction. The majority of the data available for this project relates to the use of virtual modeling for the MEP/FP systems (Mechanical, Electrical, Plumbing, and Fire Protection). Prior to the start of construction, Navisworks was used to identify and resolve 126 MEP/FP interferences. Once construction commenced, zero RFIs (Request For Information) were generated for conflicts between systems modeled in 3D. The early detection and resolution of the interferences resulted in 30% fewer sheet metal workers and 55% fewer pipe fitters than originally estimated. These labor efficiencies saved the HVAC contractor $400,000 on a total GMP (Guaranteed Maximum Price) contract of $9.04 million. By implementing virtual design and construction methodology, the project owner, Camino Medical Group, saved $9 million in construction costs and shaved 6 months from the project schedule. Total construction costs for the project were $100 million, and project duration spanned from October 2003 (start of design) to April 2007, with construction beginning in February of 2005. Thus, construction savings were 9% of the total construction costs, and schedule savings were approximately 14% the total project duration, and 22% of the construction period.[11,56]

The second case example is LucasFilm's Letterman Digital Arts Center (LDAC) in San Francisco, CA. The LDAC is comprised of four buildings and a theater with a total area of 865,000 sf, along with a four level, 1,500 space underground parking garage. BIM was not adopted until the post-design phase for this project, after most of the design documentation had been completed in 2D. The use of BIM on this project evolved with time and gathered momentum as the value of creating a detailed, dimensionally accurate 3D model became evident. During the BIM process, which ran in parallel to construction, many discrepancies and unresolved design issues were identified between the structural, architectural, and mechanical systems. These issues were conveyed to team members during weekly variance meetings allowing corrections to occur often days before the relevant components were built. The contractor's shop drawings were included in the BIM process which led to the discovery of additional errors, which, if left unresolved, would have resulted in considerable cost to the contractor and significant schedule delays.[15]

In order to assess the benefits of BIM on this project, the LDAC development team conducted several design coordination variance cost studies. An example of those studies is shown in Figure 1, which contains a graph showing the cost implications of incorrectly cast concrete beams on one portion of the project. Using BIM, the issue was identified in the orange zone (between 8 and 10 months) of the graph when the forms were already in place, but soon enough to avoid expensive rework had the error been found in the red zone (between 10 and 12 months), after the concrete pour.[15]

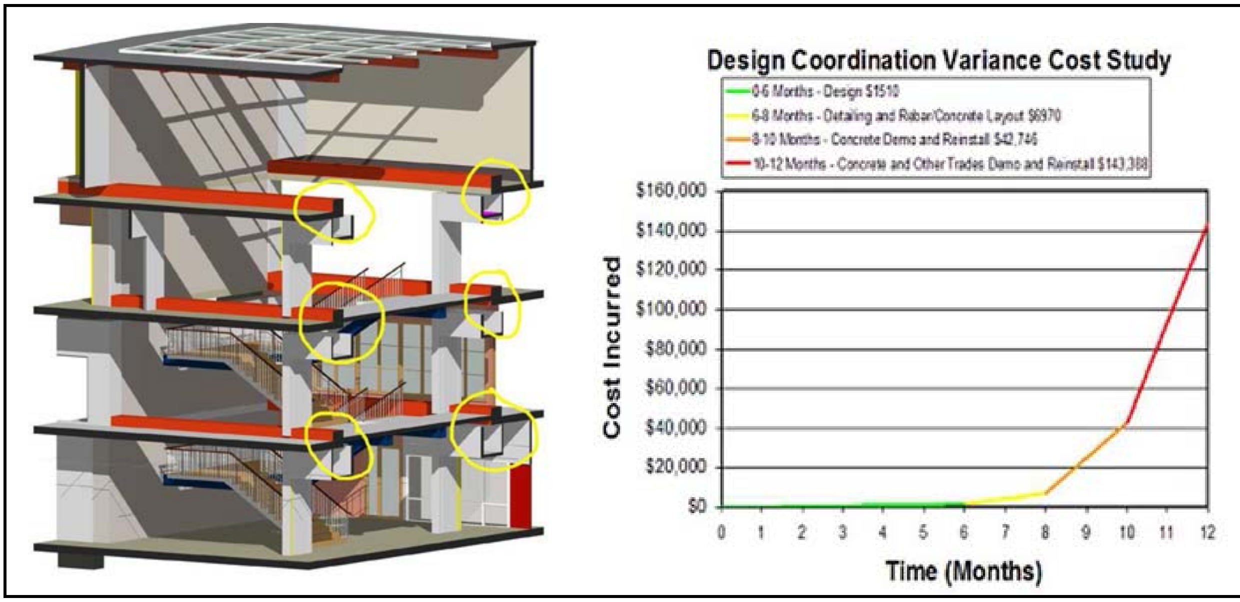

Figure 1: Design Error Identification on LDAC Project[15]

Although LucasFilm required many design changes on this project to accommodate company restructuring, the LDAC project was completed on time and below budget. Since most of the problems were solved before construction, there was no finger pointing during and after completion of the project. As a result of careful site coordination using BIM, over 200 design and construction conflicts were detected and resolved. This resulted in an estimated savings of over $10 million on this $350 million project.[15]

This successful result was due in part to several key factors and protocols. First, project owner George Lucas fully supported and encouraged the use of BIM on this project. Mitch Boryslawski, design and construction coordinator for the LCAC project, said “the LDAC project demonstrates that far-sighted building owners who invest in the construction of smart building information models can realize significant costs savings, not only in the design and construction process but also in the maintenance and operation of the life cycle of the building.”[15] Second, as updated models became available from each of the team members (architects, contractors, MEP engineers, etc), those models were incorporated into a core building model that was compressed and made available to the entire team as a read only file. Third, this core model was updated weekly by designated model managers and redistributed to the team. Old versions of the model were automatically deactivated after one week, ensuring that everyone had the most recent version.[15]

3.4.2 Cost Estimation and Quantity Extraction

As mentioned earlier, tools like DProfiler can produce cost figures early on in a project, but more detailed cost estimates and quantity take-offs are produced later in the development process using micro BIM tools. A BIM model is object-based, and each object (doors, windows, etc) carries descriptive information about itself that can easily be extracted, with cost being one of the most typical types of carried data. Based on the amount of easily found case data, BIM's cost estimation and quantity take-off capabilities appear to represent more of the "low hanging fruit" available with BIM use. The following examples show how BIM's cost estimation and quantity extraction capabilities can help to create more design flexibility and further aid design decisions.

For the Capital Health project in Edmonton, Alberta, HIP Architects used Revit to pinpoint the cost of four ambulatory care buildings. Revit was also used for gauging the costs of tiny changes during the design process, such as the costs associated with shifting the buildings three degrees to deflect sun and using different types of windows. "Previously, we were reticent to explore different design strategies because it would be so time consuming and costly," said HIP partner Allan Partridge.[29]

Another example of the quantitative power of BIM comes from Chris Leary at KlingStubbins: "When you're in front of a certain kind of client, things that have numbers related to them are valued as decision-making points, whereas things that are qualitative are not."[4] Using Revit, Leary was able to quickly determine how many office occupants would have direct window views: "When considering a shift to interior offices and external workstations, thanks to the Revit model we had a quantified way to drive the decision."[4]

3.4.3 Scheduling and Sequencing

As with building a structure virtually before construction, the ability to simulate construction scheduling and sequencing in advance creates significant value, and that value increases with the complexity of the project. Time based sequencing simulation is often referred to as 4D modeling (3D + time), and based on commonly found case data, 4D modeling appears to be frequently used on BIM projects.

On the LDAC project, 4D modeling was effectively used to plan the construction process. The development team identified 248 activities, which LDAC cost estimators used to create a time-based construction schedule. Once the area of simulation and tasks were identified, a simplified 3D model was extracted from the BIM model and was imported into the 4D simulation. The schedule was then linked to each object in the 3D model, resulting in a time-based animation which was automatically updated if a task's time requirement changed.[15]

3.4.4 Verification

The spatial and visual accuracy of virtual building models can be a very effective tool to verify that the intended design is actually built. The following case examples demonstrate how virtual building models and laser scanning devices can help to verify construction integrity and also to accurately determine the conditions of an existing building.

In order to insure construction integrity, LDAC project managers conducted regular walks around the job site and digitally photographed the construction in progress. These photos were then compared to relevant parts of the 3D model, and since the building had already been constructed virtually, deviations from the design were quickly identified. The LDAC development team pushed the verification capabilities of BIM even further. Using data from the project's core BIM model, specialized software guided laser measuring and pointing devices as technicians used them to check for the accurate positioning of pipes in the LDAC's data center.[15]

Laser scanning has also been used on GSA renovation projects. Dr. Calvin Kam, BIM Program Manager for the GSA, stated that "BIM is a very wide toolkit with many different aspects," among which 3D laser scanning is "one of the more mature tools, and one for which we see a lot of business need and business value."[37] The value of laser scanning first appears in the construction planning phase by allowing the GSA to provide project teams with high-accuracy data about existing conditions, which, according to Dr. Kam, is a vast improvement over simply "handing them some archived drawings and saying, 'Go to the field and verify it.'"[37] Dr. Kam also said that laser scanning then adds value in the fabrication and construction phase by "integrating the site back to the 3D model."[37] "How can we have good construction QA/QC?," said Kam. "How can we be sure that all building elements are aligned, and verify that all as-builts are as-designed? Laser scanning provides a good feedback loop for anchoring 3D in the real world."[37]

3.4.5 Prefabrication and Just-In-Time Delivery

Offsite pre-fabrication and the just-in-time delivery techniques of lean construction are each enabled by a commitment to build from comprehensive building information models.[54] Using case data from two recent General Motors plant projects, this section shows how pre-fabrication, just-in-time delivery, and a build-to-the-model approach can save time and money, improve quality and site-safety, and promote sustainability by reducing waste. This section will also discuss the importance of an owner's mandate for collaborative BIM use along with the learning curve associated with a new BIM implementation.

Substantial savings from prefabrication and just-in-time delivery were realized on GM's 442,000 sf, V6 Engine Assembly Plant Addition Project in Flint, Michigan. August Olivier, GM's director of capital projects, said that this project was "a breakthrough change in the way we do business."[54] According to Olivier, this breakthrough was "schedule driven," or in other words, driven by the desire to minimize time-to-market not only for cars, but also for the plants used to build them. By shortening plant design and construction cycles, GM can hold off on facilities commitments until consumer preferences in the automobile market take form. Compressing these cycles allows for shorter-term market predictions, which means less risk to GM.[54]

Led by A&E firm Ghafari Associates, the design-build team for this project created a comprehensive building model which was collaboratively used to resolve over 3000 interferences prior to starting construction. The team then "locked" the model, and all project participants agreed to build to it as planned.[54,55] According to Robert Mauck, vice president of Advanced Technology for Ghafari, not only did this process eliminate rework caused by field interferences, but it "allowed the team to adopt a build-to-the-model approach using increasingly off-site fabrication and just-in-time delivery and construction, which further enhanced quality and site-safety."[55]

Olivier makes the additional point that the proof of success with BIM was seen on the project site. After observing a suspiciously sleepy jobsite, Olivier asked an HVAC contractor where his equipment was. "We pre-fab everything and bring it in and put it up," the contractor replied, as his on-site team of eight inserted long runs of ductwork into position.[54] Prefabrication enabled by the build-to-the-model approach resulted in no fabrication or trimming on site, few dumpsters, and little waste, thereby saving time, money and enhancing project sustainability.[54] "I have never seen a project go through more efficiently," says Steve Hart, estimator for HVAC contractor Dee Cramer. "Seeing everybody's conflicts and resolving them right there on the screen made it a lot easier. Our design in [the] V6 [plant] went right over the coil line and cutting table and into the field. If we could only get every project like that. It's astronomically more efficient for everyone."[54] Dee Cramer president Matthew Cramer adds: "We had zero collisions with the other trades. The owner is getting a project delivered a heck of a lot quicker than they ever could have gotten, and it's flat-out less expensive for them. It's an easier job to work on, and it's win, win, win."[54]

Overall, this project was delivered 25% faster and 15% under budget with no change orders from building component interferences.[55] One key factor that enabled these successes to occur was that the owner exercised a mandate for collaborative BIM use and was willing to cast aside old business practices built around 2D documentation. According to Mauck, "GM laid the groundwork and then pulled the trigger on all the right things."[54] GM jettisoned its rigid CAD standard for this project, which would have severely disrupted the integration of much of the specialized subcontractor software. Another cast-in-stone business practice that was dropped was GM's requirement for paper plan submissions for design reviews at 30, 60, and 90% of drawing completion. This paper-based process conflicted with the live model review process, and was quietly let go after one influential GM mechanical engineer sat in on the review sessions and was convinced of their effectiveness. "We made some real believers out of some of those crusty old guys," said Paul Sinelli, GM's manager of capital projects.[54]

Another key factor in the success of this project was that GM had endured the BIM implementation learning curve on an earlier project, the 2.4 million sf Lansing Delta Township Plant (LDT plant). Of the two projects, the V6 plant in Flint gets most of the glory for a near perfect performance, but the LDT plant was the "plowhorse for de-bugging the organizational techniques and integrating the critical 3D design technology," said Jack Hallman, GM's director of construction management.[54] Hallman added: "We got off to a rocky start at LDT, but that was the learning curve. If we hadn't done LDT, Flint would have never been."[54] Software issues and a hesitancy to commit resulted in early problems at LDT. "We didn't trust the 3D data," Hallman admitted. "We cut our teeth on LDT."[54] Todd Pugh, estimator at John E. Green Co., mechanical contractor on both projects, stated the following: "No one, quite frankly, really bought into the model when we started in that [LDT] job. But by the time the [Flint] V6 project came around, that had all changed. We had the entire job detailed and coordinated before we stepped on the jobsite."[54]

3.5 Operations

The operations phase of a building's life cycle is by far the longest and most expensive of all the phases, and therefore offers ample opportunity for new innovations and methodologies to have a positive impact. As mentioned in the introduction, the NIST report entitled "Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry" concluded that $10.6 billion of the $15.8 billion annual cost of inadequate interoperability in the AEC industry is shouldered by owners and operators. [47] One of the report's recommendations to address this problem is that building information models should be used to connect design files with facilities management (FM) and building control systems.[39] According to Adam Rendek of Anshen + Allen Architects, the building information model can be prepared early on for use during building operations: "We can input information on the fly, as we are creating the model, that can be used directly for facility management," said Rendek, and "that could bring a huge benefit to the client for little additional work."[4] This section will discuss current FM applications and their capabilities along with the benefits owners can realize by receiving a virtual building model from the contractor upon completion of construction.

Existing FM applications are far less mature than those for design and construction, so even if a good virtual building model was produced for the owner, current FM software tools would only be able to utilize a relatively small portion of the data contained in the model. However, recent developments with Autodesk's FMDesktop and Revit Building have resulted in some progress. New functionality in Revit Building allows it to export room and area data to FMDesktop, which eliminates the laborious and notoriously inaccurate process of manually creating polylines for space definitions. Unfortunately, some extraneous work is still required to make these Revit exports usable in FMDesktop. Dr. Khemlani of AECbytes made the following comment about facilities management tools being able to import information-rich spatial data previously created using BIM: "[This capability] has the potential to cut away much of the extraneous work, streamline processes, and allow facility professionals to concentrate on their core management tasks without having to worry about the process of getting the needed spatial data into their FM systems or its accuracy."[24] Dr. Khemlani also noted that with more intelligent data populating the FM database, facility managers could potentially use it to control heating and cooling systems, detect hazards, and activate the appropriate emergency systems.[24]

In order for smart building models to be used for FM, those models must be created in the design and construction phases and passed to the building owner upon construction completion. However, owners cannot simply sit back and wait for these smart models to "fall into their lap," especially in today's fragmented and inefficient AEC industry. Market research conducted by software development company Newforma revealed that there is "a recurring disconnect between the expectations of the owner and the responsibilities of the contractor."[38] This research suggested that owners consider information from the upstream design and construction processes to be a strategic asset, while contractors view this information as a final deliverable for project completion. The contractor typically delivers a set of as-built documents which consists of boxes of drawings, specifications, equipment manuals, warrantees, etc. Often these documents are delivered as field mark-up versions of the original design documents.

The challenge for owners is to clearly define the format of as-built information that will provide the information necessary to meet the lifecycle needs of the building. This definition could be included in the general requirements of the construction contract, and could specify the delivery of a virtual building model that has been updated throughout the construction process. This information-rich building model would give owners an accurate 3D representation of the building along with useable information for continuing building maintenance and operations.[38] Having such a model would also add value to the building as a whole when the owner decides to sell. In addition to maintenance and operations applications, the model could provide information relevant to the buyer's due diligence process.

3.6 Future Applications

As stated earlier, the AEC industry lags far behind the aerospace, automotive, and electronics industries when it comes to using collaborative, 3D design and fabrication tools. However, being at the back of the pack isn't all bad. In this position, the AEC industry can learn from these more forward looking industries by adopting and customizing the technologies that offer the greatest benefits. New ideas can also be found at universities around the world conducting research on architectural, construction, and fabrication technologies. Practitioners in the AEC industry would be wise to learn about these ideas and practices so they can be better prepared for future technological developments in their own fields and embrace them more readily.[9] This section will discuss some of these ideas and technologies, and how they could potentially be applied in the AEC industry.

3.6.1 Motion Capture and Virtual Reality

The term "virtual reality" (VR) first became common in the 1980's, when zealous computer enthusiasts made pronouncements about the new ability to experience computer generated realms and how such technology would change the world.[1] This first foray into VR ended up as a bust due to slow computers, complicated networking, and motion sickness issues. As of today, significant progress has been made with these issues, and VR 2.0 is having quite an impact. One key difference is that today's VR systems are enhanced by motion capture, technology that allows a computerized system to track movement and translate that movement to a viewing console and store it as data for analysis. One example is the Wii, Nintendo's wildly popular gaming system, which allows a user to swing a wand to hit a home run in an animated ballpark shown on the user's TV. Communication technology company Gesture Studios has also developed a motion capture system called GoodPoint used for delivering presentations.

GoodPoint enables a presenter to take an audience on a fly-through of a model city or on a tour of a 3D architectural design. According to Tom Wiley, Gesture's Director of Business Development, the measured theatrics of the presenter can make a big impression. "Everyone's looking for the new, sexy way to communicate with their employees and their clients," he said. "We're selling their ability to sell."[1] From a real estate perspective, using such technology could have a positive impact on developer's efforts to communicate with designers, contractors, government officials, tenants, buyers, investors, and anyone else related to the development of a project.

A more immersive application of motion capture and virtual reality is used by dozens of aerospace, automotive, and heavy equipment makers such as Lockheed Martin, Ford, and Caterpillar. Motion tracking allows workers, sometimes thousands of miles apart, to collaborate in shared virtual environments and test the ergonomics of a design for a car or plane. "Any company that creates a product used by people needs to understand how the human body moves," said Iek van Cruyningen, head of securities and investment bank Libertas Capital Group. "Motion tracking systems and virtual simulations accelerate product development and boost productivity."[1]

At Lockheed Martin's Ship Air Integration Lab in Fort Worth, Texas, motion capture and virtual reality is helping to develop the new F-35 stealth fighter jet. Designers, engineers, and customers are equipped with VR headsets and suits dotted with motion capture sensors. They then enter a darkened 15 x 24 ft area where cameras track their every move. Through their head mounted displays they see digital renderings of the fighter prototype and lifelike avatars of one another. In this environment, they can practice and test the crucial activities that will be performed thousands of times once the plane is built. If a particular task can't be performed easily in virtual reality space, the design is modified. For one task, examining the approach speed of the plane as it lands, Lockheed avoided 50% of the cost of building a mockup and saved $50 million in design changes by using the VR lab instead of traditional wind tunnel tests.[1] Firms with tighter budgets also use this technology, as shown by Ford Motor Company's implementation of motion capture to analyze the reach and posture of assembly line personnel.

According to Ford ergonomics expert Allison Stephens, these simulations have reduced the expected number of disability cases at a pilot plant by 80%.[1]

Another interesting VR application has been developed by VirtuSphere, a technology firm based in Redmond, Washington. The company's main product and namesake is the VirtuSphere, which is a large, hollow sphere positioned on a base allowing for 360° rotation. The mechanical functionality of the system is similar to a hamster wheel, but allows for rotation about three axes instead of just one. Users enter the sphere wearing a wireless, head mounted display which enables them to fully interact with a virtual environment. Users can move in any direction, and can walk, jump, crawl, roll and run for unlimited distances. Dr. Suzanne Weghorst, senior research scientist and assistant director of research at the University of Washington's Human Interface Technology Lab, said "the HIT Lab has been looking at omni-directional interfaces for some time, and we are convinced that VirtuSphere has developed the most elegant and effective solution for navigating within virtual environments."[2] The Moscow 2012 Olympic Committee used the VirtuSphere to demonstrate to the International Olympic Committee the proposed facilities that would be built if the city was awarded the Games. The demonstration focused on security, and showed how security specialists could begin preparing even before the physical structures were built.[2]

The potential applications of these immersive VR technologies are similar to those mentioned earlier in this section, but may add more value due to the "experiential" capabilities which go far beyond flashy visual presentations. Potential buyers and tenants could be immersed into virtual spaces and provide feedback early in the design process, potentially avoiding costly customization changes. By virtually experiencing a project proposal, government authorities and community residents could gain a better understanding of the developer's vision for a project, thereby streamlining the entitlement process. These potential benefits must also be weighed against the cost, which is one obstacle to widespread use of such technologies in the real estate industry. The costs of the Lockheed and Ford systems mentioned above is unknown, but one can safely assume those costs are not minimal. The VirtuSphere system sports a $50,000 - $100,000 price tag, which is the main issue holding up the mass adoption of that product.[2] As with all technologies, however, the prices of this and other VR technologies will drop and become more widespread. The application of this technology to the real estate industry seems to be far off, but definitely in the pipeline.

3.6.2 Academic and Industry Research

In addition to learning from other industries, the AEC industry can reduce its inefficiencies by supporting and implementing research at academic institutions and by emulating forward-looking AEC firms. Under the direction of Professor Chuck Eastman, the College of Architecture at Georgia Tech is pursuing a wide variety of research activities applicable to real estate development. One of these efforts involves the harmonization of CIS/2 and IFC, the leading data translators in the AEC industry. The project involves identifying cases where interoperability between CIS/2 and IFC is clearly needed, providing extensions to both IFC and CIS/2 so they can interoperate for those cases, and then developing a translator for the data exchange.[9] Another significant project is the development of a new 3D parametric modeling system for precast concrete. This is a collaborative project with participation from Tekla, a Finland-based CAD company, and the Precast Concrete Software Consortium (PCSC).[9]

At Eindoven University of Technology in the Netherlands, a research effort is underway to develop a method to simulate how space is utilized to provide reliable data on human movement for performance evaluation. This data is critical for making design decisions such as the capacity of elevators, width of corridors, and egress routes, and is also used for simulating lighting, airflow, and evacuation.[9] Another project aims to develop a multi-agent model for simulating pedestrian activity and movement patterns. Movement is simulated using a grid and steering behavior, and variability is introduced by superimposing agents, with their specific agenda, choice heuristics , beliefs, and environmental knowledge. A virtual reality environment is then used to visualize the simulation results.[9]

On the industry side, the LDAC project team has discussed the possibility of installing smart dust chips in key areas of the building MEP systems, such as fire sprinkler main valves. Once an emergency situation was detected by the smart chip, the building information model would activate the area of concern and simulate the necessary response with the use of 3D avatars, which are virtual simulations of people.[15] In the wake of both natural disasters and terrorist attacks, the GSA is also exploring the use of avatars for emergency simulations, where the avatars would be programmed with human behaviors such as walking, running, turning, and detecting the nearest exit. This type of simulation would allow egress patterns and evacuation times to be studied and optimized.[16]

3.7 The Cost of BIM

One of the most commonly asked questions by AEC professionals when BIM is discussed is: "Who will pay for the extra effort to develop the model?" Changing from one form of technology to another almost always involves extra costs. When design firms changed from hand drawings to 2D CAD, the initial costs of software, hardware, training, and productivity loss were undoubtedly felt by every firm that made the transition. Today, if an architectural firm were to demand a premium for using 2D AutoCAD, it would lose business since such technology is the norm. The same will be true with BIM – it will become the normal way of doing business and will not command a premium fee. The question previously posed could be refined to say: "Who will pay for the hardware, software, training, and initial loss of productivity resulting from BIM implementation at my firm?" Evidence shows that these costs are covered by either the user of the software (designer, contractor, engineer), the developer, or both. As BIM use becomes more common, however, it seems likely that these costs will fall more upon the users of the software since implementing BIM will be required to stay competitive.

Fender Katsalidis Architects hasn't let the question of extra upfront cost hold them back from what they see as the most logical way to design a building using currently available technologies. FKA sees BIM as its standard way of doing business, and does not expect to receive a fee premium as a result of its BIM implementation. They feel the internal benefits have been well worth the extra cost, even for their first BIM project, the Eureka Tower.[12] Scott Simpson at Stubbins Associates agrees, and feels that with BIM, firms can provide more design for the same fee.[33]

If a particular developer wants BIM on its project, it may very well have to pay for many of the associated implementation costs if the architects, contractors, or engineers on its project team have not previously employed BIM as a part of their normal business practices. Mitch

Boryslawski, design and construction coordinator for the LDAC project, noted that "the success of the LDAC project can be attributed in large part to a significant commitment made by the owner towards implementing BIM technology. Funds were allocated to the general contractor for the purchase of software applications, training, and creating the 3D MEP product data for those sub-contractors that were not trained in 3D technology."[15] George Lucas was personally involved in all the design decisions, and without his fervent advocacy for the use of advanced technology, this project would not have reaped the benefits produced by the BIM implementation.[18]

3.8 Analysis and Results Summary

Using BIM for market research related tasks appears to be minimal, however, BIM is being used to generate project fly-throughs for public awareness and marketing purposes. Virtual modeling is also being used for advertising and customer feedback in Second Life, the online virtual reality world. Participation in Second Life is growing rapidly, and this appears to be a venue worth considering for developers that rely heavily public exposure and customer preferences.

Case data shows that BIM tools such as DProfiler can help to determine project feasibility and optimize building design early in the conceptual design process. However, it should be noted that the accuracy of DProfiler cost estimates are only as accurate as the RSMeans database those estimates are based on. More real life examples are needed to fully determine DProfiler's estimation accuracy.

While BIM can potentially add value to each development phase, based on the amount of available case data, it appears that the most value from BIM is currently being created during the design and construction phases. During design, case data shows that substantial time and cost savings are being realized due to the associative modeling and documentation capabilities of BIM. Time and money is also being saved by utilizing BIM's optimization, automation, and interoperability features. However, these efficiencies do not come without a cost. Firms can expect to experience a learning curve when implementing BIM, during which there is a short-term drop in productivity. Case examples show, however, that this productivity decrease can be more than made up for by the efficiencies realized once the learning curve is complete.

Evidence suggests that using BIM during the design phase can also enable sustainable design. Some BIM tools are currently able to perform basic energy simulations and provide real time energy feedback, which helps to integrate sustainability into the design process early on. For more advanced simulations, BIM can provide some of the data required by energy simulation tools, although the transfer of this data can be problematic and incomplete depending on the type of simulation. The materials data and quantity extraction capabilities associated with BIM can enable waste reduction and help quantify the sustainable attributes of a building. The LEED certification process could potentially be streamlined by using BIM tools to generate and submit the required information for LEED certification. Based on the limited amount of real world examples, however, it appears that BIM's potential to help design more sustainable buildings is far from being fully exploited.

During construction, the major value created by BIM seems to be with interference detection and prefabrication. Using a BIM process allows project participants to virtually construct a building in advance and identify and resolve interferences prior to construction, thus saving substantial time and money. Using a build-to-the-model approach also enables extensive prefabrication to occur, resulting in less waste, better quality, lower labor costs, and a shorter construction period.

Using BIM for the operations phase seems to be relatively limited based on the amount of available case data. Huge potential for additional efficiency exists in this phase since the greatest portion of a building's lifecycle costs occur during operations. Facilities management tools currently in use are unable to use the majority of the information associated with virtual building models produced using BIM applications. However, once technology evolves to where facilities management tools can fully utilize BIM data, an information-rich virtual building model could essentially be "sold" to the next owner, thus generating additional returns on the original BIM investment.

4.0 CONCLUSION

Designers of the first automobiles dubbed their creations “horseless carriages” because they were unwilling or unable to shift their mindset to entertain an elemental change in technology. Consequently, they stuck with the familiar, and decades passed before automotive design really came to terms with technology. A similar mindset was present with the introduction of the steel frame to high-rise construction, where designers clad the first steel frames in masonry to resemble the bearing wall structures already known to the world. Years passed before designers began to capitalize on the expressive capabilities of steel, which are common-place in today’s buildings. These two examples highlight an unfortunate reality with nearly every industry. When faced with a true innovation, industries typically trudge through a period where the innovation is twisted and manipulated to conform to the familiar practices of the past. However, leaders and visionaries eventually embrace the innovation for the pathway it creates toward freedom from old restrictions.[7]

Building Information Modeling is one of these innovations, but much of the AEC industry is either avoiding this innovation or stubbornly trying to cram it into the mold of yesterday’s methodologies. As discussed earlier, this resistance to change is a major contributor to the massive inefficiency costs in the AEC industry. According to Ken Sanders, chief information officer of San Francisco-based architecture firm Gensler, BIM is a chance for a fresh start. “As we move into BIM, because it’s so new, there’s an opportunity for the industry as a whole to think more strategically and say, ‘Let's work together.’”[44]

Owners and developers are in the best position to bring on this “coming together” of AEC industry participants, since every dollar spent on a building project is ultimately spent by them. As the well known saying goes, “he who has the gold makes the rules.” When an owner truly exercises its mandate, great things can be accomplished. One example of such an occurrence is the LEED Platinum certified Genzyme Building in Cambridge, Massachusetts. To achieve the platinum rating, sustainable design initiatives such as rooftop heliostats and collector mirrors, rainwater recycling, prismatic louvers and chandeliers to distribute natural light, 800 operable windows, steam-absorption chillers, low emission paints and carpets, and computer adjusted blinds were included in the building.[38] These sustainability-enabling features, along with many others not mentioned, would not have been implemented were it not for the mandate of the owner and its tenant. "Working together with Genzyme as the single tenant in our building, we made the commitment to invest a 15% capital cost premium, not only to achieve significant lifecycle cost savings, but also to create a superior workplace for Genzyme's employees," said Randy Long, Director of Construction for Lyme Properties, the project developer.[38] Another example of an owner taking a leading role in the advancement of the AEC industry is the GSA's December 2003 policy directive calling for the use of standardized Building Information Models to support concept reviews for projects receiving design funding in FY2006. The GSA was also one of the first owners to require LEED certification for public buildings. These two initiatives demonstrate the power of owner mandate not only for driving bottom line savings, but also in the adoption of collaborative building technology.[38]

If owners and developers are to exercise their mandate to drive innovation, they must be made aware of the value that such innovation can create. This paper clearly and systematically provides examples, both actual and theoretical, of how value can be created for owners and developers by the use of BIM on their projects. These examples are arranged according to the flow of the development process, enabling an owner to pinpoint potential value-add practices for any phase of its project. Ultimately, this paper provides a framework of evidence that can help owners and developers find the motivation to shrug the status quo and lead the AEC industry into a new era of collaboration and efficiency through the adoption of Building Information Modeling technology and practices.

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APPENDIX B: Supporting Information

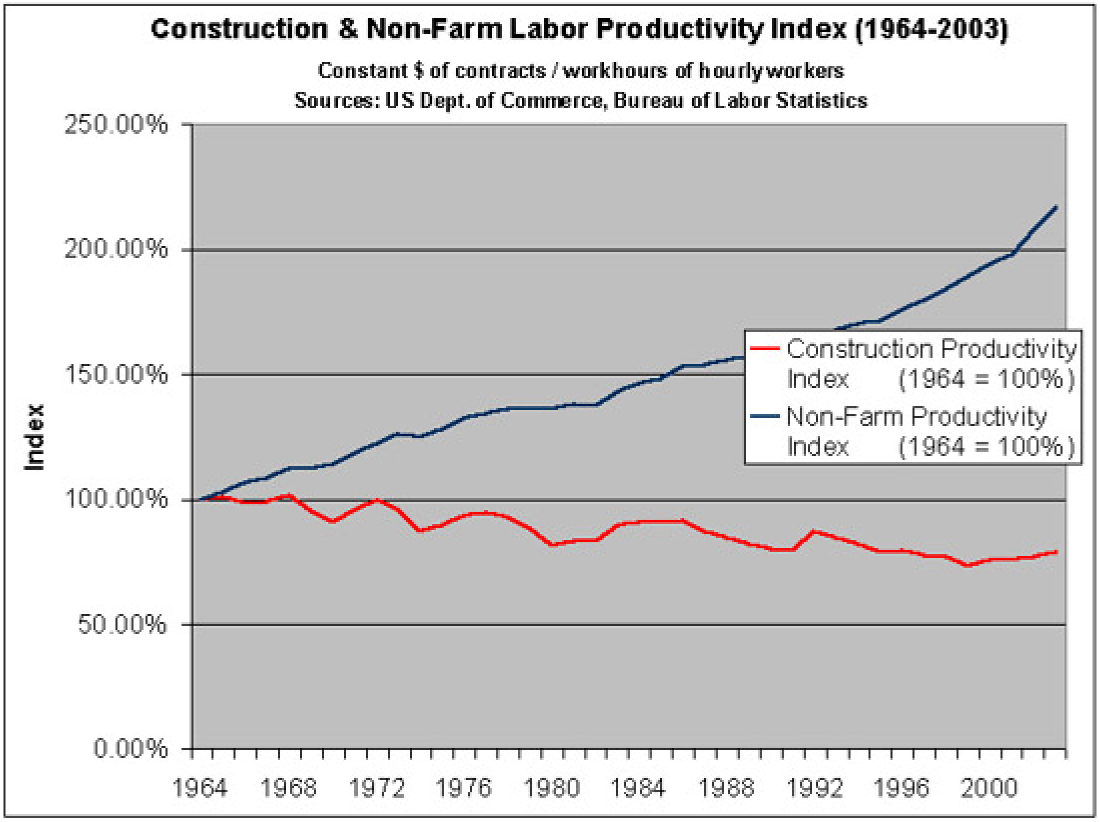

Figure 2: Construction & Non-Farm Labor Productivity Index[46]

Detailed Description of Second Life:

Second Life was launched in 2003, and was created by Linden Lab, a privately owned technology firm in San Francisco. Establishing an account is free, and after downloading and installing the client program, the user can access Second Life and select an avatar, which represents the user's virtual self. Avatars can walk or fly to get around, and can instantly teleport to a specific location by clicking on a map or using the built in search engine. The system has an understanding of matter and terrain, so avatars are unable to walk through walls and are accurately depicted climbing stairs or walking down a hill. Avatars in the same location communicate to one another by using a chat interface, and private conversations are conducted via instant messaging and do not depend on proximity. The economy of Second Life is based on the Linden Dollar (L$), which has a fluctuating exchange rate with real US dollars. Users can buy and sell virtual goods and services to one another in an open market, and people have created virtual businesses that generate real money.[31]