IMPORTANCE OF MULTIDISCIPLINARY COLLABORATION IN BUILDING INFORMATION MODELING (BIM)

By

SERGIO VILLANUEVA-MEYER

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

UNIVERSITY OF FLORIDA

2010

To Kiki, Abita, Juanita and Herbert
“Ibi victoria, ubi Concordia”

ACKNOWLEDGMENTS

First and foremost, I would like to thank my extremely hardworking mom and dad. I have been able to overcome roadblocks in my academic, professional and personal life thanks to their continuous support and extraordinary influence.

I would like to thank Tonky Beale from Beale & Associates, Mercedes Porcari from Exoticscape and John and America Gordon from Wildwoods Inc. They have provided me with indispensable experiences in the AEC field. I am also very grateful to my committee members, Dr. Issa, Dr. Olbina, and Dr. Lucas, as well as Dottie Beaupied, for having such a positive attitude.

Finally, I would like to thank Laura Finton for her abiding happiness. I owe much of my academic and personal achievements to her. Thanks for making my two year journey at the Rinker School so enjoyable.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

2D	A drawing that uses only the X and Y planes
3D	A drawing that uses the Z plane in addition the X and Y planes
4D	Refers to the implementation of Scheduling (time) in BIM
5D	Refers to the implementation of cost analysis (estimating) in BIM
AIA	American Institute of Architects
ABC	American Building Council
AEC	Architecture/ Engineering/ Construction
B	Billion (US$)
BIM	Building Information Modeling
BREEAM	Building Research Establishment Environmental Assessment Method
CAD	Computer Aided Drafting
DB	Design Build
FM	Facilities Management
IAI	International Alliance for Interoperability
IFCs	Industry Foundation Classes
IPD	Integrated Project Delivery
ISO	International Standards Organization
LEED	Leadership in Energy and Environmental Design
M	Million (US$)
PIM	Project Information Management
RFI	Request for Information
ROI	Return on Investment
USGBC	United States Green Building Council
VDC	Virtual Design and Construction

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Master of Science in Building Construction

IMPORTANCE OF MULTIDISCIPLINARY COLLABORATION IN
BUILDING INFORMATION MODELING (BIM)

By
Sergio Villanueva-Meyer

December 2010

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

The global economic downturn has affected almost every market in the world and the architecture, engineering, and construction (AEC) industry has been particularly vulnerable. Although several firms have vanished, projects have stalled, and unemployment rates have spiked, the AEC industry has been extremely busy in its technological and innovative advancements. These have originated significant and fundamental transformations. Building information modeling (BIM) software vendors have been active over the past decade, providing new solutions, innovative tools, and problem-solving updates at an unprecedented rate. The way the AEC industry operates is being deeply re-thought and the way business will be done in the future is simply not the same as it is today.

A collaborative environment is being established, and its presence is inevitable for the proper adoption and development of the latest building construction methodologies. Firms adopting BIM are setting higher goals and a high level of communication and coordination is vital throughout the lifecycle of projects. Therefore, corporate organizational structures have been altered with the introduction of new positions such

as BIM Managers, BIM Coordinators and Model Coordinators. Challenging tasks are being performed and more work is being done by fewer personnel, meeting higher standards. Nevertheless, in order to fully enjoy the benefits of BIM, the proper steps need to be taken, and a well-established collaborative setting is crucial for BIM and Integrated Project Delivery (IPD) implementation.

Some of the focal shifts in the industry are a consequence of the economic downturn, the pursuit of sustainable ratings, the adoption of improved project delivery methods, the bitter history of litigation and a long felt sense of backwardness in the industry. The increased demand for high performance green buildings and the mainstream implementation of green rating systems, such as Leadership in Energy and Environmental Design (LEED), requires an elevated degree of multidisciplinary collaboration. This research explores the paradigm shifts occurring with the recent introduction of BIM and the importance of coordination, communication and the formation of a collaborative environment. Multidisciplinary collaboration is a common denominator of the philosophies behind BIM, Design-Build (DB), IPD, and LEED and a culture of collaboration has been established by the advocates of these methodologies, which happened to be thriving simultaneously.

CHAPTER 1
INTRODUCTION

With the increase in complexity and the technicalities of the modernized world, a collaborative environment of multidisciplinary professionals is highly desired in almost every possible circumstance. As stated by Dana K. Smith, FAIA, “A basic premise of BIM is collaboration by the different stakeholders at different phases of the lifecycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder” (Suermann 2009).

Times are changing and the recent slowdown in construction provides time to reflect over the past challenges and troubles. The 21st century has been exceptionally fast paced, and most industries around the globe, have focused on sustainability, efficiency and quality of life. These trends continue to be of fundamental concern, and the methods employed to reach them will swiftly become all-encompassing. Building information modeling (BIM) brings high hopes to many of the issues experienced in the industry which has often been regarded as backward.

Collaboration is a very desirable process, which creates an environment of two or more entities working towards achieving common goals. The advancements in the key industrial economic sectors have transformed the built environment. The architecture, engineering and construction (AEC) industry is becoming highly specialized due to the constant development of advanced materials, high performance green system requirements and sophisticated methods of construction. Furthermore, the industry involves such a broad range of specialties, that a high level of multidisciplinary collaboration is imperative. BIM has gained widespread popularity due to its broad applications and numerous functionalities. It encompasses most fields of practice, and in addition to the direct benefits to individual organizations, it facilitates coordination and communication with external collaborators.

Green building practices are facilitated through BIM, and most software developers are focusing in the sustainable aspects of their platforms. With the spike in Leadership in Energy and Environmental Design Accredited Professionals (LEED AP's), AEC professionals utilizing BIM tend to have knowledge in sustainability and are helping guide the future of the industry through a greener path. Early BIM advocates have been essential in its adoption and are helping the industry adapt to the changes, while easing the transition to the new methodologies. BIM implementation has created alterations in corporate organizational structures, and new positions such as BIM Managers, BIM Coordinators and Model Coordinators have emerged. These positions are vital, and strive to facilitate benefits in productivity, coordination, scheduling, and planning, as well as to reduce the burden of elaborate and conflicting processes involving multiple disciplines.

Problem Statement

As the AEC industry embraces technology, and its disciplines become progressively integrated, ample quantities of interconnected information catapults project complexities. With the blurred lines of traditional responsibilities and a vague software and contractual language, multidisciplinary relationships remain disconnected.

The multidisciplinary collaborative climate is complex, making project coordination, model data management, and object-based communication highly challenging tasks. BIM offers many solutions to past problems, however, the vast amount of data and information makes it hard to manage. Additionally, with the integration of technical fields (engineering disciplines, energy analysis) into the design phases, better and more sustainable solutions can be achieved. Nevertheless, without the appropriate mediation and project delivery method, the excessive amount of input and cooperation could easily become conflicting and detrimental if mishandled. It is important to understand the widespread desire for a collaborative environment in today's AEC industry. The fields of practice under the pre-BIM and pre-Design-Build (DB) eras still shared mutual goals and benefited from multidisciplinary collaboration, which has been praised for centuries. Therefore it is important to understand the links between the latest AEC trends and project delivery methods (IPD) and collaboration. These trends enable a more collaborative environment geared towards solving issues in areas such as design, quality, cost, scheduling and sustainability. There is a need to investigate the methods employed in the industry to foster this constructive reciprocity which enables improvements in the nexus of time, quality, cost and sustainability.

Research Objectives

The purpose of the research is to evaluate the effect of multidisciplinary collaboration experienced with the implementation of BIM under diverse scenarios. Three groups were created with the purpose of covering the following topics: implementation and experience, scale, and project delivery method. The following objectives attempt to formulate a better understanding of the industry perceptions regarding multidisciplinary collaboration.

1. To determine the degree to which experience and BIM implementation affect the perceived level of multidisciplinary collaboration.
2. To determine the degree of multidisciplinary collaboration experienced in BIM in relation to the size of the projects and firms researched.
3. To determine the perceived benefits and problems encountered in the multidisciplinary process of BIM implementation in relation to the selected project delivery methods and green rating systems pursued.

Research Methodology

The research objectives listed above relate to each other and a well structured comparative analysis will be performed to establish relationships and patterns concerning the selected topics. The structure of the research compliments the findings and begins with a thorough research and analysis of relevant existing literature in Chapter 2. Issues regarding virtual collaboration and software platforms, as well as case studies concerning BIM use, sustainability, Design Build and Integrated Project Delivery (IPD) were discussed.

Chapter 3 provides a descriptive analysis of the reasoning behind the survey deployed thought-out the industry, which targeted BIM and virtual design and construction (VDC) professionals. The section provides an in depth description of the strategy behind the questionnaire. Some questions have been cross-tabulated as part of the statistical analysis and chapter 3 clarifies the reasoning for the pairings and established relationships.

Furthermore, a detailed analysis of the collected data is performed in Chapter 4. The data received was analyzed according to the guidelines established in Chapter 3 in order to better understand the research objectives. This chapter mainly consists of graphs, lists and tables which aim to represent the data in a visually appealing manner, addressing the concerning topics.

Chapter 5 consists of a set of conclusions drawn from Chapter 4, addressing the research objectives. The conclusions in this chapter represent the perceptions of the survey respondents as well as the insights gathered in Chapter 2. This chapter consists of multiple cross-references to the figures in Chapter 4. The conclusions are a product of the previous analysis which consists of graphs and tables containing pairings, crosstabulations and statistical methods used to understand existing relationships and dependencies. Moreover, this chapter suggests recommendations for future studies regarding BIM research, and provides recommendations to the industry regarding advances in BIM and its relationship with multidisciplinary collaboration in the AEC industry.

Summary

This research attempts to target multiple issues, trends and dependencies in regard to technology, collaboration and sustainability. Given that the BIM/VDC arena is going through an unsteady state of change, the research aims to stay in line with the industry updates throughout its duration. The purpose of the research is to further understand the current trends and parameters established in the collaborative BIM environment and observe how these affect projects that follow sustainable practices. The industry is being shaped by technology and advanced project delivery methods such as Design-Build and IPD are on the rise. It is vital to understand the shaping of the collaborative environment and the role of its key players, including owners or facility managers.

CHAPTER 2
LITERATURE REVIEW

Introduction

The introduction of BIM is enabling the pursuit of complex and more sustainable construction methods. As the construction scenario changes, opinions and observations are making their way throughout the industry as well as lectures, publications, product reviews, blogs, white pages, case studies, symposiums and conferences. The literature review seeks to identify the most pertinent sources of information that relate to the research purpose and objectives. It also aims to organize the gathered information systematically, in order to understand the differences and commonalities in the diverse viewpoints selected.

The research performs a set of comparative analyses in order to further understand the effect of building information modeling (BIM) in relation with multidisciplinary collaboration, software implementation, experience, scale, project delivery method and sustainability. Hence, the most pertinent sources were selected and respectively cited. Relevant information was extracted and categorized under four main categories in order to back up our hypotheses and validate the research. The four categories were: 1) The BIM Collaborative Environment, 2) BIM Collaboration Software, 3) Project Delivery Methods, and 4) Sustainability.

The BIM Collaborative Environment

The BIM Collaborative environment is a complex space that encompasses several entities and individuals and can be understood in diverse ways. It is constantly altered by technological updates as well as upcoming industry trends. The following sections discus the factors altering the BIM environment, it defines the problems faced, identifies the existing needs and solutions, and displays relevant and updated sources concerning BIM collaboration.

Global Changes and Technological Advancements

After the collapse of the Berlin wall brought an end to the Cold War, the closing years of the twentieth century brought much change to the new one. Globalization is here and the recent obsession with speed and efficiency has transformed the everyday of everything. The following 21st Century factors identified by Friedman (2005) changed countless processes in most industries:

1. Workflow Software: It has enabled people to work with other people on more tasks than before and a global platform for multiple forms of collaboration has been established.

2. Outsourcing: It has allowed companies to divide the service from the manufacturing activities into more efficient and cost-effective components

3. Off shoring: Refers to the internal transferring of a firm's process to a different country, with the purpose of benefiting from cheaper operations experienced in foreign lands.

4. Open Source: Refers to the growing involvement and collaborating in virtual communities such as blogs, wiki's and open source software.

5. Supply-chaining: Is described as the company's use of technology to make item sales, distribution, and shipping more efficient.

6. Insourcing: This concept, refers to companies collaborating in logistics. FedEx and UPS employees are performing services for other company's such as Toshiba (repairing Toshiba computers at the UPS hub, by UPS employees).

7. The Steroids: Digital mobile, personal and virtual. With the improvements in wireless, voice over Internet Protocol (VoIP), and file sharing technology, personal and Virtual processes can be done at high speed with total ease.

Web 2.0

In addition to the specified factors above, web breakthroughs have attracted the attention of many software developers. Among the most talked about words in information technology is "Web 2.0". It refers to an apparent second generation of web-based services. These services include communication tools, social networking sites, wikis and collaborative compositions. As stated by Grilo and Jardim-Goncalves (2009), “Web 2.0 collaborative tools have emerged with similar functionalities to those in the commercially used Autodesk Buzzsaw or ProjectNet”. The need to enrich BIM interoperability has been largely triggered by what has come to be known as Web 2.0 (Grilo and Jardim-Goncalves 2009). The emphasis is on online sharing and collaboration.

Collaboration vs. C-Three (Cooperation, Coordination, and Communication)

Collaboration is the process of collective creation or constructed knowledge. It can also be referred as a group of individuals or organizations with corresponding capabilities interacting to produce a shared solution that had not been previously identified on their own. This course, creates a mutual sense about a process, a product, or an event, and there is nothing regular about it. The following steps are vital when attempting and enabling collaboration environments (Denise 2010):

- Define the challenge
- Define the collaborators
- Create the space
- Allow the time
- Harness the result

Defining Building Information Modeling (BIM)

The AIA California Council (2007) defines building information modeling as a computable representation of all the physical and functional characteristics of a facility. AEC professionals can now enjoy the new technology platforms, in order to support the old-fashioned notion of early planning. Building information modeling is bringing fundamental changes to industry's workflow structure by assisting previously unheard of degrees of collaboration, planning, coordination, and communication (Dispenza 2010). The integrated process of BIM allows its users to digitally explore the vital characteristics of a project before it is built. This helps minimize the environmental impact as well as in delivering the projects faster and at a lower cost (Cohen 2010).

In the field of construction, with the arrival of BIM, new opportunities arise. These opportunities include, collaborative communication with multidisciplinary parties at a model level in order to utilize the information and values that were already in the model. However, due to the different modeling applications (and their proprietary file formats) new issues arise as well. Three primary strategies (below) have been identified regarding the previously described obstacle (Várkonyi 2009):

- Common language: The International Alliance for Interoperability (IAI) was formed by CAD vendors to develop the Industry Foundation Classes (IFCs)-an open and “non-proprietary” model format to provide a universal communication platform for model-based collaboration.
- Direct interfaces: An alternative solution is for software vendors to implement specialized links between their specific solutions. Sometimes, this approach is only undertaken by one of the parties, utilizing the API (Application Programming Interface) of the other solution.
- Single platform: A fundamentally different strategy is where a software vendor aims to develop competence in each Architecture, Engineering, Construction (AEC) segment and tries to supply the whole spectrum of needs with their own design solutions. Obviously in this case, the proprietary file format dimension of data exchange is likely to be a non-issue between the different applications in a “common” product family. Communication in the “native” language of the applications should achieve seamless and efficient collaboration (Várkonyi 2009).

The 3D models created by BIM not only help the architects and engineers when conveying their design concepts to owners, but they also assists with the process of multidisciplinary communication and collaboration as well as in the 4D (scheduling) and 5D (cost). The introduction of BIM with its numerous collaborative platforms enables the use of a central database, from where the collaborating disciplines can easily extract or input information. Hence, the interaction, flow of communication and collaboration are significantly improved (Holness 2006).

The BIM Process

Traditionally, contractors are responsible for the means and methods while the architects are responsible for the design. However, with the advances of BIM and the early involvement set by Integrated Project Delivery (IPD), not only do these parties perform different tasks, they perform according to different standards in a collaborative fashion. This creates issues in relation to the degree in which disciplines can rely on the information furnished by the corresponding disciplines in the BIM process.

It is important to identify the roles of the disciplines and allocate the risks and responsibilities involved in the participating disciplines. BIM benefits from the ability of the owner, designers, and contractors to share information boundlessly, however this is not always the case. The contract needs to address information ownerships and protection methods. In IPD contracts, disciplines address contractual obligations, however, the information moves freely and is shared among the disciplines, consultants, and subcontractors. This approach would present a higher success rate if the parties have contractual obligations in order to increase collaboration and reduce or eliminate the traditional tension areas between owner, designer, and builder (Dirik 2009).

The Urgency for Collaboration

BIM introduces a variety of multi-faceted capabilities. The common thread between these capabilities is that it provides an accurate and active computer model for the project's life cycle (Azar 2008). The successful implementation of BIM requires input from design teams and project participants from multiple disciplines. Because of this, collaboration is the most critical success factor for BIM and IPD as well (Laiserin 2009).

Collaboration is essential when providing a place for the project participants to view, supply, change, and extract the necessary data throughout the project stages. The multidisciplinary collaboration existing in the interactive 3D models, display information in terms of design, structure, construction as well as time and cost at any level of detail. Some of benefits from BIM include collision detection, improvements in constructability, cost reductions, schedule improvements, and request for information (RFI) reductions. Furthermore, the benefits provided by BIM do not just benefit the immediate users but all the associated parties as well. Substantial benefits are realized when BIM is used in conjunction with a compatible project delivery method (IPD or Design-Build) and a broad ecosystem of collaboration resources (Azar 2008).

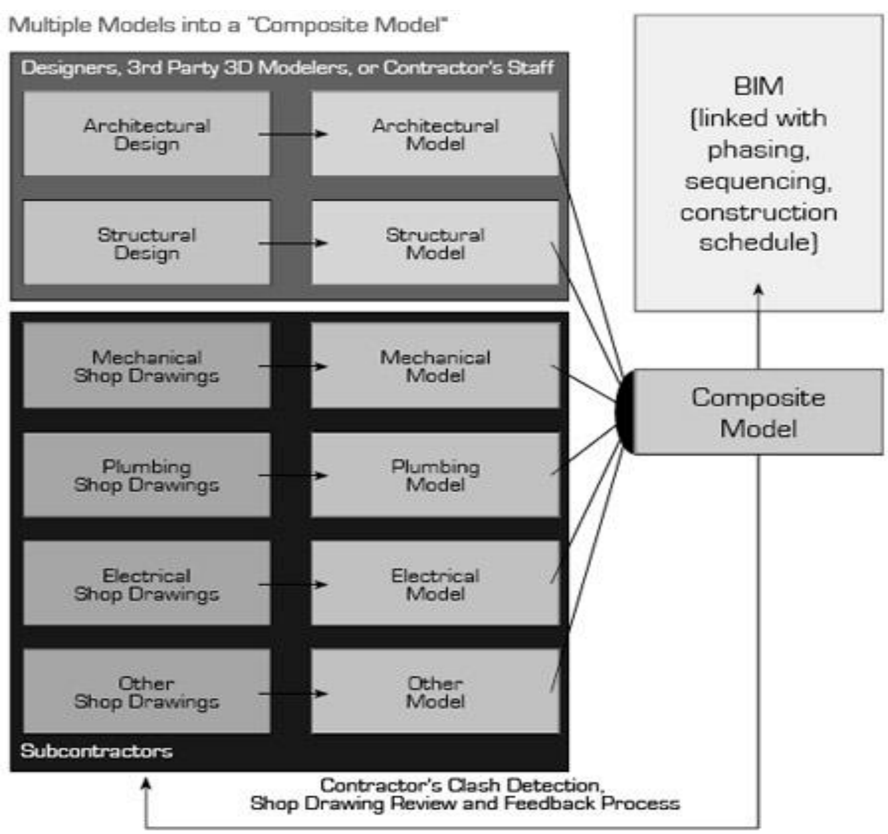


Figure 2-1. Multidisciplinary models combined (contractor's guide to BIM 2006)

Figure 2-1 shows the multiple models in BIM and the process involved in the creation of a composite model. The following section further explains the means in which the multidisciplinary participants and software vendors approach the issues faced with this process.

The Problems with BIM Collaboration

The associated benefits from implementing BIM are evident, however these benefits are not necessarily easy to achieve. Flexibility of workflow, and performance in collaboration is reduced as model data integration is amplified (Laiserin 2009). Team members can work seamlessly and uninterruptedly on the same model, however, in order to avoid inconsistencies, access to the model needs to be controlled and managed with great diligence. The users should be assigned a workspace so that other users are restricted from making changes to the same features at the same time. Then, the changes made to each user local copy must be synchronized or updated to the central project model by integration the different local copies to the central model (Laiserin 2009).

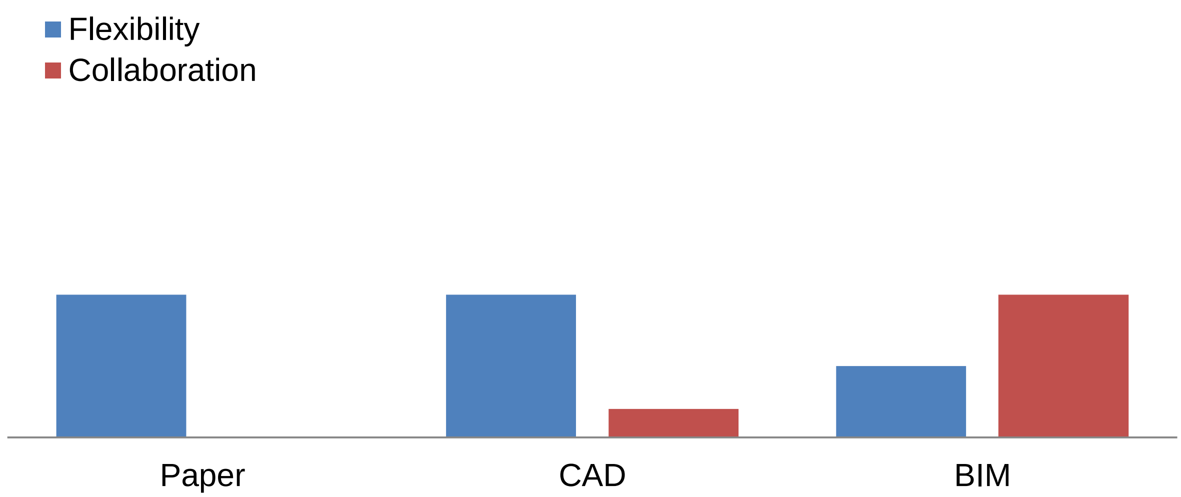


Figure 2-2. Coordination versus flexibility, adapted from Graphisoft’s graph (Khemlani 2009a)

BIM has limitations in flexibility and Figure 2-2 helps better understand the tradeoff between collaboration and flexibility in BIM. As a result of the BIM collaborative style of organization, most BIM software are affected by the tradeoff between the workflow flexibility and the barriers set in collaborative performance. Individual users lose flexibility when trying to access the multidisciplinary models. Performance suffers, while waiting for each user to update the model. These updates take increasingly longer as the project and team increases in size causing frustration over inflexible access to the necessary elements for their work (Laiserin 2009).

Design collaboration is a relatively new phenomenon to the AEC industry. Architects and engineers need to work together in order to accomplish the best outcome and utilization of a building. As architects become increasingly specialized and projects become increasingly complex, the design disciplines working on the same building remain to use their own sets of tools and practices. Hence, the well-known issues with communication and coordination experienced in design collaboration are no surprise (Várkonyi 2009). Collaboration in design and construction can be understood as internal and external. Internal collaboration occurs when the users that edit the model simultaneously belong to a single organization. External collaboration occurs when multiple modelers simultaneously view the combined or separate multidiscipline models for coordination (Sacks 2010a). Furthermore, Sacks et al. (2009), noted the following: “Whereas in the internal mode objects can be locked to avoid inconsistencies when objects might be edited to produce multiple versions, in the external mode only no editable representations of the objects are shared, avoiding the problem but enforcing the need for each discipline to modify its own objects separately before checking whether conflicts are resolved".

As stated by Grilo and Jordim-Goncalves (2010), "Building information modeling should be perceived as a dynamic process rather than a model *per se".* The process of developing an information rich 3D model is a progressive elaboration, with diverse functions and resulting benefits. BIM has the capability of supporting collaborative working environments by enabling improvements in the following (Grilo 2010)*:* owner's understanding of the nature and needs of the project, design, development, and analysis of the project, construction management, and the management of the operations of the project during its operation and decommissioning.

The collaboration problem was not as complex prior to BIM, since the participants would just worked on different sheets. BIM effectively handles the problematic inefficiencies and inaccuracies of the traditional methods, at cost of less flexibility and an increase in collaboration complexity. The collaboration problem is more complex with the introduction of BIM, since the multidisciplinary team members have to work in a highly synchronized fashion. The problem is intensified in applications that have a centralized model approach (ArchiCAD and Autodesk Revit), since most of the information (drawings, schedules, estimates), are contained in one file (Khemlani 2009a).

BIM Collaboration Software

The creation of a the virtual 3D environment may involve the efforts of multiple participants of the multidisciplinary team, thus BIM tools are used to assist in the conflicts arising from the merging and collaborative working of the teams. This process known as clash detection aims to discover and resolve issues in a proactive manner.

Using a 3D model, allows team members to visually approach and coordinate the conflicting relationships of the building components (architecture, structure, electrical, plumbing, etc.) making it a highly effective process. This process is highly desirable, since it enables teams to better understand conflicts during the earlier planning stages (Grilo and Jordim-Goncalves 2010).

Interoperability and the Development of a Common Language

The buildingSMART International alliance is an international membership organization with representation in North America, Europe, Asia and Australia. It brings together professionals from multiple disciplines including architects, engineers, constructors, product manufacturers, and facility managers with the purpose of adopting BIM, developing protocols for data exchange (IFCs), as well as to contribute to sustainability practices in the built environment (buildingSMART International 2010). The structure of responsibility is unclear with the increase of collaboration in BIM. With the growing interaction of multiple disciplines within the same mode, it has become increasingly complicated to allocate risk. Therefore, improvements are still to come in software compatibility and in contractual language. These should specify the collaborative risks and compensations involved (Thomas and Miner 2006).

Every day we see new software platforms and BIM solutions in competition. However, the problem arises when each discipline's software of preference are incompatible with the corresponding collaboration tools and platforms. The issues with interoperability have been addressed and solutions have come a long way over the recent years. However, as mentioned by Thomson and Miner (2006), it remains as one of the most significant challenges in the adoption of BIM.

The buildingSMART Collaborative Efforts

The buildingSMART alliance has chapters and partners around the world and has a strong influence in the interoperability and collaboration of construction projects and facility management processes (International Alliance for Interoperability 2010). The goals of the organization are stated below (buildingSmart 2010):

- Develop and maintain open international standards for building information modeling.
- Accelerate market assimilation of interoperability through successful sustainable projects.
- Provide networking opportunities, specifications and written guidance.
- Resolve high cost problems that hinder data sharing.
- Extend buildingSMART processes and technology to the whole built environment, over its lifecycle, and encompassing leadership, production, facilities management and engineering maintenance.

The buildingSmart alliance, formerly known as the International Alliance for Interoperability (IAI) was formed by CAD (Computer Aided Design) vendors with the purpose of developing IFCs (open and “non-proprietary” model formats to form a universal communication platform for model-based collaboration). These neutral data formats, aid in the information exchange in the building and facility management industry sectors (AEC/FM). The IFCs, now an International Organization for Standardization (ISO) standard (and in the process of becoming the official ISO standard), is composed of a built in dictionary made up of “intelligent” building elements. These elements serve as a diagram, which helps in the conversion of models among diverse applications compatible with IFCs. Users benefit from collaborating with other specialists, due to the IFC files capability of saving and opening generic files (Várkonyi 2009).

In its first major enhancement since 2003, the new IFC release (IFC2x4) has high hopes for interoperability advances. International recognition of the standard is important. The buildingSMART began working towards making the IFC specification an ISO standard in 2008 and now, their goal is to complete the necessary requirements to make the IFC2x4 a full ISO standard. Currently, IFCs is a public available specification (PAS), and the goal has been set to secure acceptance as an ISO 16739 by mid 2010. The IFC2x4 has been in development since 2006 and it provides better coverage, higher quality and precise documentation due to the increased in collaborative work. Furthermore, it provides better opportunities for energy and environmental analysis, as well as the ability to map designs into the GIS system. The improvements to the scheduling definitions (4D) as well as cost items 5D (estimating and construction resource management) are significant. IFC2x4 offers the most encompassing open specification for BIM data formats (Liebich 2010).

Available Software

The benefits from BIM can be incremented when a variety of software that fit under the BIM spectrum is used in concurrence. A 3D model of a building can be displayed in reference to 4D information (schedules and timing issues) as well as 5D information. A feedback loop is created by the incremental data computed by the participating members, streamlining the project delivery (Dispenza 2010). The software options most pertinent to our study are discussed below.

ArchiCAD 14. This product had continued to improve the application's model-based collaboration capabilities. The Teamwork module introduced with the earlier version (ArchiCAD 13) last year has been enhanced with an expanded set of techniques to find data more efficiently. Another unique feature is the BIM Server performance monitor function, which purpose is to provide feedback to server administrators on the server computer performance as well as the BIM server application. Further on, remote access has been made easier by implementing automatic recognition to the multiple addresses, which is especially helpful for the BIM users who work from multiple locations. Graphisoft's "open design collaboration" facilitates the interaction between architects and the various engineering disciplines by using model mapping, element classification, IFC management among other features. ArchiCAD 14, has significantly enhanced the "open design collaboration" environment through enhanced use of the IFC formats by providing IFC translators, optimized for several leading global and local structural and MEP applications (Khemlani 2010a).

Furthermore, ArchiCAD 14 offers two add-ins for Revit that improve model translation with Autodesk software. In reference to multidisciplinary clash-detection capabilities, ArchiCAD 14 can detect model conflicts between structures and the diverse building systems, thanks to its ability to precisely import engineering models from other applications. Hence design coordination with the engineering disciplines can be drastically improved. Typically, multi-disciplinary workflows consist of several rounds of information exchange. ArchiCAD 14 enhances multidisciplinary collaboration by comparing IFC model versions and only importing the differences. Design changes are displayed with color codes in the architectural model context to further ease complex model visualization (Khemlani 2010a).

Bentley. A significant difference between Bentley offers and its competitors is that their BIM solution is integrated and multidisciplinary. Meaning that the architectural, civil, electrical, mechanical, and infrastructure work together. The information and the components within the multiple disciplinary constantly interact. Furthermore, in terms of sustainability, elements such as insulation values, solar loads, air movement, and lighting values require technical, numeric-based analyses, which further optimize the system. These systems work together since all of the systems involve multiple disciplines (Livingston 2007).

Bentley architecture V8i. This software is Bentley's BIM architectural version. It belongs to the large integrated and multi-disciplinary set of building solutions for design, analysis, and collaboration, which is built on the new MicroStation V8i platform. As noted by Khemlani (2009b), "the "i" in V8i stands for five key new capabilities and enhancements, according to Bentley: more intuitive conceptual modeling capabilities; interactive dynamic views; intrinsic geo-coordination capability; incredible project performance and speed; and finally, a high degree of interoperability".

Bentley ProjectWise Navigator. Bentley has also continued to extend the capabilities of its solutions through the development of the ProjectWise Navigator (comparable to Autodesk Navisworks), which is used for coordination, review, and collaboration. Furthermore, the ProjectWise platform is useful for project and file management, particularly for largely distributed project teams. Bentley's has a unique approach in where project data is distributed in several files and its capability to work with multiple file formats, allows it to be used in small or large projects (Khemlani 2009b).

ProjectWise Navigator influences the interactive nature of information stored in the Bentley models, enabling high-performance visualization and multidisciplinary insight, which helps avoid costly errors. The following actions can be performed with ProjectWise Navigator V8 (Bentley Systems Inc 2010):

- Open i-models, native DGN and DWG files, and point cloud files.
- Explore models naturally and intuitively in real time
- Manipulate view settings to interactively change data display on screen
- Find business intelligence behind the geometry with ease
- Measure distances, areas, volumes with complete engineering precision
- Simulate what-ifs, optimize schedules, dynamically resolve clashes
- Group and classify items by leveraging the intelligence behind the content
- Mark up i-models with simple geometry, register and preserve comments
- Produce rich 2D/3D PDFs, create photorealistic images and animations

Autodesk Navisworks. NavisWorks can combine multiple models including the architecture, structure, and MEP models that were exported from their respective Revit BIM applications. The power of the application lays in its ability to import the corresponding 3D file formats and append multiple models into one file. Navisworks is equipped with a powerful compression technology that allows them to be easily reviewed as a whole project, regardless of the file size or format. Additionally, it offers a 4D construction simulation in its Navisworks Simulate and Navisworks Manage products. The 4D capabilities are powerful and intuitive and allow several scheduling options. The clash detection options are efficient and easily understood and offer the ability to coordinate the project prior to construction, reducing change orders, construction errors, reducing waste and keeping costs under control. The lack of IFC support was improved in the 2009 version of the software and it now has the ability of reading object data from the models (Khemlani 2008a).

BIM and the Cloud. Cloud Computing and SaaS (Software as a Service) services are on the rise. France (2010) recognized the benefits from workstation clouds when collaborating with outside firms on the same model, collaborating over wide geographical areas, general business applications, mobility and BIM automation. Due to the fact that many firms do not have the necessary design resources, they regularly work with outside consultants (engineering, fire protection, acoustical, etc). However, since everyone is working on the same project, it would be ideal if they could all work as seamlessly as internal company employees would. Nevertheless, project teams are forced to trade models via project websites. Without cloud computing, real-time collaboration is difficult between external entities (France 2010).

Newforma Project Center (server based). Newforma Project Center is a project information management and collaboration application for AEC firms. Newforma Project Center has become one of the fastest-growing applications in the AEC industry. It is used in 61 of the top 300 AEC firms, with over 120,000 projects managed. Furthermore, Newforma takes credit for the term, “project information management” (PIM), which describes well its functions (Khemlani 2009d).

Newforma recently released the Seventh Edition of its application. Improvements have been perceived with the enhancement of the following features: automatic indexes, project email management, review and markup capabilities, web-based collaboration module, and dedicated interfaces for all project items including document sets, submittals, transmittals, requests for information (RFIs), and action items. Nevertheless, with the introduction of new features, the application is becoming increasingly complex and a BIM specific support has not been implemented yet. As the AEC industry transitions to multidisciplinary models, a demand is evident for BIM-based project information management applications. Newforma Project Center still has to implement such “breakthrough” technology to achieve a BIM project information management (PIM) application (Khemlani 2009b).

Attolist (web based). Attolist is a relatively new, web-based solution for document management, construction administration, and project information management (PIM). With the increase of projects using IPD in the AEC industry, Attolist attempts to facilitate the workflow automation and collaboration capabilities of its application. Figure 2-3 presents an image of the web-based site and its graphical representation of information (Khemlani 2009d).

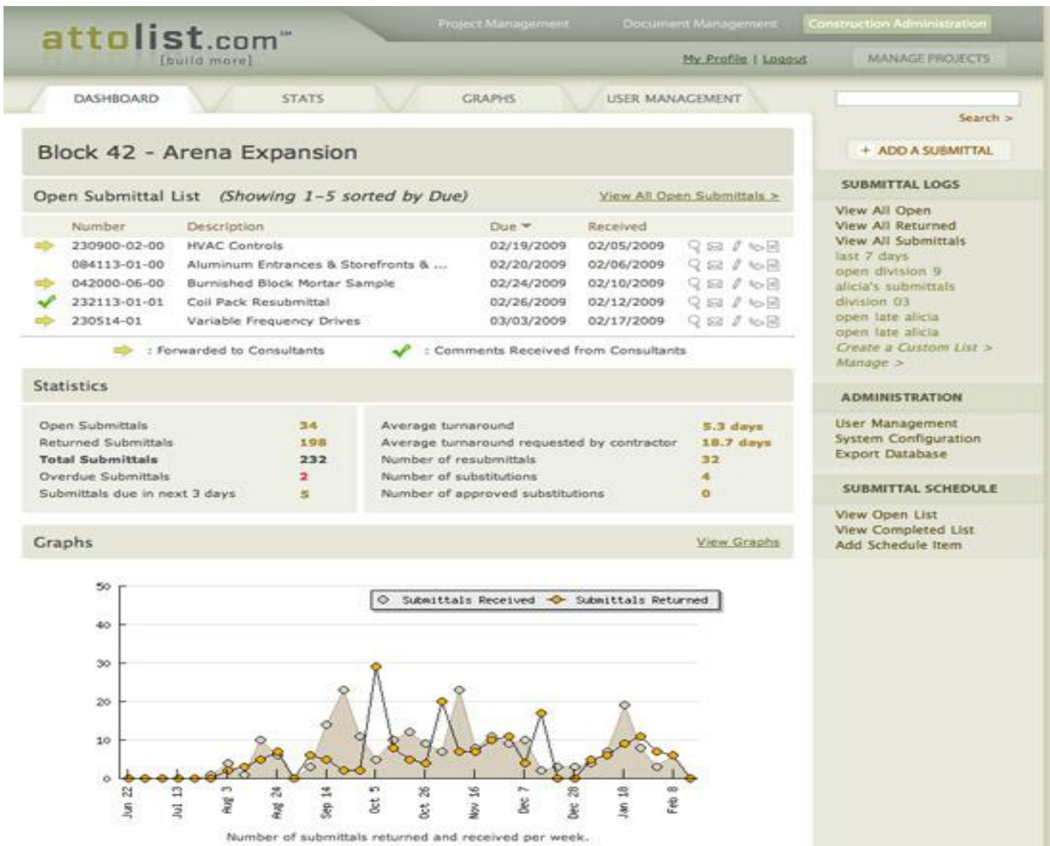


Figure 2-3. Attolist’s submittals dashboard, showing an overview of open submittals and the overall submittals statistics (source: Khemlani 2009d).

All the project documents can be organized in a single storage unit with the document management capability provided by Attolist, which also stores a history of the project from conceptual design to as-builts. Furthermore, the company is working on creating a web-based BIM model-sharing environment. In contrast to Newforma's server based application, Attolist approach to project management and collaboration is decidedly a web-based application. The project data is centrally located in the "cloud" and the participating disciplines and team members use the web interface to communicate and to access the data (Khemlani 2009d).

SharePoint-based Organice. Organice is a suite of solutions for construction document management, control, and collaboration. Since it is not an AEC-specific solution, its deployment can be challenging. Organice takes the powerful collaboration capabilities of SharePoint and customizes it for the AEC and related industries. The company has partnered with leading AEC technology vendors such as Autodesk and Bentley with the purpose of integrating their SharePoint-based collaboration applications (Khemlani 2009d).

The Organice product suite comprises several different applications that work together. The central application (Organice Explorer) provides the document management functionalities to create, store, search, retrieve, view, check in, check out, edit and revise documents. The project information management solution integrates with various CAD applications, including AutoCAD, BricsCad, Revit and MicroStation. The files from multiple software vendors can be opened directly from SharePoint and saved back to it. For instance, when working with Revit, files that are stored in SharePoint can be easily retrieved and directly opened (see Figure 2-4). Revised Revit RVT and RFA files can be opened and saved directly into the SharePoint document environment. Organice comes equipped with a "load family" function for Revit. This function stores and loads all the components that belong to a family. Once stored in SharePoint, it can be loaded into Revit in one step (Khemlani 2009d).

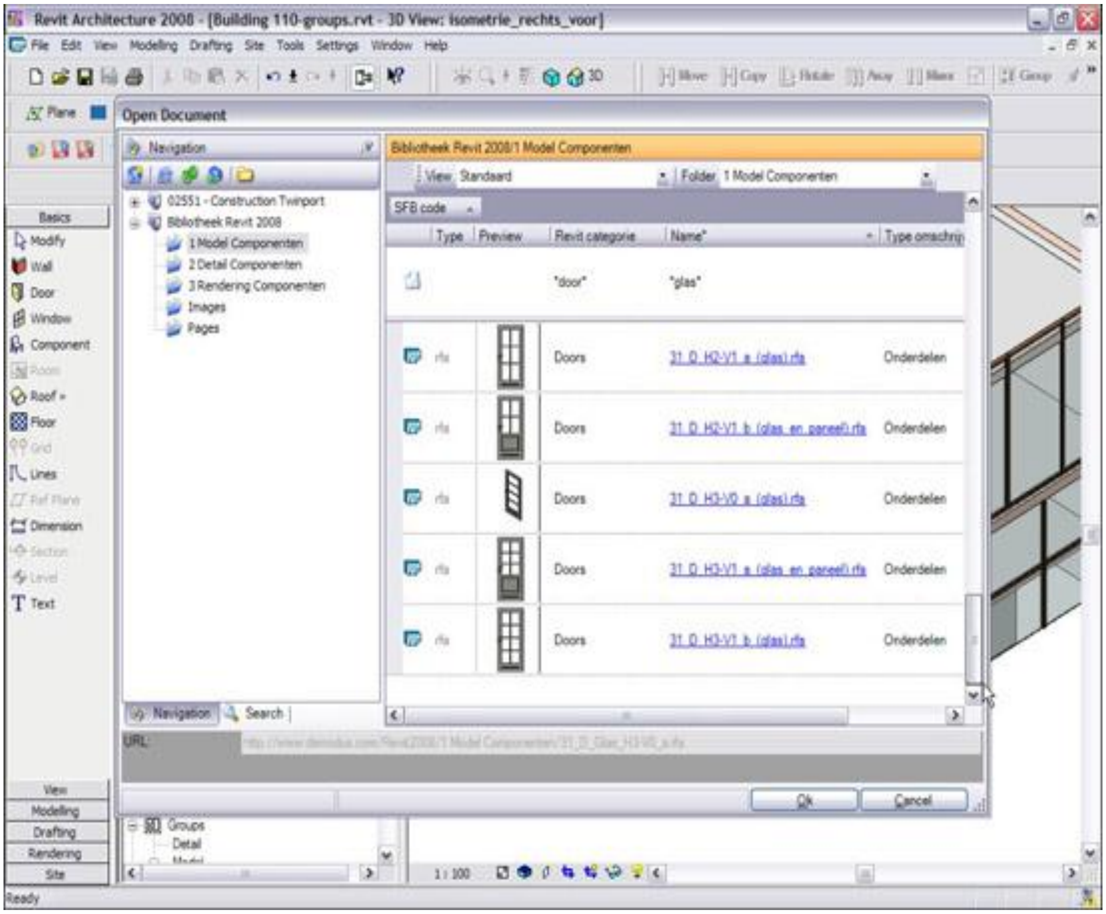


Figure 2-4. Open a Revit family using the Organice Explorer interface (adapted from Khemlani 2009d).

Summary of Project Information Management Software for Collaboration

The applications described above, vary extensively in their approach to address the issues faced in multidisciplinary collaboration. The AEC-specific solutions such as Bentley's ProjectWise, Navisworks, and Buzzsaw offer different functions than the PIM platforms (Attolist, Newforma, Organice). Nevertheless, they all attempt to improve collaboration by addressing the issues of information sharing, accountability, and transparency. Any of the described solutions above, will cause efficiencies when collaborating with external team members. Furthermore, as IPD gains popularity, these information sharing and collaboration tools will become increasingly indispensible and will prove especially helpful when addressing integration. The AEC industry should experience impressive benefits once the mentioned PIM platforms achieve the desired level of BIM integration (Khemlani 2009d).

Integrated Project Delivery (IPD)

Integrated Project Delivery (IPD) is a recent initiative in the building industry considered the most effective collaboration project delivery method. Even though collaboration is not new to the AEC industry, or humanity, the process of collaborating e is one of the foundation stones of our society. One of the largest collaborative efforts perceived are the Great Pyramids in ancient Egypt. The building industry continues to amuse us with collaborative efforts that have achieved great projects as illustrated by the skyscrapers of our age (Várkonyi 2009).

The following characteristics extracted from a case study document by Cohen (2010) for the AIA California Council, the Integrated Project Delivery Steering Committee and the AIA National Integrated Practice Discussion represent key factors in the IPD process (Cohen 2010):

- Mutual Respect and Trust
- Among Participants
- Collaborative Innovation
- Intensified Early Planning
- Open Communication within the
- Project Team
- Building Information Modeling (BIM)
- Used by Multiple Parties
- Lean Principles of Design,
- Construction, and Operations
- Co-Location of Teams (“Big Room”)
- Transparent Financials (Open Books)

BIM and IPD

The AIA California Council includes the definition for Design-Build as an example within the definition of IPD. IPD attempts to eliminate legal, financial, and organizational barriers hinders project members to collaborate around a BIM model (Azar 2008). BIM provides design professionals with a novel concepts and technology in order to create an accurate digital parametric model of a building. Additionally, it creates the need for, and ability to engage in an environment of enhanced project collaboration (Cazier 2008).

In addition to the increase of scheduling and costing information, legal documents and paperwork will increase as well. There is a need to document the excessive financial information as well as the daily decisions occurred (who made the decisions, when and where). Document management tools are necessary, in order to document and manage the shared information. The advantages of the IPD environment consists of a highly collaborative environment, in where decision-making, and information is well documented by the participants regardless the location or employer. This information, which includes a compilation of scheduling, costing, accounting, human resources, document management, and business process management tools is used to create the collaborative system necessary for BIM success (Azar 2008).

Integrated Project Delivery integrates people, systems, business structures and practices into a collaborative process, which harnesses the individual capabilities of the participants. Consequently, waste is reduced, and efficiency is optimized throughout the lifecycle of the project. The principles of IPD can be applied to a variety of contractual arrangements and it is not uncommon for the participating teams to include members not belonging to the AEC industry (AIA and AIA California Council 2007). At its minimum expression, IPD creates an intimate collaboration between the architect, general contractor and owner, from the early design stage, through project completion (Eckblad 2007).

The AIA and IPD

Integrated project delivery, can be perceived as a contract mechanism at first. Similar to a traditional project delivery structures (design-bid-build), it offers a legal outline that the architect, builder and use to collaborate. “IPD is part of an entire industry transformation,” says Markku Allison, AIA (Roberts 2008). Furthermore, IPD enables the pursuit of ambitious environmental goals, including specific targets for certification such as LEED. Building information modeling (BIM) software tactics have the potential to transform traditional trends in design and construction methods. Nevertheless, it is straining against conventional legal structures. IPD is not yet widely used, but advocates strongly believe that it will soon become a common practice (Roberts 2008).

According to the AIA’s *IPD* Guide (AIA and AIA California Council 2007), the defining characteristics of IPD include:

- Highly collaborative processes that span building design, construction, and project handover.
- Leveraging the early contributions of individual expertise.
- Open information sharing amongst project stakeholders.
- Team success tied to project success, with shared risk and reward.
- Value-based decision making.
- Full utilization of enabling technological capabilities and support.

In its 2007 Environmental Scan, the AIA observed that alternate delivery models are on the rise and causing architects to engage in more collaborative processes with builders, subcontractors, and fabricators. With the wide spread adoption of BIM, industry professionals are becoming increasingly interested in the enhanced collaboration agendas set by IPD. The AIA reported that on average 40% of firms surveyed (50 or more employees) used BIM in its 2006 firm's survey. In a similar way to sustainable design, integrated project delivery is the product of the union of opportunities that arise from the advances in technology and innovation. Moreover, it is inspired by the strong desire of the building industry for more predictable, accurate and responsible results (Autodesk Inc. 2008). Azar (2008) has pointed out that without the proper implementation of the right project delivery method, "BIM is nothing more than a design tool with unrealized potential for wider collaboration".

Sustainability and BIM

Specific calculations and exhaustive amounts of paperwork go into certifying a project for a green rating system such as the U.S. Green Building Council's (USGBC's) LEED certification. BIM has the ability to gather building materials information as well as to analyze pertinent environmental information about specific projects. Hence, BIM lends a hand in the necessary documentation for certification. Currently, project data is computer into the LEED Online system by a designated user logging in to the website. IES Virtual Environments, a closely related program to Revit MEP, comes equipped with a built-in capability to perform LEED's daylighting calculations and configure the percent of occupied space to achieve the 2% daylight requirement. Reporting these results based off the IES's daylight calculations can be used to demonstrate particular LEED credits. If these types of requirements can be calculated and reported with the help of BIM tools, documentation could eventually be obtained directly from the multi-disciplinary models. This could increase efficiencies across the board and assure certification at an earlier stage (Malin 2007).

Adobe System's Acrobat technology is the current platform of preference for the LEED Online service, which employs Adobe Lifecycle software. Portable Document Formats (PDFs) are a secure means for sharing BIM information. Adobe is currently working towards improving the ability of linking data to individual components in a 3D Acrobat file. The ability to submit the documentation easily into LEED Online has many obvious benefits. It is likely possible that in the near future, project information will come directly from BIM since USGBC and Autodesk have had a partnership since the end of 2006 (Malin 2007).

Case Study One: Phoenix Children's Hospital using BIM and Construction Manager at Risk

BIM helped Kitchell Contractors benefit from vital early decisions early in the Phoenix Children's Hospital (PCH). PCH, one of the largest pediatric hospitals in the USA decided to build a $588 million expansion to its facility. The project, which spreads over 45 acres, includes a new patient tower, an ambulatory care building, a new main entry boulevard, four concrete parking structures, landscaped gardens and a central plant. Some of the reasons for PCH to selected Kitchell included their healthcare construction experience, their collaborative management approach and their ability to understand the project's needs. Furthermore, Kitchell's main goal was to leverage their collaborative management culture, their healthcare construction knowledge and their experience with BIM (Mckenzie 2009).

The project delivery method selected was Construction Manager at Risk (CMAR), and it focused on establishing a multidisciplinary collaborative project environment of trust and ceaseless communication. The owner did not require BIM, however, due to the project scale and complexity, Kitchell decided to use BIM regardless. The architect

(HKS) produced the construction documents using Autodesk Revit Architecture. The interaction through the BIM process as well as the environment set by the delivery method encouraged collaboration between the owner (PCH), the builder (Kitchell) and the architect (HKS). The following list specifies the areas in where the BIM collaborative method brought value to the project as identified by Mckenzie and Johnson (2009):

- **4D scheduling-phasing.** $3 million savings in parking shuttle costs due to re-sequencing one of the new parking. PCH used the $3 million in savings to purchase additional adjacent property for future needs. Also used as a collaborative communication tool with Hospital Staff and Administration to explain campus disruptions throughout the construction process.

- **3D modeling-Underground Utilities.** Utilities (new and existing) were modeled (based on underground surveys) and fully coordinated prior to the start of construction. Scope gaps were identified, which assisted the Architect in producing a fully coordinated set of Civil Drawings. The process ensured that all work designed could be installed thus eliminating the cost and schedule risks associated with underground work.

- **4D Sequencing & 3D Modeling-Structural Steel**. Modeling and 4D sequencing allowed an “expedited erection plan” and lean process (as needed) delivery of steel which mitigated tight site conditions. Earlier floor and roof access for other trades accelerated the overall project schedule. The project saved two months on Erection Schedule and significant savings in productivity for steel erection translating into over $1 million in cost savings.

- **4D Sequencing & 3D Modeling**. Modeling and 4D sequencing of the central plant allowed a construction CPM schedule logic error, regarding the caisson foundation system, to be identified which avoided a potential delay to slab placement and underground pipe installation of 45 days.

- **3D Modeling & Structural Analysis**. Structural analysis performed early in the design resulted in identification of unique, high-grade steel material and bracing requirements allowing Schuff Steel and Kitchell to identify a unique steel supplier and pre-purchase (prior to a period steel material escalation) steel resulting in a $2 million total savings due to pre-purchase of material.

- **3D Modeling/laser Survey Equipment.** Translating x, y, z coordinate data from the 3D Revit models and downloading into digital survey equipment increased productivity and accuracy in building layout and component installation.

- **3D Modeling & Collaboration Project Management System**. Paperless construction documents and electronic distribution saved a considerable amount of time and money in handling, postage and reproduction costs. In addition, this turned out to be an excellent green component of the project that followed the Green Guidelines to Healthcare

Case Study Two: Encircle Health Ambulatory Care Center

The Encircle Health Center is a 156,000 square, three-story ambulatory care center. It includes physician practices with imaging, radiology, endoscopy, pharmacy and laboratories. The architect (HGA Architects and Engineers) and the builder (The Boldt Company) have had previous experience with BIM and IPD. One of the main characteristics of IPD is referred to as: “early involvement of key participants”. The key participants include the architect, owner, builder, design consultants and subcontractors. The architect and builder were selected by the owner (ThedaCare) based on excellent past experience. The core team collaboratively selected the mechanical, electrical, plumbing and glazing subcontractors. Each of the major subcontractors were present for the early schematic design stage and signed joining agreements entering a “lean partner relationship” early in the process. The collaborative decision-making and control is vital in IPD. The multi-disciplinary teams (Core Team) met weekly to resolve the upcoming issues. Teams present at the meetings (MEP, consultants, LEED compliance, and building enclosure) and owner representatives (physicians) varied depending on the objectives of the meetings. However, the owner, architect and builder were always present. The collaborative decision making allowed to perform effectively under a very a tight schedule. (Cohen 2010)

Project goals including budget, schedule, LEED goals (silver or higher) among others, were developed in a collaborative fashion by the core team. The project was able to overcome difficulties with the tight schedule under one of the coldest winters experienced and was still able to complete the project from start to move-in in 18 months. The design process was the result of strong collaborative efforts from the architect and builders. All systems were modeled in BIM and Boldt and the subcontractors were in attendance at many of the programming and design meetings. Furthermore, the Design-Build subcontractors offered some of the design services. One of the most notable benefits experienced from the collaborative efforts was that most costs were well predicted during the design stage. The architects were provided with a detailed spreadsheet of unit costs so they were able were able to make decisions based on reliable and updated cost information (Cohen 2010).

In regard to BIM coordination, Boldt, using Autodesk Navisworks, managed the primary model. The subcontractors used their preferred software, and then, Navisworks was used to perform the necessary clash detection. Boldt’s project manager said, “The money spent on building and maintaining the BIM was more than offset by less rework caused by coordination errors”. Moreover, Boldt decided to use a web-based project information exchange site, which was made available to all the participating disciplines. The field representatives were empowered to make quick decisions and most RFIs were solved and documented in the field making it effortless, and saving the architect valuable time. There were disagreements about which participant should pay for a particular item. Nevertheless the built trust and the climate for collaboration prospered and the issues were resolved with smooth and honest discussion, which followed the program set by the IPD process (Cohen 2010).

CHAPTER 3
RESEARCH METHODOLOGY

Introduction

The objective of the thesis is to determine the importance of collaboration between the main branches of the industry in regards to the new and upcoming technological trends. The architecture, engineering and construction (AEC) sectors are experiencing a drastic change in the convergence methods of project delivery. The high-tech uncharted setting seems to demand high levels of communication, cooperation, coordination and collaboration. These words can be used interchangeably but have their own role in building information modeling (BIM) implementation and are addressed uniquely by each software platform, discipline, and individual firm. The research is composed of interconnected sections that add and complement each other. The research begins with a thorough analysis of the current industry stance. The AEC industry is analyzed in terms of its need for a collaborative environment, BIM software developments, project delivery methods, sustainable trends and finally, the direction the industry is heading in the implementation of BIM mandates, guidelines and a common language. The first phase consists of a thorough research and identification of BIM literature, blogs, webinars, conferences, experiences, case studies among others. This information was gathered and analyzed in order to add substance and back the conclusions regarding the importance of multidisciplinary collaboration. BIM facilitates a wide spectrum of capabilities including scheduling (4D) estimating (5D), sustainability Leadership in Energy and Environmental Design (LEED) and productivity. The second phase consists of the deployment of a survey, which seeks to understand the experiences regarding the interactions in the multidisciplinary scene enabled by BIM when examined from varying standpoints.

The dilemmas of switching to BIM includes issues concerning cost, training, interoperability, coordination, among a multitude of reasons that switching to BIM challengers are not shy to point out. By understanding the confronted roadblocks and difficulties, as software development and language breakthroughs we can better comprehend the solutions. We can narrow down the list of problems and focus on the fundamental needs in order to make better decisions on BIM implementation, especially in regard to environmentally friendly solutions.

The benefits and disadvantages of BIM are to be weighed against each other in order to decide whether or not collaboration is fundamental to achieve a successful sustainable project. The survey will be used to supplement the literature review in order to better understand the opinion of the experienced BIM Managers, BIM Coordinators and AEC professionals. The survey population is composed of AEC professionals who work for leading AEC firms (Engineering News Record (ENR) Top 100, Fortune 500, Giants 300) who focus on sustainable (LEED) projects. The importance of collaborative teams will be evaluated to decide whether a collaboration plan would be helpful in order for a partnering team, a Design-Build joint venture or an Integrated Project Delivery (IPD) system to produce a successful project. Furthermore, the implications regarding LEED implementation will be analyzed in order to decide if it actually facilitates or hinder the BIM process. The introduction of LEED has brought changes in the way companies perform since LEED proposes and suggests that teams from different fields work together from the beginning (pre-design) stages of the project in order to achieve the best results. Ideally, the benefits from one method (e.g. LEED, Design-Build) will facilitate the work flow, collaboration and productivity of the other (e.g. BIM, Design-Build). The general methods of the research will follow the steps below:

- Literature selection and review (BIM, LEED, Collaboration, Design-Build, IPD)
- Locate firms employing BIM technologies into their projects
- Prepare surveys and interviews
- Carry-out the data and information analysis using statistical techniques
- Evaluate the results (advantages, disadvantages) of the degree of collaboration in BIM
- Produce conclusions regarding future trends and solutions

Question Screening Process

In order to assure the validity of the research, incomplete questionnaires with unclear answers were screened out. Even though the objectives of the research seek to understand broader trends and patterns in the industry, each response was analyzed on an individual basis. Initially, this exercise was helpful in trying to understand the experience and viewpoints of the population studied.

Research Objectives

The goals of the research were broken down into three parts with the purpose of establishing systematic relationships in order to reach statistical conclusions. Following, An explanation of the research objectives and the questionnaire can be seen below. The questionnaire focuses on three main factors: “Degree of Implementation and Experience”, “Scale”, and “Sustainability and Delivery Method”. Most of the factors observed were intended to further compliment and help understand the research objectives described ahead.

Survey Questionnaire

The questions have been broken down into four categories in order to guide the respondents: general questions, BIM teams and performance, BIM benefits, and, the ideal BIM scenario. The questions also addressed the preferred method of delivery as well as the currently sustainability measures employed. Additionally the questionnaire was aimed at understanding the ideal BIM scenario according to the experience of the surveyed individuals. The following section further explains the different categories of questions used to understand the collaborative environment created by the implementation of BIM.

Research Objective 1 – Degree of Implementation and Experience

To determine the degree of multidisciplinary collaboration experienced in the BIM process concerning the following factors: 1) field of practice, 2) experience 3) stage of implementation and 4) software used and 5) number of licenses.

Q.1: How long have you been working in the industry?-Due to the demographics patterns and recent spike in technology, the industry BIM leaders and experts do not necessarily have the most experience in the industry. BIM has been adopted by the new generation of construction professionals and this question aims to understand and correlate expertise in BIM with years in the industry.

Q.2: What is your BIM title?-This question was designed to understand the audience more in depth. Additionally, extracting this information would enable a better grouping of the subsequent answers and results adding more validity to the research.

Q.3: How long have you held this title?-The responses to this question were used to understand how long the participants have been involved with BIM specific activities.

Q.4: What field do you work most closely with?-The more diverse the pool of responses, the more substantial the research will be. An attempt will be made to reach construction professionals across the multiple disciplines in the AEC industry. This question will provide some challenges, due to the limited exposure to all the fields, and the lack of implementation of some fields as in the case of MEP and subcontractors.

Q.7: Please indicate the BIM software currently in use at your firm? – This question was asked to indicate whether the firms used collaboration tools or just field specific software. This question is fundamental since there are several BIM vendors and software available, and they approach the issues faced with multidisciplinary collaboration in different ways.

Q.10: How many hours a week do you work on BIM related tasks? – The years of experience, and the professional title, helped understand the participant's background. However, this study gave great value to the number of hours involved with BIM activities. Since BIM technology is constantly changing and being updated, it is important to understand the number of hours that the participants are currently investing in BIM.

Q.23: What BIM collaboration software does your company employ? – This question relates to Q.7 however it asks to specify the software which brings the disciplines together.

Q24: How effectively did the software facilitated collaboration and communication throughout the teams? – This question attempts to rank in a qualitative scale the effectiveness of the mentioned software platforms.

Q26: Which field of practice (excluding yours) seemed most willing to collaborate? This question attempts to collect data regarding perceptions among the different disciplines mentioned. In this case, it attempts to identify the field of practice which seemed to be the most willing to collaborate.

Q27: Which field of practice (excluding yours) seemed the least willing to collaborate? – Similar to Q.26, the question attempts to collect data regarding perceptions among the different disciplines mentioned. In this case, it aimed to identify the field of practice which seemed the least willing to collaborate.

Q.32: What field of practice should spend the most time in BIM training? – Q. 32 belongs to the questions under the “Ideal BIM Scenario” category, and its purpose is to identify which field of practice seems to be lacking in BIM training from the perspective of the participants of the survey.

Q.33: At what stage should BIM practices be implemented? – Even though it is well understood that BIM should be implemented from the beginning, many firms fail to establish a proper BIM plan. Therefore, this question aims to identify patterns in multidisciplinary collaboration in accordance with the BIM implementation stage.

Q.34: During what stage should teams meet? – Similar to Q.33, the purpose is to understand the perceptions in the industry about BIM implementation.

Q.35: Which teams should meet at the design stage? – The responses to this question were used in conjunction with the responses of Q.34 and Q.35, in order to better understand the importance of early BIM implementation.

Research Objective 2 – Cost and Scale

To determine the degree of multidisciplinary collaboration experienced in the BIM process concerning the following factors: 6) yearly volume of work, 7) size of project, 8) initial investment, 9) Return on investment (ROI).

Q.6: Please indicate your company’s yearly volume of work. – The responses to this question were used to understand the trends in collaboration depending on the size and amount of work produced by the company.

Q.9: How many licensees does your company have?-The number of licenses a company holds is a direct representation of the scale and of the cost invested in the implementation of BIM. Therefore, a cross tabulated analysis of number of BIM licenses against five questions regarding the level of collaboration were performed.

Q.16: What type and size of projects are you employing BIM processes in? – This question was important in understanding the company's type of work performed as well as the average project size in where BIM is used. The responses were compared with questions about BIM collaboration in order to identify trends and links concerning size and type of work performed.

Q.19. How large was the initial investment when you first adopted the BIM methodology? – This question relates to scale and cost issues as well as to the degree of BIM implementation. The initial investment in BIM includes software, training, time, new hires, among others. This question was valuable in helping the researcher understand the differences in BIM investments across the companies studied.

Q.20: What was the Return on Investment (ROI) in BIM? (US $) – This question was asked to understand the ROI and its relationship with collaboration. However, after completing the literature review and understanding the lack of ROI tracking, it was noted that the question might not provide the study with the necessary information, due to the lack of expected responses.

Q.29: What is the ideal project size? – The responses of this question were used to determine the perceived BIM project size that might bring more benefits to the multidisciplinary teams.

Research Objective 3 – Project Delivery and Sustainability

The purpose of this objective was to determine the perceived benefits and problems in sustainability and project delivery method encountered in the multidisciplinary process of the BIM environment. The survey attempted to ask questions (listed below) related to the mentioned issues. However, due to the lack of responses and validity of information, a set of case studies were used in order to better understand the facts behind trends such as IPD and LEED and their influence in the multidisciplinary BIM implementation.

Q.28: Which project delivery method facilitates collaboration the most?

Q.30: What is the ideal project delivery method?

Q.37: What is the ideal Green rating system to implement BIM with?

BIM Multidisciplinary Collaboration Questions

The following questions were used in order to compare the results from the questions on the three categories described above. The comparisons established, and the trends identified from these questions were used to generate the conclusions and recommendations presented in Chapter 6.

Q.12: How would you rate the difficulty in working with multidisciplinary teams with their various discipline-based BIM Models? – The responses to these questions were used to understand the level of difficulty perceived in relation to the factors and questions described above.

Q.15: How often should the multidisciplinary teams meet (monthly) to discuss the BIM process? – This question related to collaboration through the number of multidisciplinary meetings perceived to be ideal (per month). The answers of these questions were compared among questions regarding company size, discipline, level of implementation among others, in order to establish patterns.

Q.17: What are the primary areas that you have identified improvements in? - The purpose of this question was to better understand the benefits and improvements experienced. The areas of improvements selected were: design, productivity, cost, estimating and scheduling.

Q.18: What in the multidisciplinary process did you encounter the greatest difficulty with? – Similar to Q.12, this question attempts to identify the difficulties encountered in the multidisciplinary process.

Q.25: From your experience, how would you rate the motivation for collaboration of the multidisciplinary members? – This question attempts to understand the degree of collaboration experienced by the multidisciplinary members. The purpose is to qualitatively account for positive or negative trends in the motivation perceived from the disciplines to collaborate when using BIM.

Q.38. From your experience with BIM projects, how would you rate the degree of multidisciplinary collaboration? – The responses to this question were used to determine relationships in the perceived degree of multidisciplinary collaboration. Similar to Q.25, the question attempts to qualitatively account for positive or negative trends in the perceived degree of multidisciplinary collaboration when using BIM.

Descriptive Statistics and Cross-Tabulation Analysis

In order to generate valid research results, the relationships and patterns in the items and groups described above have to be understood. The selected data was tabulated and graphed in order to determine patterns. Subsequently, the data was cross-tabulated in order to address the specified research objectives. Multiple statistical methods were used to find patters and relationships such as the Pearson Chi Square and the Mann-Whitney method to compare the groups. However, due to the small sample size, an in depth descriptive analysis was performed. Therefore, sets of comparisons were established, in order to compare the retrieved data with several levels and types of collaboration. These comparisons helped the researcher better understand the trends in the industry with regards to the scale and initial investment of BIM. The factors of collaboration include the following: disciplines represented in BIM projects, perceived difficulty in working with multidisciplinary teams, importance of early (design stage) BIM implementation, number of multidisciplinary meetings, identified improvements, encountered difficulties, unexpected benefits, perceived degrees of collaboration and perceived levels of motivation for collaboration.

Comparisons against Identified Improvements, Benefits and Difficulties

A comparative analysis and cross-tabulation was performed in order to understand the perceptions and expected results with the implementation of BIM depending on the multiple interchangeable factors among the many firms surveyed. These factors were compared against questions regarding scale, initial investment, preferred project delivery method and sustainability rating system, among others factors. The following questions belong to this category:

Q.11: How would you rate the accuracy of the BIM models you have been exposed to? – This question was used in order to identify trends that work and produce accurate BIM models.

Q.12: How would you rate the difficulty in working with multidisciplinary teams with their various discipline-based BIM Models? – The responses to this question were used to identify the degree of difficulty perceived in the multidisciplinary environment.

Q.17: What are the primary areas that you have identified improvements in? – This question was used to understand the improvements in the following areas: design, productivity, cost, estimating and scheduling.

Q.18: What in the multidisciplinary process did you encounter the greatest difficulty with? – Similar to Q.12, this question attempts to identify the encountered difficulties in the multidisciplinary BIM environment.

Q.21: What were the benefits realized by using BIM on projects? – The survey participants were presented with a checklist including the following benefits: reduction in overhead cost, improved management of project logistics, planning, communication and reporting, reduced cost and design, enhanced estimating capabilities, reduction of design errors, customer service improvements, production/fabrication improvements, and better understanding of the project.

Q.22: What were the unexpected benefits realized by using BIM (Please Specify if any)? – Similar to Q.21, this question attempts to identify the benefits presented with the introduction of BIM. However, this question asks to list the unexpected benefits.

Summary

The questionnaire was designed with the purpose of allowing for comparative analyses. First, the questions were intended to gather background and personal information from the respondents. Secondly, the questionnaire was intended to understand factors such as project size, initial BIM investment, and company size among other experiences in the multidisciplinary BIM environment. Finally, the questions were combined, cross-tabulated and compared in order to establish relationships among the several factors considered.

CHAPTER 4
RESULTS AND ANALYSIS

A total of 680 invitations were sent out inviting professionals to participate and it was deployed twice, achieving a total of 58 responses, which were received electronically. Due to the limited number of responses and the subjective nature of some questions, the results were evaluated using descriptive statistics only. The majority of the individuals who completed the survey worked for large international architecture, engineering, construction (AEC) companies in the United States.

In order to abide by the rules and regulations covering this study and to protect the privacy of the participants, any personal information is kept confidential and will remain undisclosed. The preceding methodology chapter specifies the strategy employed to extract the necessary information for grouping the answers according to the following factors: degree of implementation, scale and investment, project delivery method and sustainability. The information extracted from the specified groups was cross-tabulated in order to generate conclusions which address the research objectives.

Research Objective 1 - Degree of Implementation and Experience

As stated by Estman et al. (2008): *"Earlier collaboration of multiple design disciplines is also facilitated by BIM".* The questions under this category helped confirm the importance of early building information modeling (BIM) implementation (design stage or earlier) in order to better enjoy the benefits of BIM.

Q.1 How long have you been working in the construction industry?

Due to the recent spike in technology and change in demographics, the BIM leaders and experts do not necessarily have the most experience in the industry. BIM has been adopted by the new generation of younger construction professionals. This question aims to understand and correlate expertise in BIM with years in the industry. Among the individuals and companies surveyed, 34% (19) of the respondents indicated that they had more than 15 years of construction experience while the majority (66%) of the respondents had less than 15 years of construction experience (Figure 4-1). These result help describe the demographics of the respondents and provide a reference point for the subsequent analyses as well, which use experience as a filter.

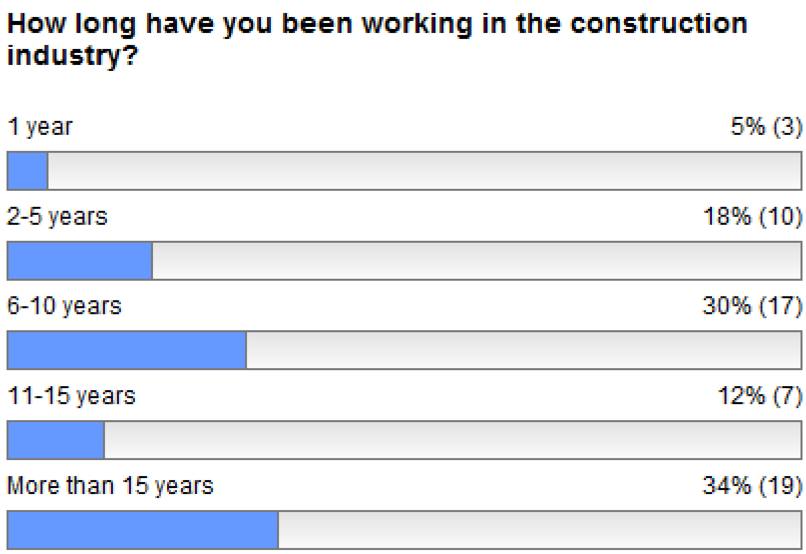


Figure 4-1. Experience in the construction industry

Q.2 What is your BIM title?

This question was asked in order to further understand the existing BIM titles and wording used to describe them. Most people utilizing BIM technology do not have a specific BIM title since BIM spreads easily throughout offices reaching and affecting most areas of work. However, the survey was designed specifically for BIM Managers. As seen in Figure 4-2, from the 56 responses received, 20% of the participants were BIM Managers, 5% were BIM Coordinators, 2% were Model Coordinators, while 52% do not have a BIM Title specified and 21% have another non-BIM specific title.

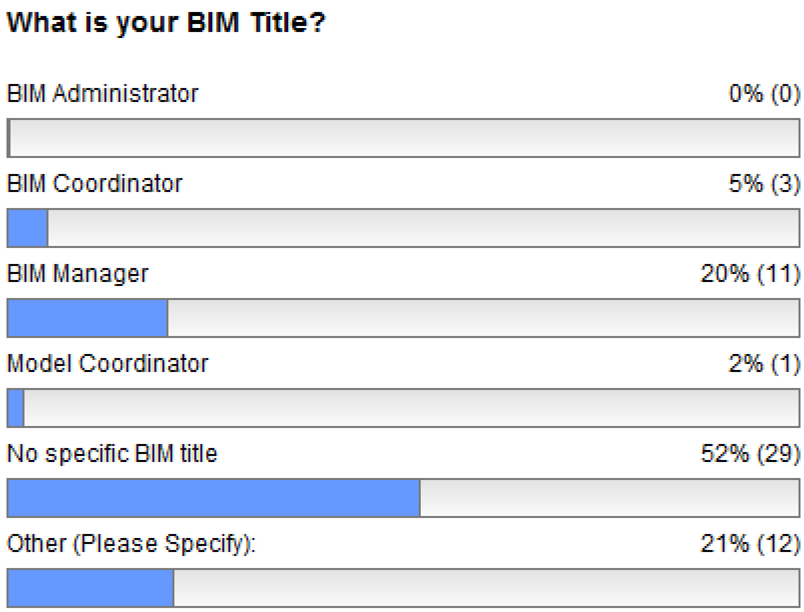


Figure 4-2. Respondent's job titles

Q.8 How many projects have you been involved with?

The importance of the experience of the participants in actual BIM projects affects the validity of their responses. The development of BIM has been felt in the industry in many companies. However, the full implementation of BIM on a project is still young and the percentage of the industry population that has been involved in multiple projects is still small. From the results of the survey, only 25% of the participants have been involved in multiple projects in a period of 4 years or more, 47% of the participants have been involved in multiple projects in a period of one to three years, while 24% of the participants have been working with BIM projects for less than one year (Figure 4-7). This analysis helps in further understanding the level of development of BIM in the field and provides the reader with an idea of the duration of the projects employing BIM methodologies.

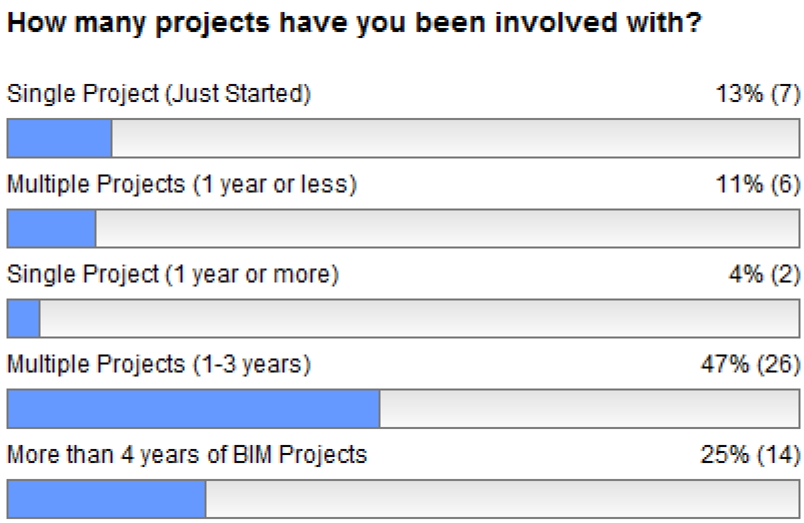


Figure 4-3. How many projects have you been involved with?

The majority of the respondents (47%) have been exposed to multiple projects (in a period of one to three years). This fact is important to the validity of the research, since BIM is still in its recent stages of deployment. While most professionals might be proficient with BIM software such as Revit, advanced exposure to BIM and its multidisciplinary capabilities is very limited. This result provides the study with significant data about the level of experience of the population. Furthermore, the results for this question help produce better conclusions when cross-tabulated against other factors such as difficulty of implementation and degree of collaboration.

Q.4 What field do you work most closely with?

The survey results obtained from this question had limitations due to the larger group belonging to the construction sector. An attempt was made to reach an even number of participants from the main fields involved, but the results obtained were limited. A significant number of participants specified multiple disciplines when answering this question. It is interesting to note how BIM foments a multidisciplinary approach. The results suggest that many of the firms using BIM include more than one field of practice under the same roof. As seen in Figure 4-4, most of the respondents came from the construction industry. Even though 40% of the population worked most closely with the fields of Architecture, Engineering and mechanical, electrical, plumbing (MEP), 73% of the respondents worked most closely with construction.

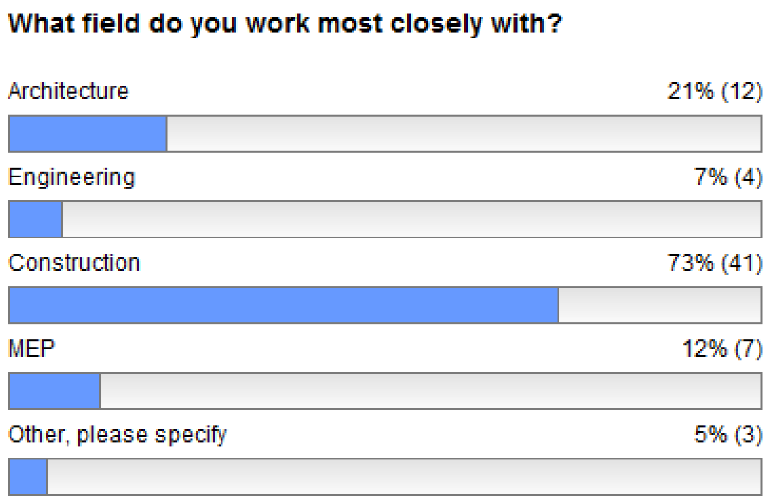


Figure 4-4. Fields of practice

Q.5 What Disciplines are represented in your BIM projects?

Figure 4-5 shows that the results were fairly consistent across the board. The majority of responses included at least the three main AEC disciplines. An average of 72% of the responses specified included the AEC disciplines.

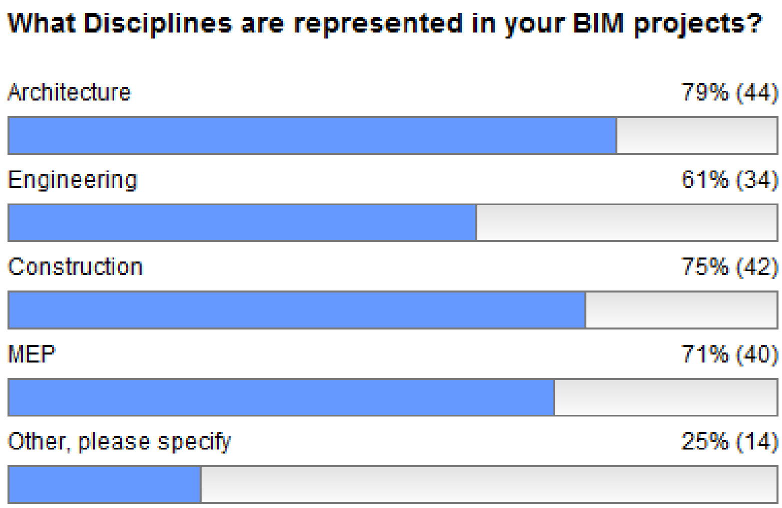


Figure 4-5. Fields represented in BIM projects

Even if multiple disciplines are performed by the same entity, for example in house design (architecture), there is a multidisciplinary collaboration that needs to be coordinated. The lowest represented field was engineering, with an average of 61% of the responses including engineering in their BIM models. Additionally, 25% of the participants specified that other disciplines were involved. These included specified fields in engineering (civil engineering, structural engineering), as well as: fire protection, facility management (FM), curtain wall/skin coordination, consultants, controls, glazing, kitchen equipment and pneumatic tube (see Table 4-1).

Table 4-1. What disciplines are represented in your BIM projects?

#	Response
1.	About 50% of the architects we work with produce 2D documents form a BIM model
2.	Fire protection, civil
4.	Structural
5.	We just began the integration process but we will work with all fields
6.	Curtain wall /skin coordination
7.	Facility management
8.	Structure
9.	We incorporate structural, MEP-FP & civil, fire protection, controls, glazing, kitchen equipment, pneumatic tube
10.	Structural

Q.26 What field of practice seemed most willing to collaborate?

This question attempts to understand the willingness of the different disciplines to collaborate. As shown in Figure 4-6, the MEP field was regarded as the field most willing to collaborate with 51% (25 responses) of the votes. Nevertheless, it is important to note that several difficulties (6 responses) came from the MEP field, as seen in Table 4-2. The architecture field was regarded as the second most willing to collaborate with 27% of the responses, followed by the construction field (22%) and by the engineering field (16%). However, it is important to note that most of the participants (73%) came from the construction field and the question specifies to exclude the participants own field of practice when answering the question.

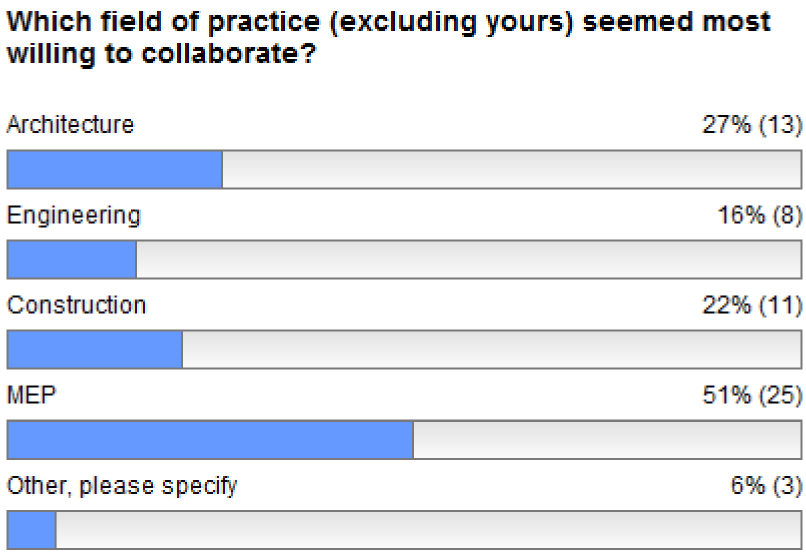


Figure 4-6. Field most willing to collaborate

Q.15 How often should the multidisciplinary teams meet to discuss the BIM process? (monthly)

The question asks the participants to specify the number of times the multidisciplinary teams should meet each month. The results as shown in Figure 4-7, indicate that 75% of the respondents believed that one to five meetings per month are enough. Furthermore, 19% of the respondents believed that the teams should meet more than 5 times each month. It is interesting to note, that the opposing answers ("less than once", and, "more than 10 times") had the same number of responses (3, 6%). These results help confirm the perception that there are opposing schools of thought in the adoption of BIM in the AEC industry. One that is strongly supporting it and the other that is constantly challenging it. The more times the disciplines meet to discuss the issues and needs of the projects, the higher the potential for proper collaboration.

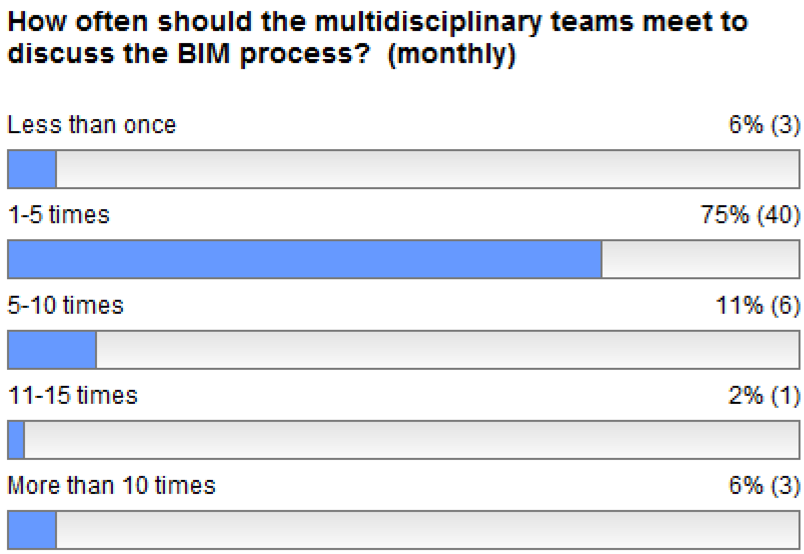


Figure 4-7. BIM multidisciplinary meetings (per month)

Q. 25 Based on your experience, how would you rate the motivation for collaboration of the multidisciplinary members?

This question asks the surveyed respondents to rate the multidisciplinary motivation for collaboration on a scale ranging from “very high” to “very low”. As shown in Figure 4-8, a 12% (6) of the responses rated the motivation levels “below average”. However, no participants perceived “very low” levels of motivation.

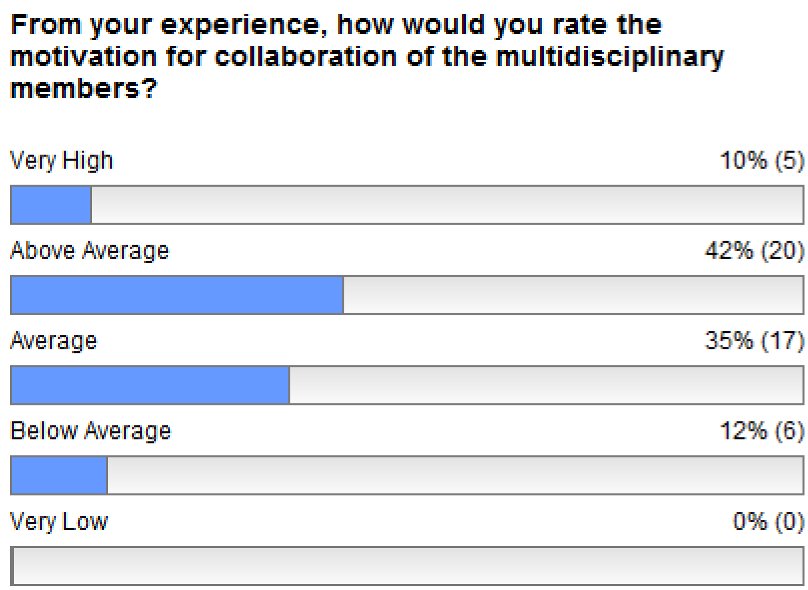


Figure 4-8. Motivation for multidisciplinary collaboration

Five respondents (10%) believed that there was a “very high” motivation to collaborate, while the largest group of respondents (20, 42%) perceive an “above average” motivation for collaboration. Finally, 17 responses (35%) believed that there was an “average” level of motivation to collaborate from the multidisciplinary members.

Early Implementation for Collaboration

The importance of early involvement has been a well discussed subject in BIM implementation. Project delivery methods such as integrated project delivery (IPD) help enforce early interaction of the corresponding fields in order to promote collaboration and reduce errors and litigation. The results obtained present many trends and patterns that suggest varying levels of success in the implementation of BIM, depending on the degree of multidisciplinary involvement. The questions and their responses discussed below, present scenarios that further explain the importance of a constant interaction among the fields of practice across the industry. In addition to regular communication, the timing of the implementation of BIM methodologies on a project is fundamental.

Q. 13 How important is it for the BIM teams to work together from the beginning?

This purpose of this question was to understand the varying opinions of the participants. As shown in Figure 4-9, the vast majority of the respondents (82%), believed that it is “very important” for the BIM teams to work together from the beginning (design stage). A total of eight (15%) respondents stated that early BIM collaboration is “quite important, while two respondents (4%) believed that is “fairly important” and no participants believed that it was “slightly important” or “not at all important”. The responses to Q. 13 indicate an optimistic environment and a common willingness for multidisciplinary collaboration.

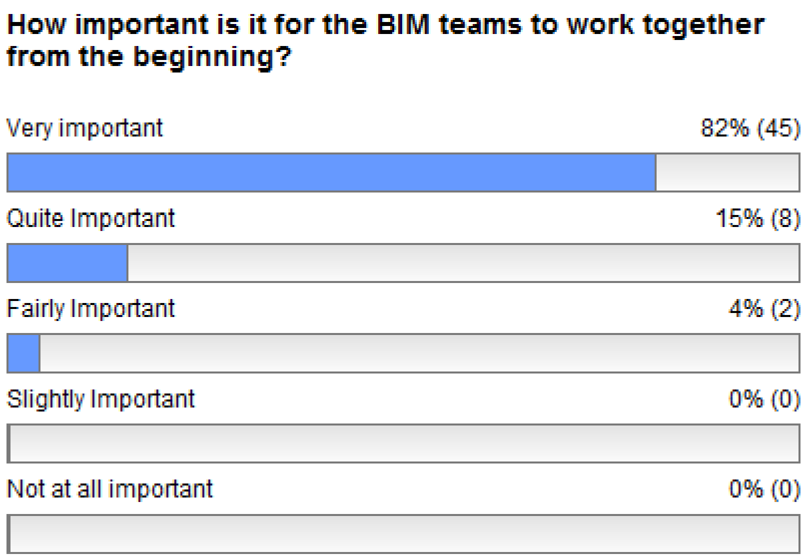


Figure 4-9. Early BIM multidisciplinary collaboration

Figure 4-10, shows a trend in early implementation and identified improvements. While 76% of the respondents who believe early interaction of the disciplines is “very important” experienced improvements in design, 74% saw improvements in productivity, 45% in cost reduction, 41% in estimating and 43% saw benefits in scheduling. On the other hand, those who believe early collaboration is “quite important” perceived improvements as well, but not as significant as the former group.

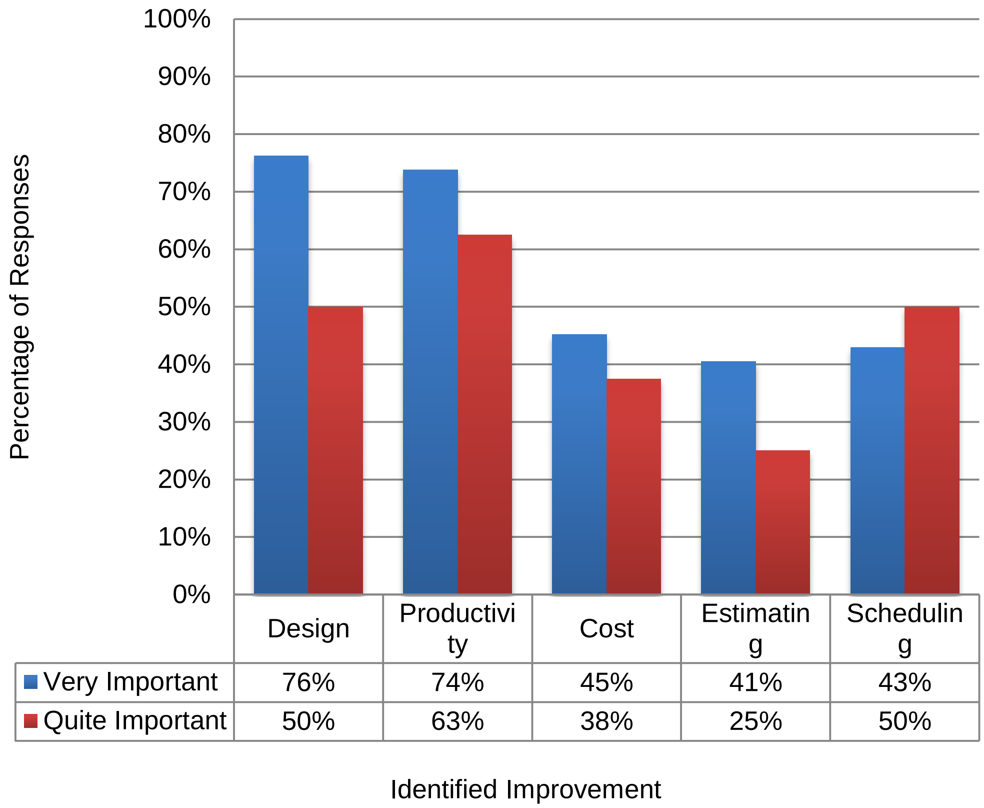


Figure 4-10. Comparison of early BIM collaboration and identified improvements

BIM Tasks Performed

Q. 10 How many hours a week do you work on BIM?

This question asks the participants to specify the average number of hours a week involved in BIM related tasks in order to determine the extent to which they used BIM.

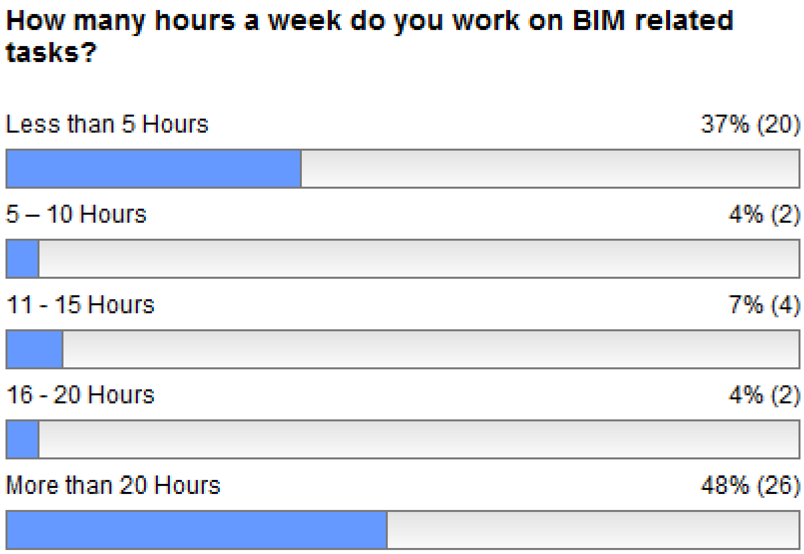


Figure 4-11. Hours a week of BIM tasks

As shown in Figure 4-11 most of the participants are either very involved in BIM tasks, or not that involved at all. A total of 26 responses (48%) indicated that they worked more than 20 hours a week on BIM related tasks. On the other hand, 20 respondents (37%) stated that they used BIM for less than 5 hours a week. The responses to this question were best understood when cross tabulated against the perceived motivation for collaboration within multidisciplinary teams. From those results, 17%(23) of the participants who had worked 20 weekly hours or more with BIM technologies, believed that there was a "very high" degree of motivation for collaboration while 0% of the participants who had worked 5 hours or less (17) believed that there was a "very high" level of motivation for collaboration (Figure 4-12). The responses to this question indicated that the true believers in BIM methodologies were more likely to work more than 20 hours a week with BIM. Therefore this group was more likely to have a positive attitude towards collaboration and a better understanding of the essential necessities to collaborate to achieve a higher level of accuracy and success.

On the other hand, 9% of the participants that had a high exposure to BIM on a weekly basis, had “below average” motivation for collaboration across the border, while more than twice the number of respondents (22%) that is barely exposed to BIM believed that there is a ‘below average” level of motivation to collaborate. The goal of this question was to determine some factors that are out of the hands of the respondents and are directly related to the fields of practice outside their own across the industry. Furthermore, 76% of the populations studied (Less than 5 weekly hours and more than 20 weekly hours) experienced an “above average” to “average” degree of motivation to collaborate. Hence the largest differences in motivation were noted between the groups at either end of the spectrum.

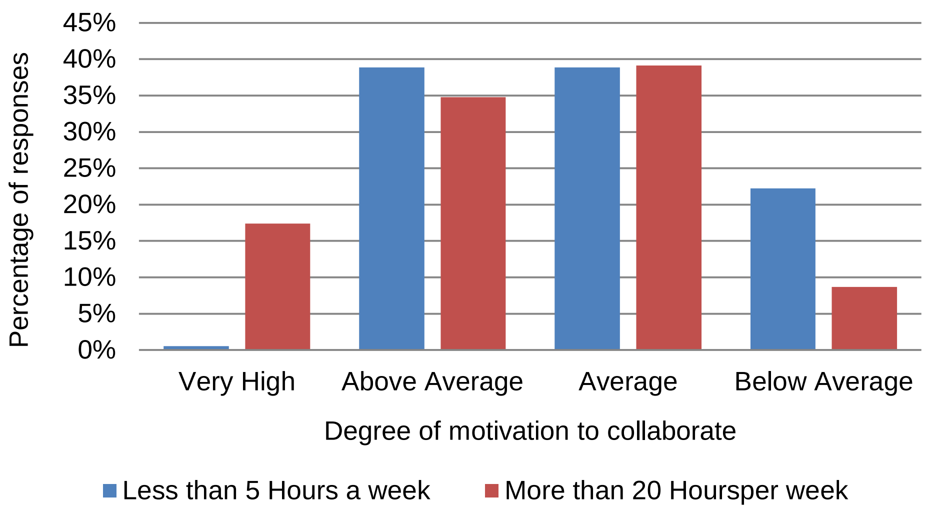


Figure 4-12. Hours of weekly BIM exposure and motivation to collaborate

Difficulties in the BIM Process

Table 4-2 helps further explain the difficulties faced when working with BIM. The participants were asked about what in the multidisciplinary process they encountered the greatest difficulty with. The responses were grouped under nine categories and include difficulties with the following: architect (A), construction management (C), engineers (E), MEP (M), collaboration, coordination or communication (Q), software (S), training (T), subcontractors (U) and others (O), as shown in Table 4-2. Each problem was allocated a specific group in order to understand the patterns presented. A total of 54 difficulties were reported with the highest number of difficulties belonging to the "collaboration, coordination and communication" (Q) category, with 14 identified difficulties. The second most problematic category was "training" with 10 reported difficulties. The "software" and "MEP" categories had a total of 6 difficulties each, while the "architecture", "engineering" and "subcontractors" categories recorded 3 difficulties each. Construction management (estimating) accounted for one difficulty while the "other" category accounted for 5 difficulties. The information gathered from the Table 4-2 suggests that there are several problems with the collaboration, coordination and communication of BIM processes. Figure 4-13 helps visualize the data in Table 4-2.

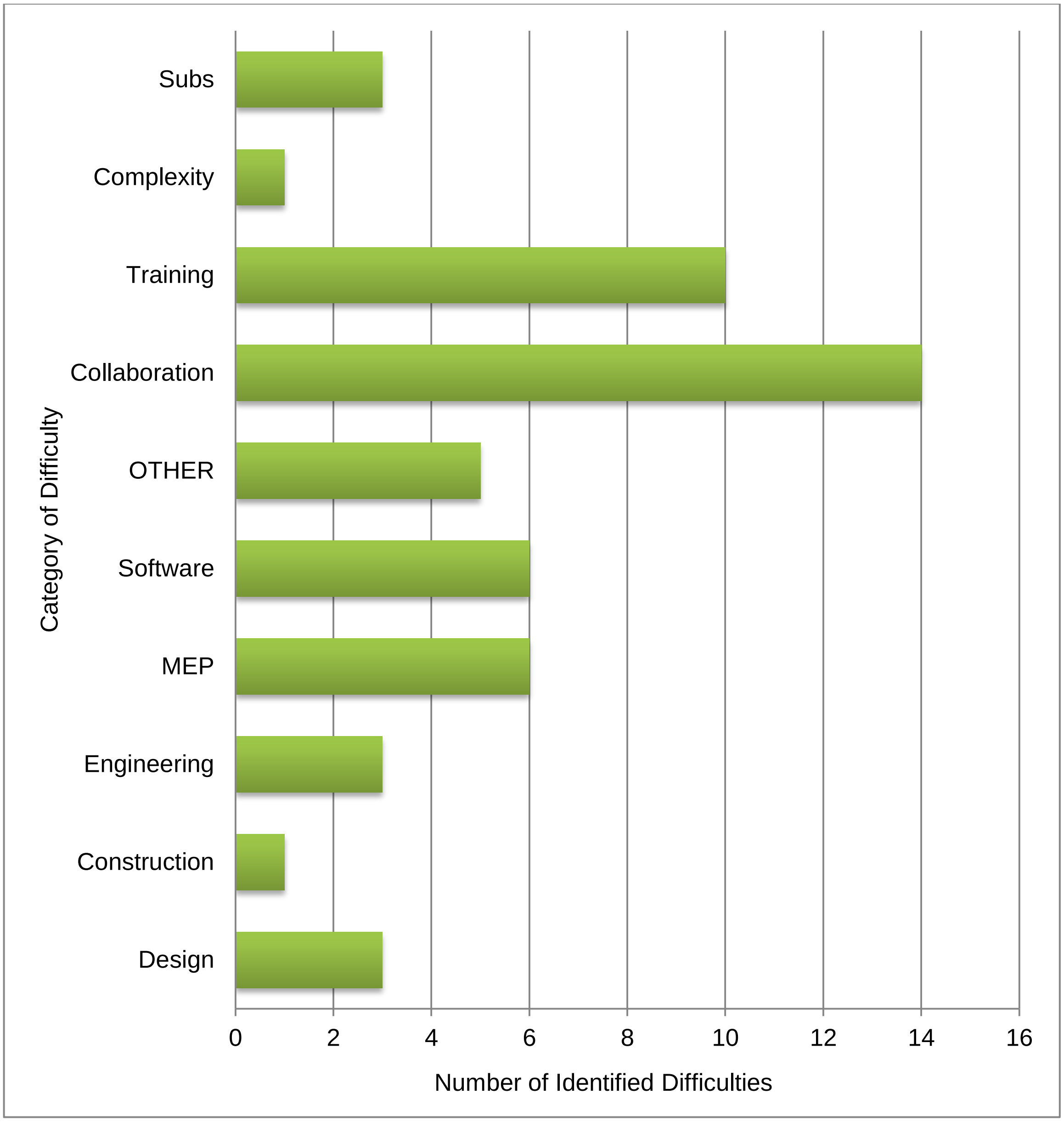


Figure 4-13. Identified difficulties

Table 4-2. Verbatim regarding identified difficulties in BIM

#	Difficulty Described **	Identified Difficulty
1.	Learning/training.	S, T
2.	MEP Coordination.	M, O
3.	Finding systems in that all participants were comfortable using and getting MEP engineers onboard to use systems that can be integrated with Revit.	M, S, Q
4.	Mep/Civil.	M, E
5.	The complexities of all systems is the difficulty; no single system brings more problems than others.	X
6.	Lack of subcontractor BIM proficiency and lack of design team BIM proficiency.	T U
7.	Consultants not using BIM.	T
8.	Other trades not taking the time to do their work correctly in the coordination process.	T, Q
9.	Getting designers to embrace BIM and fixing poor drafting.	A
10.	Structure.	E
11.	Close collaboration on design and cost estimating during the design process.	Q, C
12.	Not having enough lead time for the BIM modeling and coordination and uninformed or unwilling participants.	Q
13.	Cross-platform model consolidation and collaboration between tools from differing manufacturers.	Q, S
14.	Communication between the different partners.	Q
15.	Fire sprinkler.	O
16.	Some of the issues will be the liability issues associated with intellectual properties (model ownership), getting subcontractors and our own employees up to speed with the software, and getting buy-in from all the stakeholders of the project and ensuring that the service warrants the cost.	T, O
17.	Coordination with Designers.	Q
18.	Communication.	Q
19.	Converting efficiencies into dollars and making it the norm in lieu of the exception.	O
20.	Architecture (lack of BIM info).	A
21.	Coordination.	Q

Table 4-2. Continued

#	Difficulty Described **	Identified Difficulty
22.	Adoption.	T
23.	Getting everybody on board and setting common expectations.	T, Q
24.	MEP.	M
25.	Specific consultants and/or subcontractors that are not BIM savvy.	T, U
26.	Structure.	E
27.	Coordination between MEP trades.	Q
28.	MEP. Because of the different software platforms used between design intent and fabrication.	M
29.	Interface with other systems.	S,Q
30.	Obtaining a model from the design team.	A
31.	Commissioning.	O
32.	Software format.	S
33.	Merging models as sometimes not started at same point.	Q
34.	Upper management understanding processes and the existing consultants not understanding the BIM work schedule.	T, O
35.	Interoperability.	Q
36.	MEP.	M
37.	Initial pushback from subcontractors.	T, U

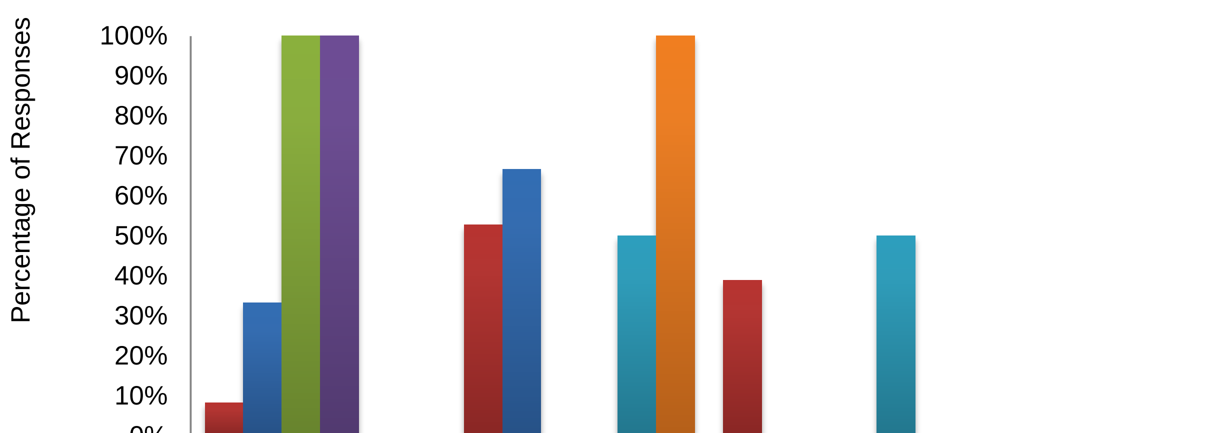
** Definition of Difficulty Categories:
A = Problem linked to architecture.
S = Problem linked to software.
E = Problem linked to engineering.
M = Problem linked to MEP.
C = Problem linked to construction management.
Q = Problem linked to Collaboration, Coordination or Communication issues.
T = Problem linked to training.
U = Problem lined to subcontractor.
O = Problem linked to other reasons

Results on Software Used

The respondents were asked to indicate the BIM software currently in use. The selection and degree of implementation of software is vital to the success of BIM in the industry. BIM can only be properly implemented with the right hardware and software and this aspect presents some of the most challenging barriers to its implementation. Research of the capabilities of the available software is necessary and fundamental for the overall success of its implementation. Further on, a cost-benefit analysis or value-engineering of the available options would help better understand its power and capabilities in order to justify the initial investment. Figure 4-15 shows the ratings for the specified software. Most of the respondents had a preference for the Autodesk Revit Suite and for Autodesk Navisworks. A wide variety of software has been introduced in the market and has proven to be exceptionally helpful in trying to document the necessary building information. Chapter 2 covered the benefits and pitfalls of most of the widely used software in the industry, and while competition intensifies and software pioneers such as Graphisoft and Bentley are making progressive strides in attracting market share, Autodesk still seems to dominate the BIM software market.

Q. 23 How effectively did the software (Collaboration Software, e.g. Navisworks) facilitate collaboration and communication throughout the teams?

This question has some limitations since the majority of the respondents used Autodesk Navisworks. However, 8% believed that Navisworks was “very effective”, 53% believed that it was “effective”, while 39% believed it was “slightly effective” in facilitating collaboration. No respondents reported Navisworks as being ineffective in facilitating collaboration. Furthermore, 100% of the users of Solibri believed that the software was “very effective” in facilitating collaboration while 100% of the Tekla users, believe the software is “effective” in facilitating collaboration. It is important to note that participants had good reviews for Solibri and Tekla products. Both software products offered model collaboration tools such as the free of charge Tekla Model Reviewer application and the Solibri Issue Locator. As discussed in Chapter 2, both companies are active members of the buildingSMART Alliance and have been making strides in sharing models between disciplines and addressing the issues faced due to lack of interoperability. The web-based Glue Platform by Horizontal Systems Inc. was regarded as “very effective” as well, this software attempts to address the issues of collaboration by using their high speed web service. ArchiCAD has also made strides in its collaborative capabilities with the launch of ArchiCAD 14 and its “Open BIM Collaboration” between architects and engineers. With the introduction of its server based Teamwork solution described in Chapter 2, the management of team working on BIM projects has been optimized.



	Very Effective	Effective	Slightly Effective	Not Effective
Navisworks	8%	53%	39%	0%
Solibri	33%	67%	0%	0%
Glue Platform	100%	0%	0%	0%
ArchiCAD	100%	0%	0%	0%
ProjectWise	0%	50%	50%	0%
Teckla	0%	100%	0%	0%

Degree of Effectivenes

Figure 4-14. Effectiveness of collaboration software

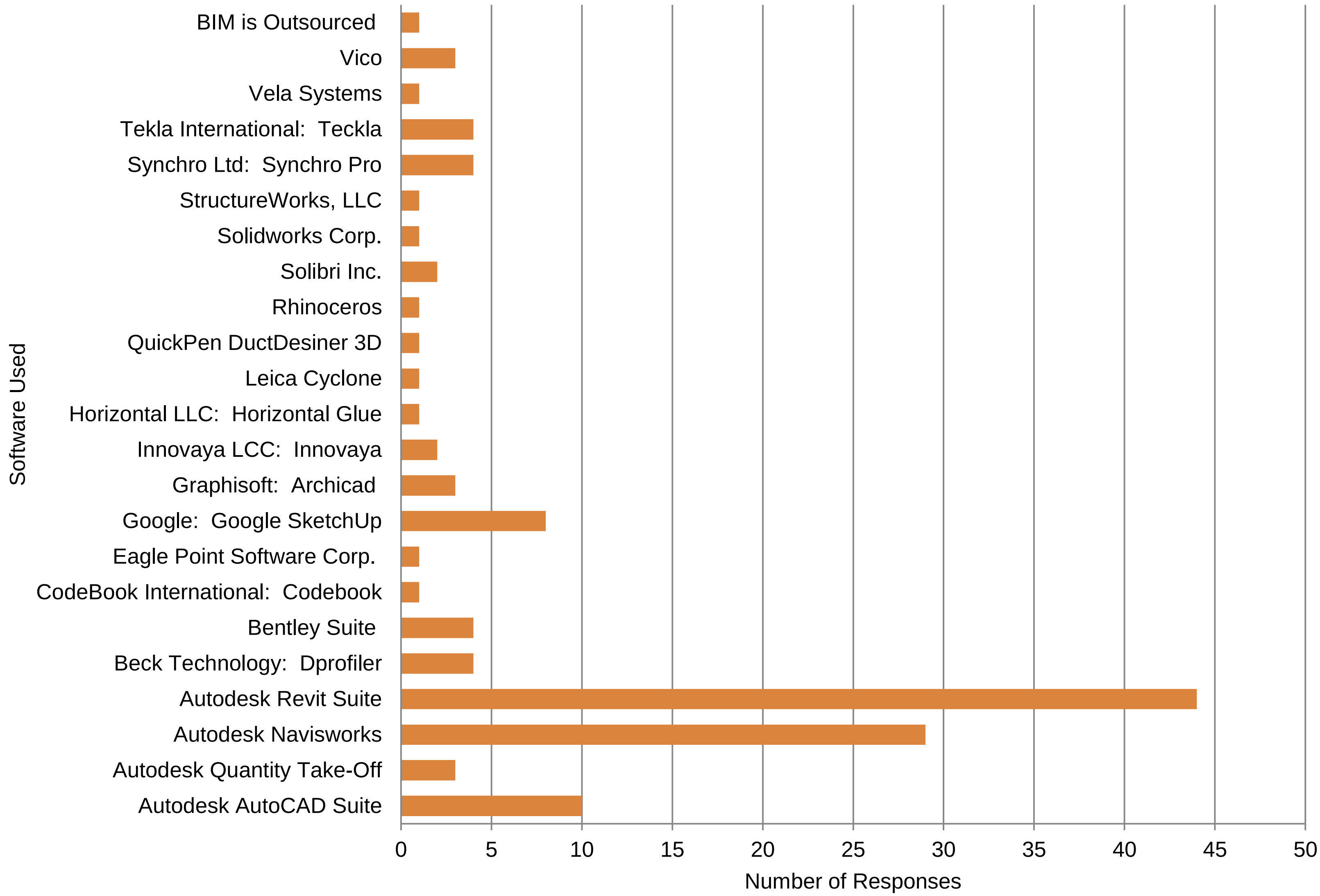


Figure 4-15. Software used

Table 4-3. Comparison between “What were the benefits realized by using BIM on projects?” and “How many hours a week do you work on BIM related tasks?”

	Less than 5 Hours	5 – 10 Hours	11-15 Hours	16-20 Hours	More than 20 Hours
Reduction in Overhead Costs	2 (10 %)	0 (0 %)	1 (25 %)	2 (100 %)	11 (46 %)
Improved Project Logistics	12 (60 %)	0 (0 %)	2 (50 %)	2 (100 %)	17 (71 %)
Planning	13 (65 %)	0 (0 %)	1 (25 %)	2 (100 %)	18 (75 %)
Communication and Reporting	7 (35 %)	0 (0 %)	2 (50 %)	2 (100 %)	15 (62 %)
Reduced Cost of Design	3 (15 %)	0 (0 %)	2 (50 %)	2 (100 %)	10 (42 %)
Enhanced Cost Estimation Capabilities	6 (30 %)	0 (0 %)	2 (50 %)	2 (100 %)	10 (42 %)
Reduction of Design Errors	11 (55 %)	1 (100 %)	4 (100 %)	1 (50 %)	18 (75 %)
Improvement in Customer Service	8 (40 %)	1 (100 %)	3 (75 %)	1 (50 %)	16 (67 %)
Production/Fabrication	10 (50 %)	0 (0 %)	3 (75 %)	1 (50 %)	19 (79 %)
Better Communication	11 (55 %)	1 (100 %)	4 (100 %)	2 (100 %)	19 (79 %)
Other, please specify	6 (30 %)	0 (0 %)	0 (0 %)	0 (0 %)	7 (29 %)

Research Objective 2 – Cost and Scale

The questionnaire focused on several areas regarding cost and scale. The purpose was to gather information from a variety of firms including size, average project size, initial investment, and return on investment (ROI) in order to better understand their collaborative practices.

Q. 6 What is your company's yearly volume of work?

This question asks the respondents to specify the company's yearly volume of work (in US $). Table 4-4, shows the information gathered from the participants.

Table 4-4. What is your company's yearly volume of work?

#	Yearly Volume of Work	#	Yearly Volume of Work
1.	$70,000,000	24.	$15,000,000
2.	$600,000,000	25.	$1,000,000,000
3.	$180,000,000	26.	$1,000,000
4.	$200,000,000	27.	$1,500,000,000
5.	$150,000,000	28.	$10,000,000
6.	$10,000,000	29.	$4,000,000,000
7.	$4,000,000,000	30.	$2,000,000,000
8.	$4,000,000,000	31.	$2,700,000,000
9.	$2,000,000	32.	$7,000,000,000
10.	$50,000,000	33.	$75,000,000
11.	$10,000,000	34.	$4,600,000,000
12.	$100,000,000	35.	$60,000,000
13.	$800,000,000	36.	$250,000,000
14.	$3,400,000	37.	$3,000,000,000
15.	$10,000,000	38.	$4,000,000,000
16.	$100,000,000	39.	$700,000,000
17.	$10,000,000	40.	$4,000,000,000
18.	$200,000,000	41.	$22,000,000
19.	$1,750,000,000	42.	$35,000,000
20.	$4,000,000,000	43.	$1,600,000,000
21.	$1,500,000,000	44.	$10,000,000,000
22.	$8,000,000	45.	$500,000,000
23.	$500,000,000	46.	$700,000,000
Average	$1,435,247,826		

Figure 4-16 shows the diversity in the size of the studied group. As expected, the largest group of participants (37%) belongs to firms with a yearly volume of work of $1 billion (B) or higher followed by the range of $1million (M) to $10M (20%) and $11 M to $100 M (20%). Subsequently, 13% of the respondents were from companies whose volume of work was between $101-$500 M and 9% do work in the $501 M to $1 B range.

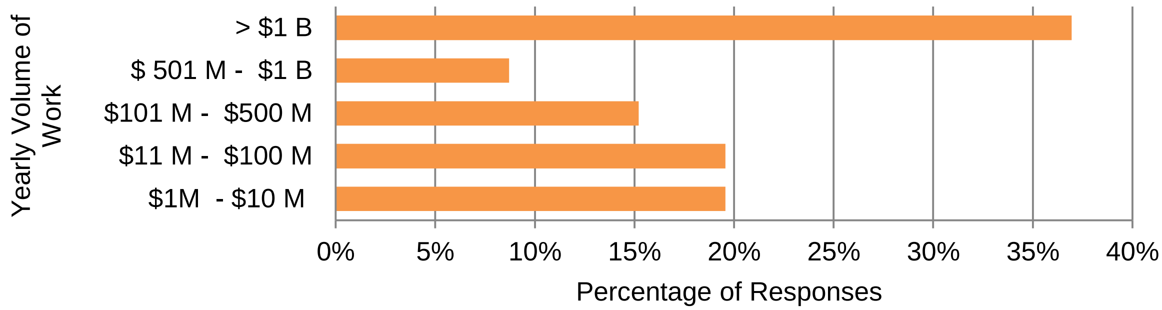


Figure 4-16. Yearly volume of work

Q. 16 What type and size of projects are you employing BIM processes in? The answers to this question varied but the replies ranged from $1 million (M) to more than $1 billion (B). The most frequent project size range (16%), was between $200 M and $300M. The data collected indicated that only 3% of the respondents worked on projects of $2 M or less, while only 6% work on projects $500 M or larger. Figure 4-17 shows the distribution of the answers.

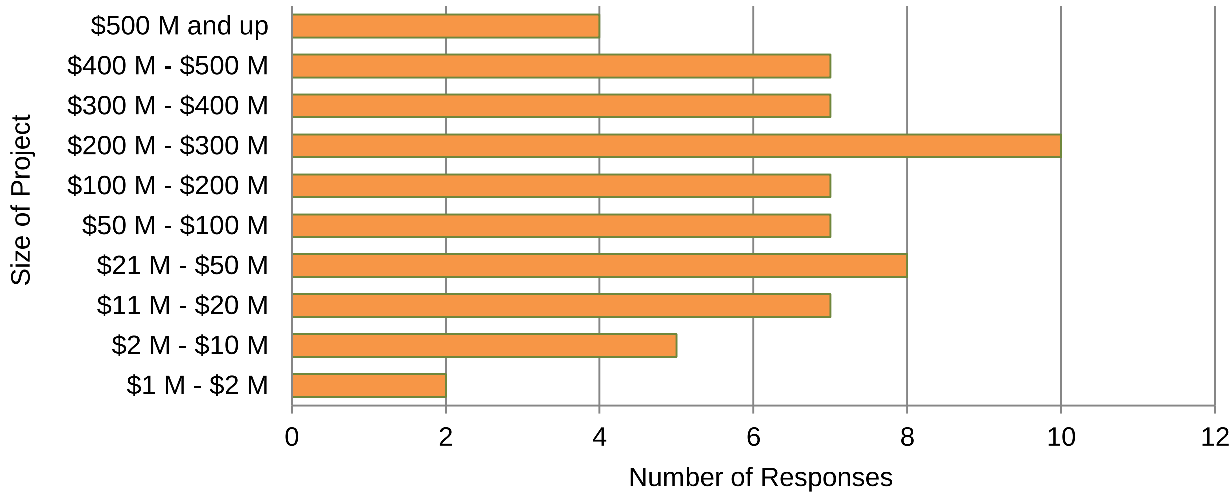


Figure 4-17. Average project size (using BIM)

The question also asks to specify the type of construction involved with. The literature in Chapter 2 suggests that BIM is especially useful in complex projects. Healthcare and commercial construction can present some complex situations and BIM seems to be the most popular in these types of construction. Figure 4-18 indicates that 19 (31%) of the respondents use BIM for commercial construction. Healthcare construction accounted for 19% (12), while Institutional was the third most popular type of construction with 16%.

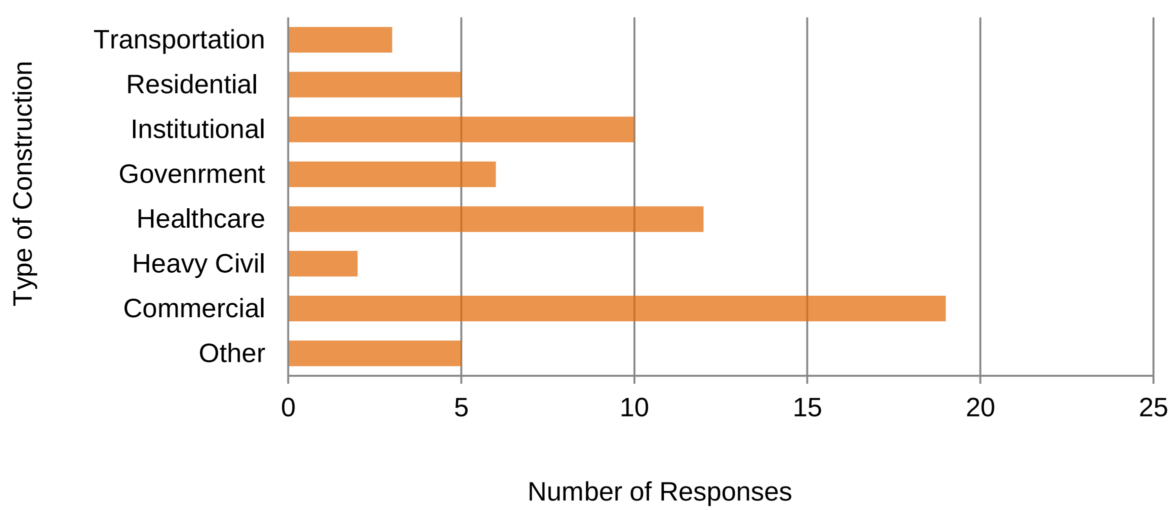


Figure 4-18. Type of construction

Towards the end of the survey, the participants were asked to state the ideal project size for BIM purposes (Q. 31), the information has been displayed in Table 4-19. The question is subjective and the purpose was to find a pattern rather than to find a specific project size. The answers provide an idea on the experiences and viewpoints from the BIM professionals. A total of 44 responses were collected, and as shown in Figure 4-19, the more frequent responses include the following ranges: “$21 M to $50 M”, “$51 M to $100M” and “any size”. Some of the participants felt comfortable specifying a range or a specific number; however, most believed that any size larger than $5 M will highly benefit from BIM.

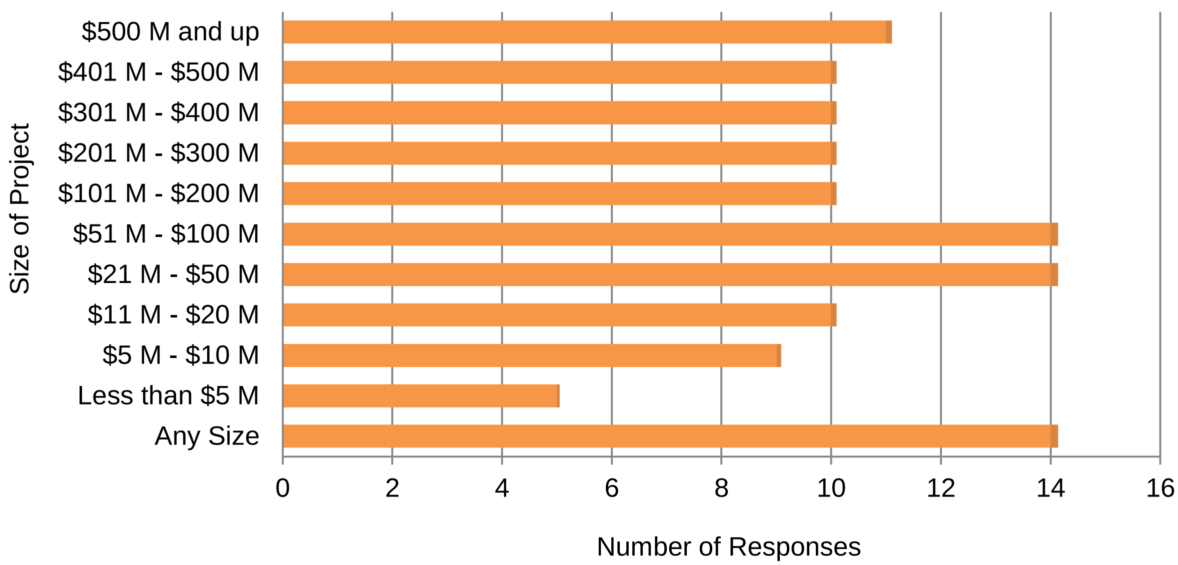


Figure 4-19. Ideal project size

Q. 19 How large was the initial investment when you first adopted the BIM methodology?

This question asked the respondents to specify the initial investment when transitioning to BIM. As shown in Figure 4-20, the majority of the respondents (40%) indicated an initial investment of more than $30,000. BIM software can be expensive especially when accounting for time spent in training and the learning curve. It is hard to quantify the time spent at the initial stage of BIM implementation so this question can be challenging to address. The larger the company, the more seats are needed and the larger the investment. It is important to consider that, 40% of the participants work for companies with a yearly volume of less than $100 M (yearly), as shown in Figure 4-16. With an average yearly volume of work of $1,435,250,000 (range of the 48 responses), 60% of the participants experienced an initial investment of less than $30,000. This is remarkable, since this represents a very small fraction of the average work performed and project budgets involved.

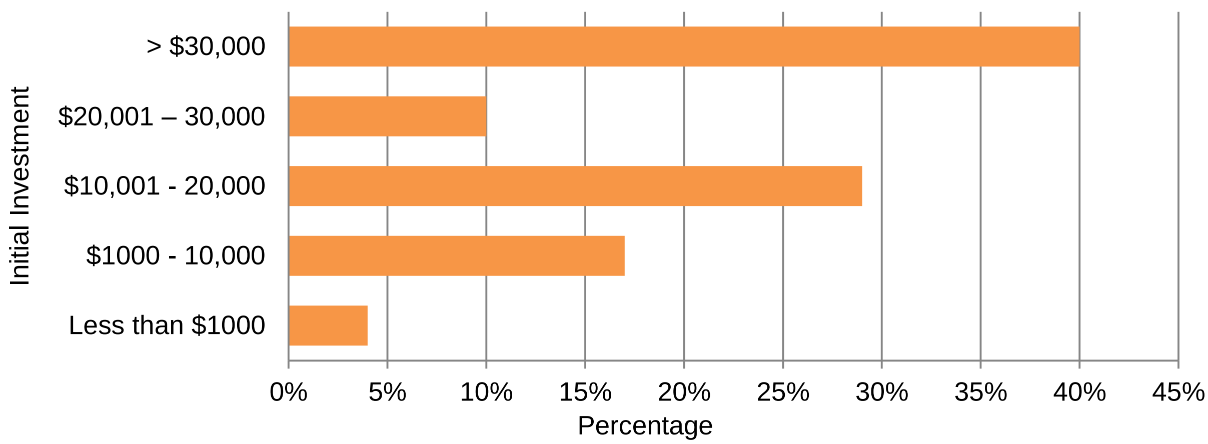


Figure 4-20. Initial investment

Q.20 What was your company's Return on Investment (ROI) in BIM?

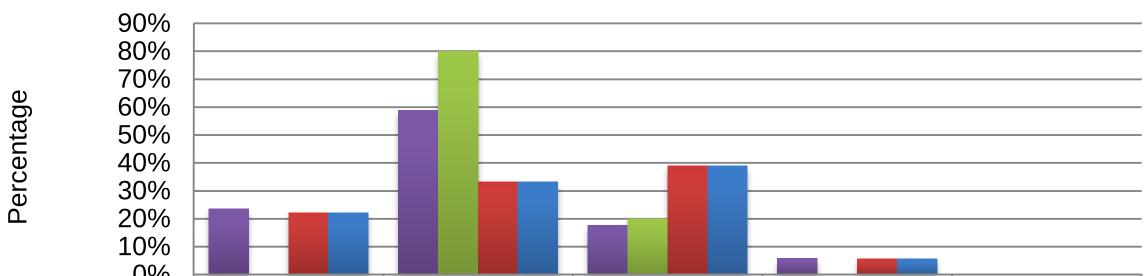
The return on investment (ROI) has been a highly discussed topic in the implementation of BIM. However, it has been challenging to calculate, due to the many variables involved. McGraw Hill (2008 p.3) found that 48% of industry professionals who participated in their survey, pointed out that they were tracking the ROI in relation to BIM. This report found that initial ROI values ranged anywhere from 300-500%. The study also reported that many experienced ROI's of over 1000%. While the expectations for this question were low, the results presented some interesting facts. From the 39 responses received, only 9 replies indicated a value or a percentage. The answers varied drastically and indicated a lack of ROI monitoring and tracking in the industry. Table 4-5 includes some of the numbers received as well as fragments from the original responses.

Table 4-5. Return on investment (ROI)

#	Answer
1	50%.
2	Millions.
3	0.
4	10 Fold.
5	500%.
6	14%.
7	300-500%.
8	200%.
9	Millions.
10	Difficult to measure-different on all projects.
11	It has not been tracked.
12	Difficult to measure-different on all projects.
13	I'm not upper management-don't have a clue. I know they probably lost their client.
14	We do not calculate ROI.
15	I'm not upper management-don't have a clue. I know they probably lost their client.
16	Villanueva-Meyer, you'll find it hard to measure this one.
17	Presently unknown.

The number of licenses held by a company is a key indicator when trying to understand the scale of the company, as well as their investment on BIM implementation. Hence, a set of comparisons were established, in order to compare the retrieved data with several levels and types of collaboration. These comparisons (presented below) help us better understand the trends in the industry in regards to scale and investment.

The cross-tabulated analysis, shown in Figure 4-21, shows the relationship between the number of BIM software licenses and the perceived accuracy of the BIM models. The data presents a trend and a positive relationship between number of licenses and perceived accuracy. A total of 83% of the respondents who worked for companies with 20 or more licenses believed that the BIM models used have a “very accurate” to “accurate” quality. Nevertheless, 55 % of the responses from companies with "less than 5 licenses" and with "10 to 15 licenses", perceived “very accurate” to “accurate” BIM models. Usually, the more seats a company hold, the larger and more complex their projects are, and the higher their budgets and time invested in BIM accuracy. However, smaller companies with less than 15 licenses tend to work on less intricate projects, and are able to achieve higher accuracy with less effort and investment.

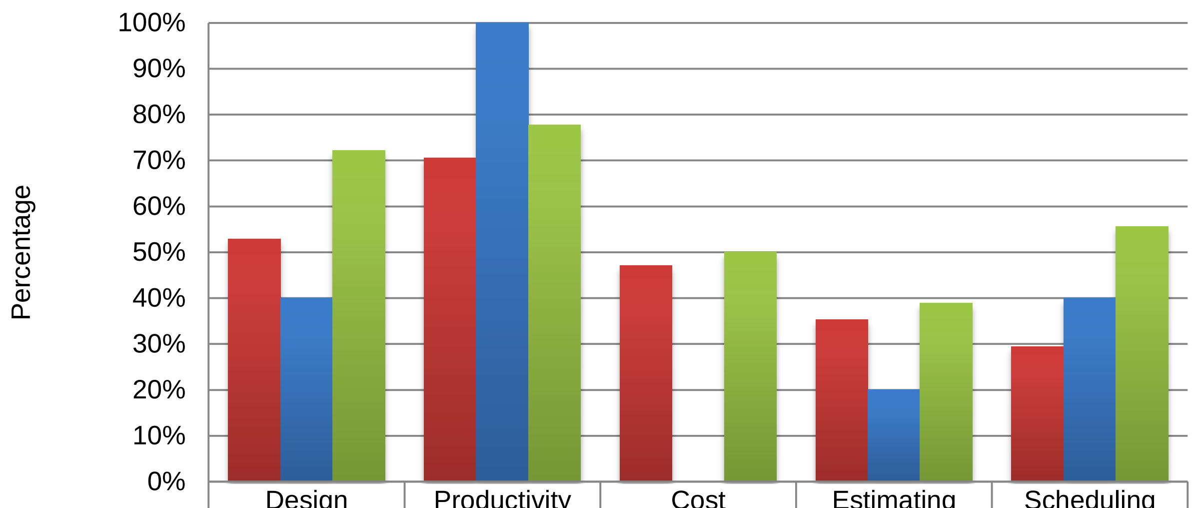


	Very Accurate	Accurate	Neither	Inaccurate	V. Inaccurate
More than 20	24%	59%	18%	6%	0%
16 to 20	0%	80%	20%	0%	0%
10 to 15	22%	33%	39%	6%	0%
Less than 5	22%	33%	39%	6%	0%

Accuracy of BIM Models

Figure 4-21. Comparison of number of licenses and accuracy of BIM models

In order to better understand the benefits of BIM, the five factors presented in Figure 4-22: design, productivity, cost, estimating and scheduling were compared against the number of licenses held by the studied firms. These factors were used in order to understand different perceptions towards BIM in relation to the scale of the firms. Companies with more than 20 licenses perceived the highest improvements in design, productivity, estimating and scheduling. Companies with 16 to 20 licenses experienced the highest improvements in productivity. A trend is perceived, suggesting that companies with more licenses identified more improvements with the introduction of BIM. Nevertheless, companies with less than 5 software licenses reported high benefits. 53% reported improvements in design, 71 % indicated improvements in productivity, while improvements in cost reduction (47%), estimating (35%) and scheduling (29%) also presented significant values.



	Design	Productivity	Cost	Estimating	Scheduling
Less than 5	53%	71%	47%	35%	29%
16 - 20	40%	100%	0%	20%	40%
More than 20	72%	78%	50%	39%	56%

Identified Improvements

Figure 4-22. Comparison of number of licenses and identified improvements

Research Objective 3 – Project Delivery and Sustainability

The information gathered from the surveys regarding project delivery methods and sustainability was limited. Although some findings from the survey are described, two case studies were also selected in order to further evaluate the importance of multidisciplinary collaboration in the BIIM environment. The results of these case studies are presented below along with conclusions relating to the project delivery methods and successful sustainability approaches.

Q. 28 Which project delivery method facilitates collaboration the most?

The options provided included the traditional Design-Bid-Build, as well as Design-Build, IPD, and an option to specify other. As shown in Figure 4-23. The most popular project delivery method with 59% of the responses was IPD, followed by Design-Build with 45%, and finally, Design-Bid-Build, had a total of 15% of the responses. The other specified delivery methods included Construction Manager at risk (CMAR) which obtained 4% of the responses.

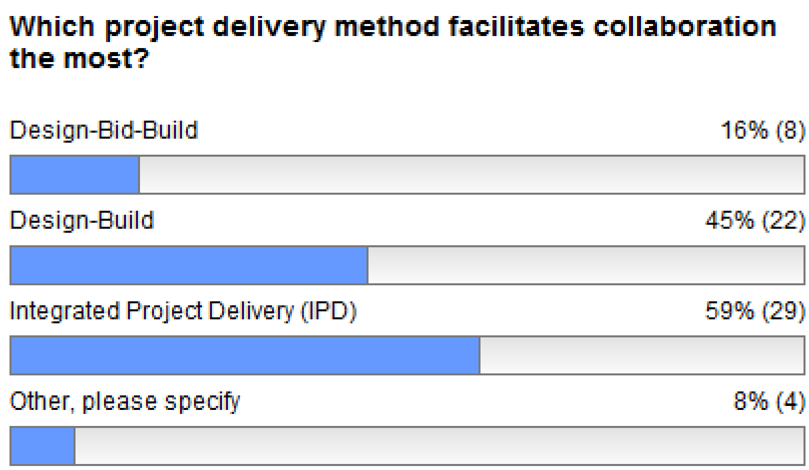


Figure 4-23. Project delivery method

In order to compare and better understand the project delivery methods and the green rating systems, two similar case studies were analyzed. The purpose of the case studies was to find trends in the collaborative environment created by the multidisciplinary teams using BIM, IPD, CMAR and Leadership in Energy and

Environmental Design (LEED). The first selected case study used the CMAR delivery method, and used BIM to aid in the collaborative goals established from the beginning. The Phoenix Children's Hospital (PCH) enjoyed significant savings and benefits due to the contractor's (Kitchell) well-established collaborative management culture. Numerous benefits were attributable to BIM, a multidisciplinary approach and the collaborative environment. The new parking area was re-sequenced in the 4D scheduling phasing, which accounted for a $3 million savings in parking shuttle costs. The savings were attributed to the collaborative communication with hospital staff and administration which explained campus disruptions through-out the process. The $3 million saved were then used to buy adjacent property. 3D modeling-of the underground utilities ensured that all of the designed work could be installed and the process was fully coordinated prior to the start of the project. Furthermore, the 3D modeling and collaboration project management system, helped achieve a paperless environment. The electronic distribution saved time and money while being an acceptable component for the requirements under the prescribed Green Guidelines to healthcare.

Case study two, involved the construction of the Encircle Health Ambulatory Care Center. The project delivery method used was IPD and the sustainability goal was to achieve LEED Silver certification. The main characteristics of the case study included the following: early involvement of key participants, BIM collaboration, collaborative decision making and control, jointly developed and validated project goals and shared risk and reward. The initial design cost of the project was $2,901,071 and the final cost ended up being $3,185,917. The initial construction cost was $34,977,404, and the final cost ended up being $35,408,131. However, an owner initiated change order of

$1,514,911, caused variations in the project cost and schedule. Due to the way the project was organized, following a multidisciplinary structure, the participants enjoyed several benefits. Most costs were well predicted during the design stage, allowing for important changes to take place before construction. Most RFI's were solved in the field, avoiding miscommunications and excessive time consumption. One of the projects most important goals was to achieve a LEED Silver certification. Due to the benefits of the teams working together with the owner, the necessary adjustments were made for the project to achieve the LEED Gold certification which was eventually achieved.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

In the modern high-tech building information modeling (BIM) construction environment there is no doubt that multidisciplinary collaboration is indispensible. Even though collaboration alone is a highly regarded factor which helps pave the way for success, the recipe for a profitable, sustainable and successful BIM project lays in the ideal combination of the many factors discussed in this research. Project delivery methods like integrated project delivery (IPD) and Design-Build (DB) and green rating systems can be customized depending on the company, project, budget, or team size in order to address the indicators for successful BIM implementation. Furthermore, an adequate set of BIM collaboration tools is vital and needs to be carefully selected. Moreover, factors including: geographical location, distance between team members, BIM experience, hardware, software, sustainability goals, type of construction, and stage of BIM implementation, need to be acknowledged early on with a proactive approach. The analyzed survey data in conjunction with the selected literature supports the following conclusion: “A climate of unswerving collaboration, with well specified multidisciplinary roles, is indispensible for the proper execution of building information modeling.”

BIM users have not been able to take full advantage of its power due to factors such as cost of software, training time, and lack of. It is interesting to note that 47% of the surveyed individuals have been exposed to multiple projects or more in a range of one to three years. It is evident that a superior level of consistent communication and coordination is necessary to avoid wasted time and negative consequences. However, these factors, usually enabled by a high level of collaboration will help achieve the multiple benefits experienced by many (see Table 4-3). Hence, experience with multiple BIM projects is fundamental. This experience will be passed along and the industry will continue to educate itself in BIM and collaborative practices. The most experienced BIM users will have to take a leadership position and facilitate the coordination to ensure a high degree of collaboration across the fields for each project.

Moreover, early BIM implementation is another substantial indicator for collaborative BIM success. From the survey conducted, 82% of the participants believe that design stage multidisciplinary collaboration is “very important”. The IPD case study of The Encircle Health Ambulatory Care Center included all the major subcontractors in the early schematic design stage, and the teams met weekly to perform collaborative decision making problem solving. Therefore it is evident that the early creation of a collaborative culture is important in the facilitation of the BIM process.

In regard to scale factors, the results suggest that larger companies seem to be on the cutting edge of technology, and are taking full advantage of the latest BIM collaboration tools and project delivery methods. However, smaller companies involved in less intricate projects, have also indicated monetary benefits arising with the implementation of BIM. If properly implemented, BIM will bring vast benefits and improvements to its users as well as to the multidisciplinary environment. From the results, companies with a yearly volume of work ranging between $1 M to over $1 B and projects ranging from $1 M to $500 M reported benefits in multiple areas (planning, scheduling, estimating, etc.) regardless of their size.

BIM has brought an ocean of change to the architecture, engineering, construction (AEC) industry and recent literature suggests that technological advancements are facilitating a collaborative environment However, it is essential to understand the complexity of the highly interconnected and collaborative environment. New challenges arise from the implementation of BIM and accurately worded contractual agreements (often seen in IPD), which account for risks and rewards are vital.

The results indicate that with the successful implementation of BIM across the industry is evident that the highest the exposure to BIM, the more benefits attained, and the higher the level of collaboration. From the performed analyses, individuals who worked more than 20 hours a week in BIM related activities experienced the most benefits. The higher involvement with BIM meant higher perceived levels of collaboration and less obstacles and costly errors experienced.

Bernstein and Pittman (2004) posed the following question: “The productivity and economic benefits of BIM to the global building industry are widely acknowledged and increasingly well understood. Further, the technology to implement BIM is readily and rapidly maturing. Yet despite the obvious benefits and readiness of BIM software, BIM adoption has been slower than anticipated. Why?” The research verifies the importance of collaboration in relation to field of practice, experience, scale, and cost among other factors. Bernstain’s (2004) inquiry can be better addressed in terms of lack of experience, interoperability barriers, slow multi-disciplinary adoption and weak collaboration. Among the individuals and companies surveyed, 34% reported to have more than 15 years of experience in the industry; nevertheless, only 25% of the studied population had been involved in multiple projects in a period of four years or more. These facts help better understand the issues regarding BIM maturity and experience, which plays a big role in its adoption. There are many factors affecting BIM implementation and since most of the procedures are relatively new to most AEC professionals and the expectations involve a lot of hype, the experiences and perceptions may be distorted. However, it is evident that as the learning curve fades in the horizon, an environment of collaboration will rise.

The software tools that help bring the disciplines together becomes the backbone of the BIM project and its efficiency, compatibility, ease of use, speed, coordination, communication and collaboration capabilities are essential for the appropriate implementation of BIM. Many things can go wrong in the fast paced, high risk, construction environment and a proactive approach that nurtures a collaborative environment needs to be established. Moreover, the software of preference needs to be highly reliable, and all the team members should have access to the corresponding BIM models.

There is a lopsided preference for the Autodesk Revit Suite and for Autodesk Navisworks. This affects the degree of collaboration but the necessary steps are being taken by software developers and by the buildingSMART International Alliance, in order to solve the compatibility problems while addressing interoperability. Some of the most significant achievements seen in the past year include language and IFC development. The development and accessibility of web-based BIM collaboration and coordination servers is transforming the way BIM is being used and it will continue to foster a collaborative environment. There are several options for BIM software. Vendors around the world are polishing the capabilities of their products, and there is no doubt that uninterrupted workflow and multidisciplinary collaboration have become priorities. With the influence of the buildingSMART alliance and the industry foundation classes (IFC) strides in interoperability, companies are turning to other options. The market still belongs to Autodesk, but due to the affordability and high effectiveness of other vendors and software solutions, the market shares are bound to even out to some extent.

It was remarkable to find out that one of the largest difficulties experienced when working with BIM teams was perceived in the collaboration process; may it be through lack of coordination or communication. It appears that the industry is not fully satisfied with the BIM tools and their utilization. Out of the 54 difficulties identified, 26% were attributed to issues in collaboration, coordination or communication.

In regard to the project delivery method of choice, IPD is regarded as the most helpful in stimulating an environment of collaboration from the beginning. One of the goals of IPD is to promote collaborative decision making and control (Cohen 2010). As seen in the Encircled Health Center case study, the combination of experience, early multidisciplinary collaboration, and BIM implementation led the project to surpass its goal of achieving a Leadership in Energy and Environmental Design (LEED) Silver certification, and to obtain the LEED Gold certification instead. Both the survey results and analysis of the case study implementing IPD indicated that IPD is successful in establishing a collaborative work environment. Even though the Phoenix Children's Hospital used a construction manager at risk (CMAR) project delivery method, the well-established collaborative culture employed by the contractor allowed the project to obtain significant successes. Communication allowed for savings, efficient use of time, and superior sustainability achievements. The implementation of BIM in both case studies allowed for design issues to be resolved before construction began, saving time and money without sacrificing quality or the sustainability goals.

Retrospective improvements to this research. In order to obtain a better understanding of the different views of the industry, the survey should have been distributed evenly across the multiple disciplines in the industry. Ideally the same number of responses should have been collected from the architecture, engineering, and construction management fields as well as from subcontractors, structural, mechanical electrical and plumbing branches of work. With a more balanced set of data, the study would gain more validity and the comparisons among the fields of practice could have been use to better understand the existing issues practitioners face in the BIM collaborative environment.

Moreover, the processes involved in BIM are meant to be adopted by facility managers in order to effectively track the lifecycle of the buildings. By including project owners and facility managers in the research and survey questionnaire, the study would have had a broader impact. Furthermore, as the main disciplines in the architecture, engineering, construction (AEC) industry become more integrated and projects become increasingly complex, it is essential to take advantage of the right software tools. BIM implementation comes at a cost, and while the learning curve, spent time, training, and initial investment may be problematic, it is important to bear in mind that the end result makes it all worth it.

APPENDIX A
IRB SURVEY PROPOSAL SUBMISSION

UFIRB 02 – Social & Behavioral Research

Protocol Submission Form

This form must be typed. Send this form and the supporting documents to IRB02, PO Box 112250, Gainesville, FL 32611. Should you have questions about completing this form, call 352-392-0433.

Title of Protocol:	Importance of Multi-Disciplinary Collaboration in Building Information Modeling (BIM)		
Principal Investigator:	Sergio Villanueva-Meyer		**UFID #:** __________
Degree / Title:	Masters of Science in Building Construction	**Mailing Address:** ______________	**Email:** _________________
Department:	M.E. Rinker Sr, School of Building Construction		**Telephone #:** __________________
Co-Investigator(s):	None	**UFID#:** __________	**Email:N/A**
Supervisor *(If PI is student)***:**	Dr. R. Raymond Issa	**UFID#:** ____________	
Degree / Title:	Prof & Director	**Mailing Address:** ____________________	**Email:** ___________________
Department:	**Building Construction**		**Telephone #:** ___________________
Date of Proposed Research:	August 2010 – December 2010		

Source of Funding *(A copy of the grant proposal must be submitted with this protocol if funding is involved):*	None

Scientific Purpose of the Study:

To identify the importance of multidisciplinary collaboration in construction projects employing Building Information Modeling (BIM) technology.

Describe the Research Methodology in Non-Technical Language: *(Explain what will be done with or to the research participant.)*

The participants will answer an online questionnaire that would indicate how they utilize Building Information Modeling and how the process of collaboration and coordination is reflected in the projects.

Describe Potential Benefits:

To understand the importance of collaboration throughout the design, pre-construction and construction of the project and provide the industry of a better understanding of proven practices and methods regarding the topics of the research.

Describe Potential Risks: (*If risk of physical, psychological or economic harm may be involved, describe the steps taken to protect participant.)*

No more than minimum risk.

Describe How Participant(s) Will Be Recruited:

An online survey link will be sent to various construction companies via e-mail.

Maximum Number of Participants (to be approached with consent)	1,000	**Age Range of Participants:**	18+	**Amount of Compensation/ course credit:**	None

Describe the Informed Consent Process. (Attach a Copy of the Informed Consent Document. See http://irb.ufl.edu/irb02/samples.html for examples of consent.) An e-mail would be sent the participant where it describes the purpose and consent of the survey, the participant will agree to the consent by clicking on the link to the survey website.		
(SIGNATURE SECTION)		
Principal Investigator(s) Signature:		**Date:**
Co-Investigator(s) Signature(s):		**Date:**
Supervisor's Signature (if PI is a student):		**Date:**
Department Chair Signature:		**Date:**

APPENDIX B
SURVEY QUESTIONNAIRE

1. How long have you been working in the construction industry?	
1 year	3
2-5 years	10
6-10 years	17
11-15 years	7
More than 15 years	19

Total Number of Replies: 56

2. What is your BIM Title?	
BIM Administrator	0
BIM Coordinator	3
BIM Manager	11
Model Coordinator	1
No specific BIM title	29
Other (Please Specify):	12

Total Number of Replies: 56

3. How long have you held the title?	
Less than 1 year	10
1 - 3 years	23
4 – 6 years	7
7 - 9 years	2
10 years or more	6

Total Number of Replies: 48

4. What field do you work most closely with?	
Architecture	12
Engineering	4
Construction	41
MEP	7
Other, please specify	3

5. What Disciplines are represented in your BIM projects?	
Architecture	44
Engineering	34
Construction	42
MEP	40
Other, please specify	14
Total Number of Responses:	56

6. Please indicate your company's yearly volume of work: (US $)
48 Responses

7. Please indicate the BIM Software currently in use at your firm?
52 Responses

8. How many projects have you been involved with?	
Single Project (Just Started)	7
Multiple Projects (1 year or less)	6
Single Project (1 year or more)	2
Multiple Projects (1-3 years)	26
More than 4 years of BIM Projects	14
Total Number of Responses:	55

9. How many licensed professionals does your company have?	
Less than 5	18
5 to 10	6
11 to 15	4
16 to 20	5
More than 20	18
Total Number of Responses:	51

10. How many hours a week do you work on BIM related tasks?	
Less than 5 Hours	20
5 – 10 Hours	2
11 - 15 Hours	4
16 - 20 Hours	2
More than 20 Hours	26
Total Number of Responses:	54

11. How would you rate the accuracy of the BIM models you have been exposed to?	
Very Accurate	10
Accurate	29
Neither Accurate nor Inaccurate	13
Inaccurate	3
Very Inaccurate	0
Total Number of Responses:	55

12. How would you rate the difficulty in working with multidisciplinary teams with their various discipline-based BIM Models?	
Very Easy	0
Easy	11
Neither Easy nor Hard	33
Difficult	9
Very Difficult	1
Total Number of Responses:	54

13. How important is it for the BIM teams to work together from the beginning?	
Very important	45
Quite Important	8
Fairly Important	2
Slightly Important	0
Not at all important	0
Total Number of Responses:	55

14. How important is it for BIM teams to work together during construction?	
Very important	42
Quite Important	11
Fairly Important	2
Slightly Important	1
Not at all Important	0
Total Number of Responses:	56

15. How often should the multidisciplinary teams meet to discuss the BIM process? (monthly)	
Less than once	3
1-5 times	40
5-10 times	6
11-15 times	1
More than 10 times	3

16. What type and size of projects are you employing BIM processes in?
44 Responses

17. What are the primary areas that you have identified improvements in?	
Design	37
Productivity	39
Cost	23
Estimating	20
Scheduling	24

18. What in the multidisciplinary process did you encounter the greatest difficulty with?
41 Responses

19. How large was the initial investment when you first adopted the BIM methodology?	
	2
$1000 - 10,000	8
$10,001 - 20,000	14
$20,001 – 30,000	5
> $30,000	19
Total Number of Responses:	48

20. What was your company's Return on Investment (ROI) in BIM? (US $)
39 Responses

21. What were the benefits realized by using BIM on projects ? (Check all that apply)	
Reduction in Overhead Costs	16
Improved Management of Project Logistics	34
Planning	35
Communication and Reporting	27
Reduced Cost of Design	18
Enhanced Cost Estimation capabilities	21
Reduction of Design errors	36
Improvement in Customer Service	30
Production/Fabrication	34
Better understanding of the project by team members	38
Other, please specify	14

22. What were the unexpected benefits realized by using BIM (Please Specify if any)?
20 Responses

23. What BIM collaboration software does your company employ? (e.g. Autodesk Navisworks)
45 Responses

24. How effectively did the software facilitated collaboration and communication throughout the teams?	
Very Effective	6
Effective	24
Slightly Effective	13
Not Effective	2

Total Number of Responses: 45

25. From your experience, how would you rate the motivation for collaboration of the multidisciplinary members?	
Very High	5
Above Average	20
Average	17
Below Average	6
Very Low	0

Total Number of Responses: 48

26. Which field of practice (excluding yours) seemed most willing to collaborate?	
Architecture	13
Engineering	8
Construction	11
MEP	25
Other, please specify	3

Total Number of Responses: 56

27. Which field of practice (excluding yours) seemed the least willing to collaborate?	
Architecture	21
Engineering	15
Construction	3
MEP	8
Other, please specify	3

Total Number of Responses: 50

28. Which project delivery method facilitates collaboration the most?	
Design-Bid-Build	8
Design-Build	22
Integrated Project Delivery (IPD)	29
Other, please specify	4

29. What is the ideal BIM team size?
43 Responses

30. What is the ideal project delivery method?
46 Responses

31. What is the ideal project size? (US $)
43 Responses

32. What field of practice should spend the most time in BIM training?	
Architecture	27
Engineering	14
Construction	6
The same	18
Other, please specify	3

33. At what stage should BIM practices be implemented?	
Design Stage	51
Preconstruction Stage	22
Construction Stage	16

34. During what stage should teams meet?	
Design Stage	48
Preconstruction Stage	30
Construction Stage	21

35. Which teams should meet at the design stage?
40 Responses

36. Is there a field of practice that you think should have a larger involvement in the BIM development and implementation?	
Architecture	21
Engineering	12
Construction	21
MEP	12
Other, please specify	10

37. What is the ideal Green rating system to implement BIM with?	
LEED	37
Green Globes	2
Green Star	2
BREEAM	3
Other, please specify	7
Total Number of Responses:	51

38. From your experience with BIM projects, how would you rate the degree of multidisciplinary collaboration?	
Excellent	5
Above Average	17
Average	22
Below Average	8
Low	1
Total Number of Responses:	53

LIST OF REFERENCES

AIA and AIA California Council. (2007). *Integrated project delivery: A guide*. 1.2-34. Retrieved from http://www.msa-ipd.com/IPD_Guide_2007.pdf (Dec 11 2009).

Autodesk, Inc. (2008a). *Improving building industry results through integrated project delivery and building information modeling.* Retrieved from http://images.autodesk.com/adsk/files/bim_and_ipd_whitepaper.pdf (June 26 2010).

Azar, C. (2008). Collaboration: Paving a win-win road to profit. *Northwest Construction*, *28.*

Bentley Systems Inc. (2010). *Dynamic collaboration for iterative project review.* Retrieved from http://www.bentley.com/en-US/Products/ProjectWise+Navigator/Product-Overview.htm (Aug 12 2010).

Bernstein, P. Pittman, J. (2004). *Barriers to the adoption of building information modeling in the building industry*. Retrieved from http://images.autodesk.com/adsk/files/bim_barriers_wp_mar05.pdf (Nov 12 2009).

Building Design and Construction. (2009). *ASHRAE research targets tying together BIM, energy efficiency*. Retrieved from http://www.bdcnetwork.com/article/CA6675774.html (Aug 13 2009).

BuildingSmart International. (2010). *About us.* Retrieved from http://www.buildingsmart.com/content/buildingsmart_international (Dec 25 2009).

Cohen, J.W. (2010). Integrated project delivery: Case studies. *AIA California Council*, 9-34.

Denise, Leo. (2000). *Collaboration vs. C-three (cooperation, coordination, and communication)*. *Innovating, 7*(3) 1-6

Dirik, J. (2009). Integrated project delivery, part two: Legal issues. *Texas Construction, 38*.

Dispenza, K. (2010) *The daily life of building information modeling (BIM)*. Retrieved from http://buildipedia.com/in-studio/item/1212-the-daily-life-of-building-information-modeling-bim (Jun 15 2010).

Eastman, C., Teicholz, P., Sacks, R., and Liston, K. (2008). *BIM handbook: A guide to building information modeling for owner, managers, designers, engineers, and contractors* (1st ed.). New Jersey: Wiley.

Eckblad, S. (2007). *Integrated project delivery—A working definition*, AIA California Council, Sacramento, California.

France, C. (2010*). BIM and the cloud*. Retrieved from http://www.aecbytes.com/feature/2010/BIM_Cloud.html (Oct 21 2010)

Friedman, T. L. (2005). *The world is flat: A brief history of the twenty-first century*. New York: Farrar, Straus and Giroux.

GGHC. (2010). *About GGHC: Who we are: Overview*. Retrieved from http://www.gghc.org/about.whoweare.overview.php (12 Oct 2010).

Grilo, A., and Jardim-Goncalves, R. (2010). Value proposition on interoperability of BIM and collaborative working environments. *Autom.Constr., 19*(5), 522-530.

Holness, G. (2006). Building information modeling. *ASHRAE Journal*, *48*(8), 38-46.

Khemlani, Lachmi. (2006). *The AGC's BIM initiatives and the contractor's guide to BIM*. Retrieved from http://www.aecbytes.com/buildingthefuture/2006/AGC_BIM.html (July 15 2010).

Khemlani, L. (2008a). *Autodesk NavisWork 2009*. Retrieved from http://www.aecbytes.com/review/2008/NavisWorks2009.html (May 14 2010).

Khemlani, L. (2009b). *Bentley architecture V8i*. Retrieved from http://www.aecbytes.com/review/2009/BentleyArchV8i.html (Feb 26 2010).

Khemlani, L. (2009d). *Collaboration, project management, and project information management solutions in AEC*. Retrieved from http://www.aecbytes.com/feature/2009/Collaboration_PM_PIM_Solutions.html (Feb 26 2010).

Khemlani, L. (2009e). *Revit architecture 2010*. Retrieved from http://www.aecbytes.com/review/2009/RevitArch2010.html (Feb 26 2010).

Khemlani, L. (2010a). *ArchiCAD 14*. Retrieved from http://www.aecbytes.com/review/2010/ArchiCAD14.html (Sep 10 2010).

Khemlani, L. (2010b). *Newforma project center seventh edition*. Retrieved from http://www.aecbytes.com/review/2010/NewformaProjectCenter7.html (Aug 18 2010).

Laiserin, J. (2009). Next-Gen BIM: Graphisoft teamwork 2.0 will revolutionize BIM/IPD workflow and collaboration. *The LaiserinLetter, 25*.

Liebich, T. (2010). Next generation of open interoperable working with BIM*. BuildingSMART, 1.*

Livingston, H. (2007*). BIM and sustainable design*. Retrieved from http://www.cadalyst.com/cad/building-design/bim-and-sustainable-design-part-2-3618 (May 7 2010).

McGraw-Hill Construction. (2008). *Building information modeling (BIM): Transforming design and construction to achieve greater industry productivity.* New York: McGraw Hill.

Malin, N. (2007). Building information modeling and green design. *EBN, 21*.

Mckenzie, J., Johnson S. (2009). *BIM means business: Phoenix children's hospital project-case study.* Retrieved from http://au.autodesk.com/?nd=material&session_material_id=6036 (Oct 12 2010).

Roberts, T. (2008). *Integrated project delivery: A platform for efficient construction*. Retrieved from http://www.buildinggreen.com/auth/article.cfm/2008/10/29/Integrated-Project-Delivery-A-Platform-for-Efficient-Construction (Nov 1 2008).

Sacks, R., Koskela, L., Dave, B. A., and Owen, R. (2010a). Interaction of lean and building information modeling in construction. *J.Constr.Eng.Manage., 136*(9), 968.

Sage Software, Inc. (2008). *Collaborative construction: Making BIM work for builders.* Retrieved from http://www.aspenational.org/Files/13/Sage_White_Paper_-_Making_BIM_Work_for_Builders.pdf (Aug 2 2010).

Suermann, P. (2010). *Evaluating the impact of building information modeling (BIM) in construction.* Retrieved from http://buildinginformationmanagement.wordpress.com/2010/02/02/evaluating-the-impact-of-building-information-modeling-bim-on-construction (Sep 14 2010).

Thomson, D. and Miner, R. (2006). BIM: Contractual risks are changing with technology. *Consulting-Specifying Engineer, 40* (2), 54-66.

Várkonyi, V. (2009). *"Thou shalt collaborate…": Interdisciplinary collaboration strategies in the age of BIM*. Retrieved from http://www.aecbytes.com/viewpoint/2009/issue_43.html (Sep 10 2010).

BIOGRAPHICAL SKETCH

Sergio earned a master's degree (MSBC) from the M.E. Rinker, Sr. School of Building Construction with a concentration in sustainable construction. In 2008, he graduated from the University of Florida's College of Design, Construction and Planning with a degree in architecture. During the completion of his master's degree, he worked as a BIM Coordinator for Wildwoods Incorporated (Williston, FL), where he dealt with the intricacies of healthcare construction and design.

Prior to completing his master's degree, Sergio worked for Beale and Associates (San Juan, PR) and for Exoticscape (Key Biscayne, FL). There, he developed his architectural skills, while being exposed to the design, coordination and management of several high-end residential projects. He obtained his Leadership in Environmental Energy and Design Accredited Professional (LEED AP) credential in 2009 and has been involved in residential, commercial and healthcare projects in Florida, Peru, Puerto Rico and the Bahamas.

Sergio grew up in Peru, where he developed a passion for sailing and the ocean. He has traveled around Asia, Europe, South America and the Caribbean while competing in international regattas. He is continuously learning about sustainable design and construction techniques, while working towards acquiring his contractor's license and becoming a registered architect.