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Analysis Of Factors Influencing Return On Investment (roi) For Building Information Modeling (bim) Implementation

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**ANALYSIS OF FACTORS INFLUENCING
RETURN ON INVESTMENT (ROI)
FOR BUILDING INFORMATION MODELING (BIM) IMPLEMENTATION**

by

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DISSERTATION

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DEDICATION

Dedicated to my mother, father and brother…

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Completion of this doctoral dissertation was possible with the inspiration and support of several individuals; I would like to express my sincere gratitude to all of them.

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TUGCE KULAKSIZ

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CHAPTER 1 INTRODUCTION

1.1 Introduction

Construction projects are complex because of the interaction of several components between construction processes and the challenges associated with their management. Williams (1999) states that complex project term is widely used by project managers, but what constitutes a complex project is not clearly defined, other than the understanding that a complex project is more than just a large project. The Oxford dictionary defines complex as consisting of many different and connected parts. Gidado (1996) indicates that the construction process is always composed of a collection of interacting parts and therefore this may suggest that construction projects are generally complex. According to Williams (1999), due to the rapid changes in the environment, an increase in product complexity and increase in time pressure result increase in the project complexity. Dalcher (1993) states that "contemporary project management practice is characterized by late delivery, overrun budgets, reduced functionality and questioned quality. As the complexity and scope of attempted projects increase, the ability to bring these projects to a successful completion dramatically decreases." Gidado (1996) suggests that the complexity of the construction arises from the resources involved in the process, the environment that the construction is operating in, the level of scientific knowledge required and the interaction of different components during the processes.

The capability of managing a complex project is the main factor in the overall project success in the construction industry. Remington and Pollack (2007) believe that "Managing complex projects requires approaches to management that extend beyond those traditional methods used to manage discrete, stable projects". Adding more, Williams (1999) states that the complexity of the projects are increasing and the conventional project management approaches are no longer sufficient, and new methods are required for analysis and management of projects, and these statements hold true today as well.

Information and communication technology have been evolving with new methods and tools to cope with the complexity of projects (Taxén and Lilliesköld 2008). Among recent technology advancements in the construction industry, Building Information Modeling (BIM) has been emerging as one of the most promising developments in the architecture, engineering, and construction (AEC) industries (Eastman et al., 2011). Recent developments in BIM and the evolution of virtual design and construction methodologies in the architecture, engineering, and construction industry are fundamentally changing the process by which buildings are designed and constructed (Giel and Issa 2011). BIM technology and associated processes can respond to the increasing pressure of greater complexity while reducing the cost of the building (Eastman et al., 2011). For the purpose of this study, BIM implementation is defined as selection, evaluation and improvement of the BIM technology knowledge and capability.

Despite the benefits of BIM, according to Gieland and Issa (2011) "[…] the perceived high initial cost of BIM implementation has deterred many industry professionals from adopting this technology." Therefore an appropriate investment analysis needs to be done, and the results need to be well understood during the feasibility evaluation of BIM implementation.

This study aims finding the factors influencing BIM investment by conducting a construction industry wide survey to build a framework for investment analysis and assessment of potential gains of BIM investment.

1.2 Research Objectives

It is anticipated that an improved understanding of the critical factors that influence BIM's efficacy will ultimately be useful in making better investment decisions and setting expectations for ROI. A framework explaining the effects of the factors that influence the ROI of BIM implementation could be used as a decision tool. Lastly, if a company wants to improve or change some of the specific factors influencing BIM, the expected ROI of this improvement/modification can be calculated from the model. For example, by changing the levels or categories of a factor, the firm can compare the financial benefits of different cases. Furthermore if the firm wants to improve or change one of the factors, it can calculate the expected financial benefits, the firm has an idea about the effect of target improvement/change on ROI. It is believed that this tool would be very helpful in improvement/modification decision making processes. It is important to emphasize that this approach can be applied to any new technology investment evaluation.

This study targets filling the gap in the state of knowledge by studying the effects of the factors that influence the ROI of BIM and proposing a framework which models the relationship between ROI of BIM and these factors.

The aim of this study is summarized as follows:

1. Identifying and understanding the factors that influence the ROI of BIM.
2. Assessing the relationship between the factors and ROI.
3. Developing a statistical model for ROI for BIM implementation.

1.3 Problem Statement

When BIM investment studies of Azhar (2011) and Giel et al., (2011) were examined, it could be observed that these studies had just focused on a single construction company and its specific type of projects. Consequently, ROI values resulted from these studies were not likely to be generalizable for today's construction industry because those results depended not only BIM implementation of the company but also some specific factors affecting ROI of BIM implementation. The construction industry currently did not have an industry-wide general framework showing the relationship between ROI and factors influencing ROI. Besides considering different companies and calculating their ROI of BIM, the factors which have a significant impact on ROI of BIM should also be studied.

Level of BIM adoption is different for different project types such as building projects, infrastructure projects, etc. According to McGraw Hill Smart Market Report (2012), BIM adoption and usage in infrastructure projects were behind the vertical construction projects. Therefore, the implementation level of BIM and expected benefits from BIM usage vary from the project type to project type. Consequently, the project type was studied as a key variable in this study.

The level of technology implementation depends on the project sector. Porwal and Hewage (2013) claim that implementation of new technologies depends on the sector type in the construction industry, they emphasize that the public sector lags behind the private sector in its use of new technologies. This lag due to sector type is expected to affect the potential benefits and gains that can be obtained from BIM implementation. Therefore, the project sector was selected as a key variable for this study.

Major project team members have different needs from BIM, which will influence their investment on BIM and their expectation from BIM. According to Eastman et al., (2011) owners can realize significant benefits on projects by using BIM processes and tools to streamline the delivery of higher quality and better performing buildings. For contractors, BIM implementation allows a smoother and better-planned construction process that saves time and money and reduces the potential for errors and conflicts. For designers and engineers, BIM process benefits include guaranteeing consistency across all drawings and reports, automating spatial interference checking, providing a strong base for interfacing analysis, reliable cost analysis applications and enhancing visualization, communication at all phases of the project. Therefore, project team member was considered as a key variable in this study.

Project budget is expected to have a major influence on BIM investment, according to Mollaoglu and Syal (2015) who state that despite the potential benefits, the high initial investment required in adopting BIM presents a challenge for many small size home-builders who become reluctant to adopt BIM practices. According to Mollaoglu and Syal (2015), although BIM promises greater efficiency in residential projects, it might take a while before small home-building businesses to cover expenses from the BIM implementation process and start making greater profits. The budget capability to cover BIM expenses play an important role in BIM investment and as a result project budget was included as a key variable in this study.

Zhang and Wang (2009) state that the performance of the construction industry can be improved by implementing both BIM and Integrated Project Delivery (IPD) method together. Authors also underline that the BIM implementation and IDP are complementary to each other. These statements emphasize the effect of project delivery system on BIM implementation. Also, it should be questioned, how other types of major project delivery systems affect BIM implementation. Therefore project delivery system was assessed as a key variable in this study.

Efficient information exchange and sharing between project parties are expected to influence BIM implementation success. According to the National Institute of Science and Technology (NIST) (2004) report, interoperability is defined as the ability to manage and communicate electronic product and project information between collaborating firms and within individual companies' design, construction, maintenance, and business process systems. For successful BIM implementation, seamless information exchange between project participants' systems is crucial which means interoperability is expected to be a critical factor. As a result interoperability was examined as a key variable in this study.

As BIM implementation maturity, which according to Succar (2010) is the quality, repeatability, and degree of excellence within a BIM Capability, increases the benefit of the process is expected to increase proportionally. Gilligan and Kunz (2007) state that as the intensity of BIM technology use increases and advanced users become more proficient, users will perceive increasing value and significant organizational and strategic shifts in their operations. Consequently, BIM maturity levels and their effect on ROI should be studied. BIM implementation maturity level was considered as a key variable in this study.

ROI of BIM investment is a multi-layered concept, and these layers (factors) should be considered for understanding ROI of BIM. However, when publications on ROI of BIM were reviewed, it was observed that the influence of these major factors were not evaluated at all. Therefore multiple factors influencing ROI of BIM were analyzed in this study.

1.4 Research Scope

The scope of the study was focused on studying the relationships between ROI of BIM and the factors influencing BIM implementation; namely project type, project sector, project team members, project budget, project delivery system, interoperability, and BIM implementation maturity level.

1.5 Research Approach

The research approach of this study was composed of three stages: literature review, information collection, and statistical analysis and modeling, as illustrated by the Flowchart in Figure 1. The flow chart was the roadmap of the study. The research stages of the flowchart are explained in this chapter.

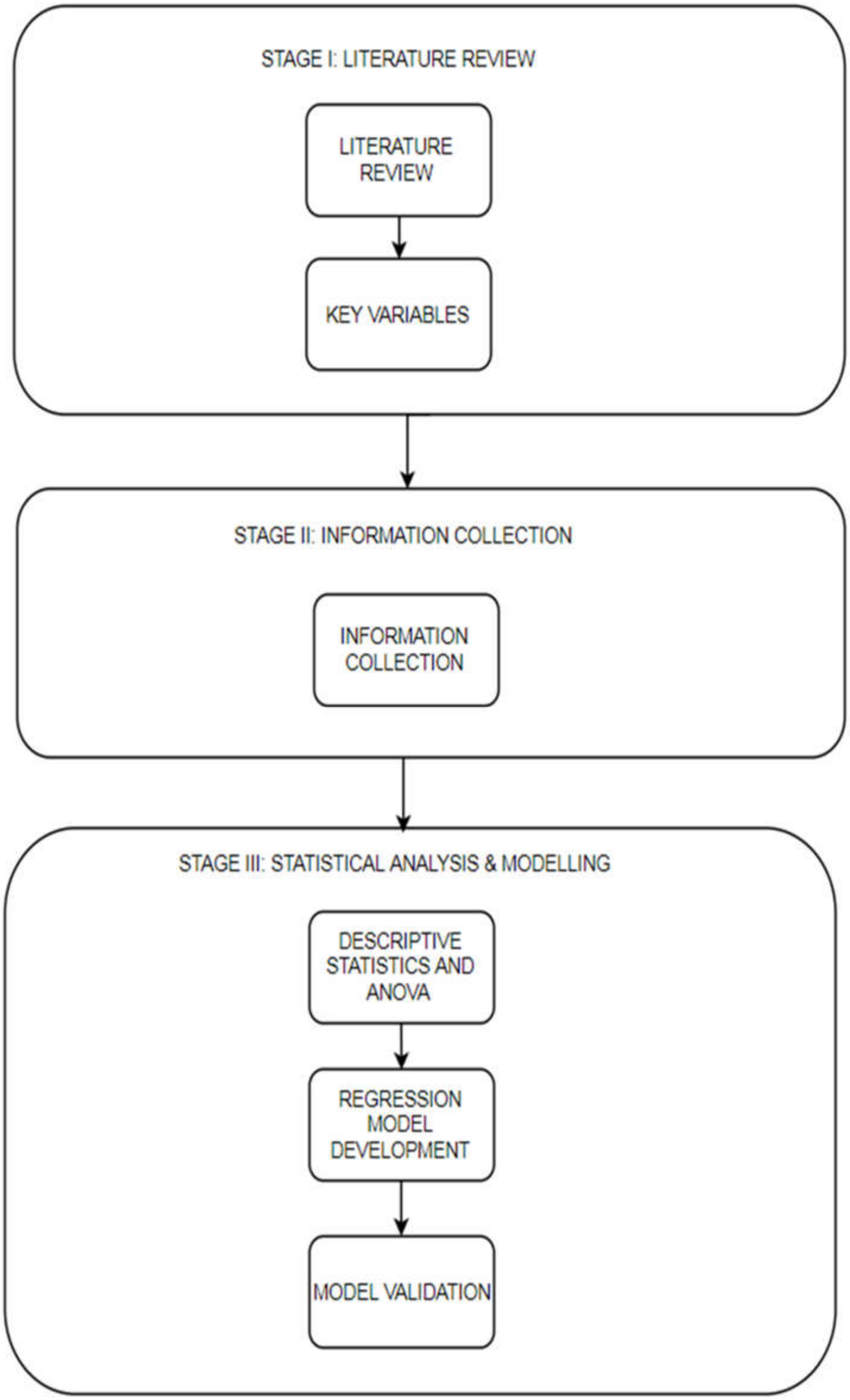

Figure 1: Research Approach

For the stage I a broad review was performed on BIM related literature and independently ROI literature. Work performed about BIM ROI had also been revised. Based on the findings noted from the literature review, the factors that could influence ROI were identified, and they were titled as key variables. While taking consideration of the key variables, dependent and independent variables were specified, and metrics of quantification of the variables were determined. After classification of variables, in stage II, a survey was prepared for information collection purpose. Survey responses were analyzed with statistical procedures to establish the relationship between dependent and independent variables. In stage III, descriptive statistical analysis was performed to understand the features of the collected information, analysis of variance was performed to study the relationship between every single independent variable and the dependent variable. A multiple linear regression model was developed to examine the relationship between the dependent and all the independent variables, a simulation model was generated from multiple linear regression model, and the developed model was validated.

CHAPTER 2 STATE OF THE ART REVIEW

The United States General Service Administration's (GSA) Office of Chief Architect defines BIM as "The development and uses of a multi-faceted computer software information model to not only document a building design but to simulate the construction and operation of a new capital facility or a recapitalized (modernized) facility. The resulting Building Information Model is an object-based, intelligent and parametric digital representation of the facility, from which views appropriate to various users' needs can be extracted and analyzed to generate feedback and improvement of the facility design (Perkins, 2007)." According to Holness (2006), the main aim of BIM is to generate a common database of intelligent information which can be used by all project team members throughout the building's lifecycle.

Succar (2009) defines BIM as interrelated procedures, methods, and technologies that are used to manage the building design and project information in digital format throughout the building's life-cycle. According to the National Building Information Modeling Standard (NBIMS) Committee of the National Institute of Building Sciences (NIBS) Facility Information Council (FIC), BIM is an upgraded design, construction, operation, planning process that includes all necessary information that are formed and collected about the building that can be used by all the project participants throughout the project's lifecycle.

Eastman et al., (2011) claims that the created virtual models allow more successful analysis and control when compared to the traditional processes. According to Bazjanac (2006), BIM is a model of projects that includes interdisciplinary information related to a specific building. Azhar (2011) claims that the BIM model contains information related to the geometry, spatial relationships, geographic information, quantities and properties of building elements, cost estimates, material inventories, and project schedule. Carmona and Irwin (2007) state that BIM is a virtual process that includes all disciplines and systems of a building which enables all the members of the project such as designer, engineer, contractor and owner to cooperate and collaborate more efficiently than the conventional methods. For the purpose of this study, design firm represents designers, architects and design engineers.

Additionally, they state that as the model is being built, the members of the project start continually refining and modifying their discipline designs according to the owner requirements, design purpose, and system compatibility to make sure that the project is as precise as possible before the project construction starts.

BIM implementation has many benefits throughout the building design and construction processes. During the preconstruction stage, BIM helps with the analysis for determining whether a building with the desired size and level of quality can be constructed within given constraints of time and budget. The creation of a schematic model before the detailed design model would be helpful for model assessment to understand if the model meets the intended functional, sustainability requirements while maintaining the desired level of quality.

During the design stage, 2D views are automatically generated from the model, and related drawings can be obtained from the specified views of the project. Automatically generated drawings decrease the time required to generate these drawings and also decreases the errors related to generating the design and construction drawings for all project disciplines. When a change is entered in one element of the model, all related drawings are automatically updated, and modified drawings can be obtained immediately. (Eastman et al., 2011). Holness (2008) states that BIM technology increases the collaboration between project participants and adds that BIM implementation allows project team members to understand the project better. BIM implementation enables synchronous progress with different design disciplines. As the design develops, more detailed information will be available which can be used for building more detailed and accurate design. The more accurate design enables detailed and reliable cost estimates, and BIM enables linking the model to different types of analysis tools which help further improvement of design accuracy and quality.

During the construction stage, clash detection will be automatically performed for cross-system updates. Additionally, design changes can be processed more quickly in BIM system because all changes can be electronically shared, presented and resolved when compared to traditional paper-based systems. When a 3D model is built, this model will be the source of all 2D drawings, and because all drawings originate from the same single source, design errors related to inconsistent drawings will be eliminated. Since 3D model includes all disciplines of the project, analysis of multisystem interfaces can be done systematically and visually (Eastman et al., 2011). Another advantage of BIM is that, before construction starts the design errors, conflicts and constructability problems can be identified and resolved. As the coordination among project team members and project constructability increase, the errors of omission are noticeably reduced which improves the efficiency of the construction processes, shortens the duration of processes, and reduces cost (Eastman et al., 2011). BIM improves the coordination between the contractor and subcontractors which will increase the success and efficiency of the work performed at the site. This efficiency will reduce the time and material waste during construction (Eastman et al., 2011). The building model provides accurate quantities for all materials and elements of the project. These accurate quantities increase the efficiency of procurements from suppliers, vendors, and subcontractors (Eastman et al., 2011).

The introduction of BIM can be dated back to 1970s. Extensive research and development studies were conducted between the late 1970s and early 1980s in Europe. In 1980s Building Information Modelling was named as Building Product Models in the USA and Product Information Models in Europe. The important step was to take out the duplicated product term and combine the two remaining terms so that the Building Product Model + Product Information Model merged into Building Information Model. Although these development studies are dated back to the late 1970s, BIM gained significant progress in the construction industry in the 2000s.

Adaptation to this new technology however has been relatively slow. The process started by manual hand drafting and followed by Computer Aided Drafting (CAD) in the 1970s and 1980s (Eastman et al. 2008). Currently 2D technology forms the core of most CAD applications and the technology is composed of graphic entities which are unable to embed additional information about the building (Tse, Wong and Wong, 2005). The CAD technology evolved to three-dimensional (3D) modelling in the mid-1990s. Nowadays, more and more design and construction firms have started implementing BIM into their operations. Although BIM utilization is constantly growing, the factors affecting the decision to use it have not fully understood.

Despite the benefits of BIM, according to Gieland and Issa (2011) "[…] the perceived high initial cost of BIM implementation has deterred many industry professionals from adopting this technology." Therefore an appropriate investment analysis needs to be done, and the results need to be well understood during the feasibility evaluation of BIM implementation.

According to Schachner (1986), Return on Investment (ROI) is a yardstick that enables both the financial executive and the financial analyst to get a quick insight into the profitability of an existing or future investment. It compares the gains anticipated from an investment against the cost of the investment (Autodesk 2007). According to Feibel (2003), ROI is a measure of investment profitability, not a measure of investment size. It gives the ratio of percent return on the amount of capital expenditure. It can be defined as the ratio of the net benefits produced by an investment divided by the cost of the investment and then multiplying the ratio with 100. ROI can be calculated using Equation 1 (Feibel 2003):

$$\text{ROI} = \frac{\text{Gain from Investment} - \text{Cost of Investment}}{\text{Cost of Investment}} \text{ x } 100 \qquad \text{(Eq.1)}$$

A proposal to make an investment in a new plant or buy a company should be tested by ROI (Schachner 1973).BIM has not yet been fully utilized in the construction industry. Gilligan and Kunz (2007) performed a study through the Center for Integrated Facility Engineering (CIFE) on BIM implementation within the Architecture, Engineering, and Construction (AEC) industry. The authors pointed out that BIM technology was not widely used in large projects. Holness (2006) performed a research study on the benefits of BIM technology and mentioned that the construction industry has been slow to implement BIM technology when compared with other industries such as automotive, aircraft, petrochemical, etc. Moreover, Gilligan and Kunz (2007) point out that BIM implementation is increasing as users find more value from the implementation of BIM technology.

Past researches has focused on the benefits of BIM. Since this study is related to the ROI of BIM, the studies related to cost analysis of BIM implementation are the main focus of this chapter. Azhar, Hein, and Sketo (2008) performed a case study of Hilton Aquarium project in Atlanta and they specified the cost and time savings realized by BIM implementation. They assigned an estimated cost saving for each resolved overhead clash.

Azhar, Hein, and Sketo (2008) concluded that an additional $200,392 saving could be obtained with BIM implementation when compared to the traditional approach. Giel and Issa (2011) performed an analysis of four different projects' case studies done by the same company. Two of the projects were implemented with BIM, and the other two were not. They compared similar type of BIM implemented and non-BIM implemented projects, according to the number of change orders, request for information, and schedule delays. It was concluded that with BIM implementation there was a reduction in the number of request for information (RFI), change orders and schedule delays.

Holness (2006) claimed that potential savings from using BIM in the construction industry was expected to be between 15% and 40% of the total construction cost. Further, the author stated that for large industrial projects which have budget between $75 million and $150 million, BIM implementation cost was found out to be between 0.25% and 0.5%

of total construction cost. BIM cost percentage to total construction costs were expected to changes as project type and project size changed.

According to Kumar (2008), interoperability is the exchange of information among software tools, which eliminates the need for duplicate information entry and allows the flow of changes between the software tools. The National Institute of Science and Technology (NIST) (2004) performed a cost analysis of inadequate interoperability in the US capital facilities industry and pointed out that construction industry had not used information technologies effective enough, and that there was still a widespread usage of paper based systems for information exchange between project participants. According to the study, inadequate interoperability increased the cost burden of the construction industry. It was reported that $15.8 billion in annual interoperability cost burden occurred for the capital facilities industry in 2002. Grilo, and Jardim-Goncalves (2010) emphasized that the interoperability factor is critical for achieving success with BIM implementation.

Barlish and Sullivan (2012) worked on three project case studies and they claimed that using BIM in the construction of semiconductor manufacturing facilities is beneficial. In each study, they compared Non-BIM projects and BIM projects in terms of the number of request for information (RFI), project duration, and the number of change orders.

It can be observed that, the past studies have either focused on the financial benefits or investment analysis of BIM for a single construction company and its specific type of projects and these results may not be generalizable to construction industry. Because these analyses results hold true for the given company with its specific conditions. The specific conditions composed of factors such as the kind of project types that the company was working with, the company’s BIM experience level, the project delivery system the company is working with, etc. The construction industry needs a framework that is considering the factors influencing BIM investment and their potential effects on the BIM investment. To fill this gap, a return on investment framework including the factors that influencing it was the scope of this study.

CHAPTER 3 METHODOLOGY

The stages of the research methodology were presented in this chapter. The research variables were presented first. Secondly, information collection techniques were explained. Then, research hypotheses were formulated based on these variables. Finally, statistical analysis and modeling methodologies were discussed.

1.1Research Variables

The research variables were the factors influencing ROI, and they were the building blocks of this research. These factors were studied to determine their effect on ROI of BIM. Each factor are discussed briefly in the following sections.

3.1.1 Project Type

According to Construction (2014), BIM is being implemented on a variety of project types all over the world, not only in buildings but also infrastructure, industrial projects. Construction (2014) classifies building types into two categories namely building and non-building where building projects composed of commercial, institutional, government and residential projects and non-building projects are infrastructure, industrial, energy, mining and natural resources. In this study the project type factor was studied in two categories as well; namely building projects and non-building projects. Building project type included residential, commercial, industrial projects and non-building project type included infrastructure projects.

3.1.2 Project Sector

This study investigated the project sector factor under two categories, which were the public and private sector. Kassel (2016) defines public projects as a temporary endeavor, undertaken, managed, or overseen by one or more publicly funded organizations to create a unique product of public value. The Oxford dictionary defines the private sector as the part of the national economy that is not under direct state control. Porwal and Hewage (2013) claim that implementation of new technologies also depends on the sector type in the construction industry and they emphasize that public sector lags behind the private sector in its use of the new technologies. In this study, it was expected that private projects to have higher BIM return on investment when compared to public projects.

3.1.3 Project Team Member

According to Rsmeans construction dictionary (2013), the owner is defined as the entity owning the project, and that is also party to the owner-contractor and owner-designer agreements. The contractor is defined as constructor who is acting under the terms of a contract for construction and the entity managing the construction process. When architect and engineer definitions are combined, they are the entity responsible for preparing project plans, specifications, construction documents, project design, project development and engineering of the project disciplines. In this study, the project team member factor will be studied in three categories as owner, contractor, and design firms. It was expected that owner's BIM return on investment to be higher than other categories because the owner would benefit from both design and construction cost savings whereas design firms would save on design phase and contractors would save on construction phase.

3.1.4 Project Budget

The project budget is an important decision factor for BIM implementation. According to Autodesk (2018), BIM benefits have larger shifts with large project teams on complicated projects. In this study it was expected that the project with a larger budget (larger projects) would have higher ROI on BIM implementation because, the number of design errors, RFIs, and RFCs were expected to be higher in those projects. Thus BIM could provide solutions to a large number of problems, which in turn would lead to more savings. Lastly as stated before, the budget capability to cover BIM investment costs plays an important role in BIM investment as well. Project budget factor was studied in six budget range categories as listed below:

- Less than $500K
- +$500K - $2M
- +$2M - $5M
- +$5M - $10M
- +$10M - $25M
- More than $25M

3.1.5 Project Delivery System

The selected project delivery system impacts all phases of the project and the efficiency of project phases, which in turn is expected to have an important influence on BIM implementation. The project delivery type also has an impact on the collaboration of project participants which in turn affects the success of BIM implementation. For example, the integrated project delivery system is expected to provide more opportunities with BIM implementation when compared to the design-bid-build project delivery system because of early coordination and collaboration of project participants. The project delivery systems' collaboration with BIM utilization will impact the financial outcome of BIM implementation. According to Oyetunji and Anderson (2006), project delivery systems define the roles and responsibilities of the parties involved in a project. They also establish an execution framework regarding the sequencing of design, procurement, and construction. The Construction Management Association of America (2012) claims that construction management at risk, design-build, and design-bid-build are three principal project delivery systems.

Hale, Shrestha, Gibson and Migliaccio (2009) state that design-bid-build is a project delivery method which owner, design firms sign agreements which provides design services based on owner requirements. The design firm provides project plans and specifications for the project construction. Owner uses these documents to make a separate contract with a construction company. The most common implementation of this approach is, different construction companies bid for the project and the construction company offering the lowest bid will be awarded the contract. The awarded construction company will build the project based on project plans and specifications. Asmar (2012) states that under design-bid-build, the owner contracts with the designers, and then when their design is 100% complete, the owner would contract separately with a general contractor to build the facility. According to Hale et al., (2009) design-build is a project delivery method in which the owner sets project specific requirements and awards a contract to one company which will both design and construct the project. There will be one contract between the selected company and the owner. According to Asmar (2012) in design-build delivery method, the contractor generally would be involved when the design is around 20% complete (the portion of design complete varies based on the project at hand), and the designer and general contractor would join forces, therefore providing a single point of responsibility for the owner. While carrying interviews, it was observed that many respondents had difficulty in selecting between design-bid-build or design-build. Some respondents claimed that they use the two delivery system very frequently, they were not able to make a healthy selection, but they could say one over another which may not be reflecting the reality. Also, some of the respondents selected both delivery systems thus design-bid-build and design-build were treated as one single category together.

Huang (2011) defines construction management at risk as a project delivery method that is created to provide input to the designer to increase constructability of designs and to decrease schedule duration through the overlapping of the design and construction phases. According to Construction Management Association of America (2012), construction manager at risk holds the risk of the construction performance and provides advisory professional management assistance to the owner before construction, offering schedule, and budget and constructability advice during the project planning and design phases.

Zhang and Wang (2009) state that BIM, as a digital model, is the most powerful tool supporting integrated project delivery. Because BIM has all project relevant information in one database, and it provides a platform for collaboration throughout the project's design and construction. According to Eastman et al., (2011), one of the most important aspects of IDP is that early involvement of the contractor in construction projects. The traditional design-bid-build approach limits the contractor's ability to contribute their knowledge to the project during the design phase. IDP requires that the designer, general contractor, and key trade contractors work together from the start of a project, which makes the best use of BIM as a collaborative tool. According to Asmar (2012), Integrated Project Delivery is an emerging construction project delivery system that collaboratively involves key participants very early in the project timeline, often before the design is started. Glick and Guggemos (2009) defined Integrated Project Delivery as a novel approach which integrates systems, business structures, and practices into a collaborative process which reduce waste and optimize efficiency.

In this study, the project delivery system factor was studied in three main categories; namely design-bid-build and design-build, construction management at risk and integrated project delivery systems. It was expected that IDP projects to have higher BIM return on investment when compared to other project delivery systems.

3.1.6 Interoperability

Interoperability enables project participants to share, exchange and manage electronic information seamlessly where parties can identify and access information whenever required and integrate information across different systems. This capability implies that information required will be entered to the system once, and after that this information will be accessible to all project team members as needed NIST (2004). In this study, the interoperability factor was composed of three categories to measure the interoperability levels; namely low, medium and high.

In this study the frequency of the below three cases determined the level of interoperability:

How often do the project teams manually re-enter project data from other project parties' applications to their own company applications because of incompatibility between systems?

How often do the project teams spend a considerable amount of time to check that they are working with the correct version of documents, drawings, plans, revisions, etc. because of software incompatibility issues or poor coordination?

How often do the project teams have rework issues due to using the incorrect version of the project document, plans, drawings, revisions, etc.?

If the frequency answer was always, it had 0 point for each answer; if the frequency was sometimes, it had 1 point for each answer; if the frequency was never it had 2 points for each answer. Then the answer points of the three questions were summed up, and if the total point sum was less than or equal to 2, it corresponded to low interoperability, if the total sum were either 3 or 4 it referred to medium interoperability and if the total sum were 5 or 6 it denoted high interoperability.

3.1.7 BIM Implementation Maturity Levels

BIM can be implemented in different levels by various companies according to their needs, backgrounds, capabilities and experiences. According to Succar (2009), BIM implementation maturity can be defined in three levels; namely Level 1, Level 2, and Level 3. Level 1 refers to the migration from 2D to 3D and object-based modeling. The BIM model is made of real architectural elements that are represented correctly in all views. Level 2 progresses from 3D modeling to collaboration and interoperability. Designing and managing a building is a highly complex process that requires smooth communication and collaboration among all members of the project team. Level 2 maturity requires integrated information communication and sharing between the project team members to support this collaborative approach. Level 3 is the transition from collaboration to integration, and it reflects the real underlying BIM philosophy. At this stage, project players interact in real time to generate real benefits from increasingly virtual workflows. BIM Level 3 models allow complex analyses at early stages of virtual design and construction. Khosrowshahi and Arayici (2012) added a pre-BIM status (referring to Level 0) additional to Succar's maturity levels which represent the traditional construction practice that does not implement BIM. Khosrowshahi and Arayici (2012) claim that Level 0 embraces significant barriers and inefficiencies such as storing project information on paper-based systems. The paper-based system approach is frequently unstructured and difficult to use, and project information can be easily lost or damaged. Poor information management processes lead to an incomplete understanding of the planned construction, functional inefficiencies, inaccurate initial work or clashes between components.

Furthermore, lessons learned are not well organized well and may be buried in details. It is therefore difficult to compile and disseminate useful knowledge and best practice for other projects. In this study, the BIM maturity level factor was composed of Level 0, Level 1, Level2 and Level 3 categories. It was hypothesized that higher BIM maturity levels to result better BIM return on investment.

3.1.8 Return on Investment (ROI)

Phillips and Phillips (2006) state that ROI is the ultimate measure of accountability which finds the answer to the question: Is there a financial return for a certain investment? It is an economic tool which compares earnings to investment. ROI has been used in business for centuries to measure the success of a variety of investment opportunities.

ROI of 100% means that for every $1 invested, it returns $1 back after the costs are covered.

In this study, ROI was composed of five categories. The first category was low ROI having a negative ROI value and interpreted as BIM ROI had a negative impact, at best no positive impact. The second category was medium-low ROI having a value greater than or equal to 1% and less than 25% which was interpreted as BIM ROI had some positive experience. The third category was medium ROI having a value greater than or equal to 25% and less than 50% which were interpreted as satisfaction with BIM experience was obtained and there was still room to grow. The fourth category was medium-high ROI having a value greater than or equal to 50% and less than 75% which was interpreted as a reasonable degree of satisfaction with BIM experience was obtained and there were opportunities to get better. The fifth category was high ROI having a value greater than or equal to 75% and interpreted as positive impact and a high degree of satisfaction with BIM experience was achieved. All research variables are presented in Table 1.

Variables	Values of Variables
Project Type	Building Non-Building
Project Sector	Public Sector Private Sector
Project Team Member	Owner Design and Engineering Firm General Contractor
Project Budget	Less than $500K +$500K - $2M +$2M - $5M +$5M - $10M +$10M - $25M More than $25M
Project Delivery System	Design-Bid-Build Design-Build Construction Management at Risk Integrated Project Delivery
Interoperability	Low Medium High
BIM Maturity Level	Level 0 Level 1 Level 2 Level 3
Return on Investment (ROI)	Low Medium-Low Medium Medium-High High

Table 1: Research Variables

3.2 Research Hypotheses

Research questions are listed as below:

1. Is there a relationship between project type and ROI of BIM?
2. Is there a relationship between project sector and ROI of BIM?
3. Is there a relationship between team member category and ROI of BIM?
4. Is there a relationship between project budget and ROI of BIM?
5. Is there a relationship between project delivery method and ROI of BIM?
6. Is there a relationship between BIM maturity level and ROI of BIM?
7. Is there a relationship between interoperability and ROI of BIM?

Research Hypotheses of this study are presented in Table 2.

Null Hypothesis	H_{01}: $\beta_1 = 0$. There is no statistically significant relationship between project type and ROI of BIM.
Alternative Hypothesis	H_{A1}: $\beta_1 \neq 0$. There is a statistically significant relationship between project type and ROI of BIM.
Null Hypothesis	H_{02}: $\beta_2 = 0$. There is no statistically significant relationship between project sector and ROI of BIM.
Alternative Hypothesis	H_{A2}: $\beta_2 \neq 0$. There is a statistically significant relationship between project sector and ROI of BIM.
Null Hypothesis	H_{03}: $\beta_3 = 0$. There is no statistically significant relationship between team member category and ROI of BIM.
Alternative Hypothesis	H_{A3}: $\beta_3 \neq 0$. There is a statistically significant relationship between team member category and ROI of BIM.
Null Hypothesis	H_{04}: $\beta_4 = 0$. There is no statistically significant relationship between project budget and ROI of BIM.
Alternative Hypothesis	H_{A4}: $\beta_4 \neq 0$. There is a statistically significant relationship between project budget and ROI of BIM.
Null Hypothesis	H_{05}: $\beta_5 = 0$. There is no statistically significant relationship between project delivery method and ROI of BIM.
Alternative Hypothesis	H_{A5}: $\beta_5 \neq 0$. There is a statistically significant relationship between project delivery method and ROI of BIM.
Null Hypothesis	H_{06}: $\beta_6 = 0$. There is no statistically significant relationship between BIM maturity level and ROI of BIM.
Alternative Hypothesis	H_{A6}: $\beta_6 \neq 0$. There is a statistically significant relationship between BIM maturity level and ROI of BIM.
Null Hypothesis	H_{07}: $\beta_7 = 0$. There is no statistically significant relationship between interoperability and ROI of BIM.
Alternative Hypothesis	H_{A7}: $\beta_7 \neq 0$. There is a statistically significant relationship between interoperability and ROI of BIM.

Table 2: Research Hypotheses

3.3 Information Collection Techniques

This chapter presents the information collection techniques of this study.

3.3.1 Survey Development

A survey instrument was developed for data collection. After developing the survey, the survey was reviewed with Wayne State University Center for Urban Studies survey research group.

The aim of the review was to address the following questions:

1. Are the survey questions consistent with the research objectives?
2. Do the questions provide measurable outcomes?
3. Are the questions sufficiently clear?

The survey was revised based on the feedback obtained from these reviews, and the revised survey was pilot tested on a small group to make sure the survey was serving its designed purpose. The survey aimed to take responses from management roles of the companies who had the financial perspective for the BIM investment analysis questions. Since the survey aimed input from managerial level professionals which were hard to reach and the length of time that they would agree to be surveyed was limited, the survey was designed as less response time consuming as possible. The target survey response time was 5 to 6 minutes and during the pilot study it was confirmed that, the response times were within this range. After finalizing the survey development, the survey was distributed to leading construction, design firms which were believed to have experience with BIM. After the survey responses were gathered, the data collection phase was completed.

3.3.2 Survey Delivery

The questionnaire was prepared in electronic format, and the survey link delivered through the internet. The survey link was shared in Associated General Contractors Michigan Construction Leadership Council and in LinkedIn professional groups namely Construction Owners Association of America – COAA, Construction Users Roundtable, The BIM Roundtable, BIM Experts, Revit users, BIM Architecture & Digital Design, Group for Building Information Modeling, Emirates BIM User Group, International BIM Consultants, BIM for Infrastructure, Construction Operations Building Information Exchange (COBie), BIM Journal, RICS Digital Construction (incorporating BIM), BIM Middle East Community, Construction IT Alliance (CITA) BIM Group, ! Contractor for BIM, Doha BIM Users Group, BIM & the AEC Profession, Club Revit – Revit MEP, BIM and Architecture, Engineering & Construction, and Club Revit – Revit Structure. Professionals implementing BIM or working on companies that implement BIM were searched from internet. Then phone calls were performed to the BIM implementing companies to reach out target professionals. Follow up emails, and telephone reminders were used. Also a snowball sampling strategy was used which aimed to pass the survey questions to related professionals through the main contact persons within the target organizations. The survey data was collected from May 3, 2018 to June 1, 2018 and a total of 182 responses were obtained in return. It was difficult to establish a response rate because of snowball sampling strategy.

3.4 Statistical Analysis and Modeling

In the statistical analysis and modeling section, descriptive statistical analyses were performed to understand the features of the collected data, and analysis of variance (ANOVA) was performed to study the relationship between each single independent variable and the dependent variable. A regression model was then developed to examine the relationship between the dependent and all the independent variables. Then a simulation effort was performed to draw conclusions based on broader information about the study. A final multiple linear regression analysis was developed to examine the relationships between the simulated variables. Lastly the developed model was validated.

3.4.1 Variable Measurement Metrics

Variable types and the measurement metrics of the variables were determined to categorize each variable, before performing any statistical analysis. According to Chatterjee and Simonoff (2013), the target variable that the researcher is interested in understanding and modeling is called the dependent variable. A set of variables that the researcher thinks might be useful in predicting or modeling the dependent variable are called independent variables. In this study, the aim was to understand and model the dependent variable ROI with the help of the identified independent variables. According to Gravetter and Wallnau (2016) the nominal scale includes set of categories that have different names and does not make any quantitative difference between observations. The ordinal scale consists of a set of categories that are listed in an ordered sequence (Gravetter and Wallnau, 2016). Based on these definitions, the variables ROI, project budget, BIM maturity levels and interoperability were ordinal variables because their categories were organized in an ordered sequence. The variables project type, project sector, team member type and project delivery system were nominal variables because they were consisting of categories which did not have any quantitative distinction in between. Variable and measurement types of the variables are presented in Table 3.

Variables	Variable Type	Measurement Types
Project Type	Independent	Nominal
Project Sector	Independent	Nominal
Project Team Member	Independent	Nominal
Project Budget	Independent	Ordinal
Project Delivery System	Independent	Nominal
Interoperability	Independent	Ordinal
BIM Maturity Level	Independent	Ordinal
Return on Investment (ROI)	Dependent	Ordinal

Table 3: Variable and Measurement Types

3.4.2 Data Screening

Trustworthiness of survey responses differs in the respondents' levels of attention and effort when responding to questions. Researchers may use to identify the responses which fail to increase the rigor of analysis and enhance the trustworthiness of study results. (DeSimone, Harms and DeSimone, 2015) To increase the reliability of the survey results, a data screening process was applied to eliminate the responses that were not coming from target respondents, that fail to provide consistent answers and that contain irrelevant answers to questions.

The total number of responses obtained from the survey was 182. To analyze the factors influencing the ROI of BIM, the responses had to be received from companies that implemented BIM on their projects. To eliminate the non-BIM user which were non-target responses, a screening question was asked in the beginning of the survey. The questions asked if the respondent's company implemented BIM on their projects. The responses that answered as No to this question were eliminated.

Cross-check questions were added to the survey to maintain the quality and consistency of survey responses. Those items were used to check the consistency of answers within a response. Some of the responses claimed that they adopted BM in the first question but, on question 9 they also claimed that BIM was not implemented on their project, which resulted contradiction between two answers. The answers having contradicting responses were eliminated. When the questions sought for a single option but the response had more than one option to the questions and/or typing multiple options to “Other (please specify)” section were eliminated.

Also the answers that were written to the “Other (please specify)” sections that were not relevant to questions were eliminated. Questions requiring information about the dependent and independent variables were the main questions of the survey. Responses including blank answers to main questions were eliminated. After all these eliminations, the final response number was reduced to 137.

3.4.3 Descriptive Statistical Analysis

According to Welkowitz et al. (2011), descriptive statistics provide the understanding of the characteristics of the collected information. Gravetter and Wallnau (2016) state that, descriptive statistics include the techniques that take the raw information and organize them into more manageable formats and representations. By performing the descriptive statistical analysis, each variable was studied in detail for basic statistical information. The analysis information are presented in frequency tables and percent frequency distribution graphs.

3.4.4 Analysis of Variance (ANOVA)

One-way ANOVA is a hypothesis testing technique which is used to assess the mean differences between two or more groups. In this study for ANOVA terminology the individual classes that make up a variable is called the categories of the variable. For example, Interoperability is the variable; low, medium, high are the categories of interoperability, as presented in Figure 2.

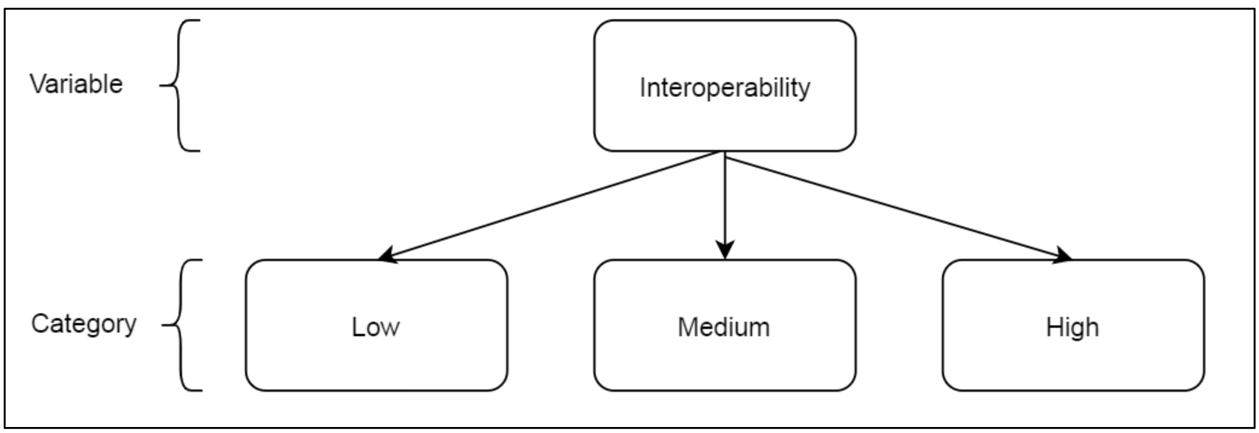

Figure 2: ANOVA Variable and Category Relationship Example

ANOVA evaluates the mean differences between categories to decide if the mean differences are statistically significant in explaining the variances in the dependent variable. In this study, to determine the influence of every single independent variable on the dependent variable, one Way ANOVA was performed. In the ANOVA approach the null hypothesis state that all the category means are equal and the alternative hypothesis states that at least there is one difference among category means. If the difference between group means is statistically significant, the p-value associated with the ANOVA will be less than the specified significance level (Weiss, 2006). In this study, the significance level was equal to 0.05. If the p-value was less than 0.05, the null hypothesis was rejected. It designated that somewhere among the entire set of mean differences there was at least one mean which was statistically significant.

3.4.5 Post Hoc Test

As stated in section 3.4.4, rejection of the null hypothesis means that there is at least one statistically significant mean difference among the set of mean differences, but this result does not show exactly which means are significant and which are not. When the independent variable has two categories, and if the ANOVA p-value of the two variables is less than 0.05 it means there is a statistically significant difference between the two means. But as the number of categories increases it is difficult to distinguish which category means have statistically significant difference from other category means. Post Hoc tests are additional hypothesis tests that designate the important mean differences (Gravetter and Wallnau, 2016). In this study, for independent variables having more than two categories, an additional Post Hoc test was conducted.

3.4.6 Multiple Linear Regression

In this study, to understand the relationships between dependent and all independent variables a multiple linear regression analysis was performed.

According to Rhemtulla et al. (2012), an ordinal dependent variable can be treated as continuous when the number of dependent variable's categories are five or higher. Since in this study the dependent variable ROI was ordinal variable having five categories that were organized in an ordered sequence, the dependent variable was treated as continuous. Meanwhile, the dependent variable was continuous, and the number of independent variables were more than one, multiple linear regression analysis was used in this study.

Multiple linear regression determines the relationship between the continuous dependent variable (y) and more than one independent variables ($x_1, x_2, \cdot\cdot\cdot, x_k$) and predicts the dependent variable according to the generated mathematical model. A general form of a multiple linear regression model is given by Equation 2 (Chatterjee and Simonoff, 2013).

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k + \varepsilon \qquad \text{(Eq.2)}$$

Where y is the dependent variable, β_0 is a constant, and β_1 through β_k are the regression coefficients, which characterize each independent variable's effect on the dependent variable. X_1 through X_k are the independent variables. The ε symbol indicates the error term, and it is the difference between the observed value of the dependent variable (y) and the predicted value of the dependent variable ($\hat{y}$). In multiple linear regression, the error terms are normally distributed, and the expected value of the error term is zero. Thus the error term drops from Equation 1 and the final multiple linear regression model is given by Equation 3 (Chatterjee and Simonoff, 2013).

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k \qquad \text{(Eq.3)}$$

3.4.7 Simulation and Resampling

During the evaluation of the survey data, the researcher needs to understand how the results would change if the same survey was given to another sample of respondents and after that to another sample of respondents. Taking responses from different samples introduces the concept of repeated samples. Repeated samples is an important concept because the researchers are generally interested in inference and the researchers do not want to make this inference using the one sample of data. Instead, the researcher wants to generalize the patterns observed from the sample data to all of the observations that could have been in the sample. In other words, the researcher wants to infer conclusions about the larger population from which the repeated samples are taken from. With limited resources, the same survey cannot be administered many times to different samples and simulation solves this issue. “Simulation allows analysts to easily create many samples of data in a computing environment, then assess patterns that appear across those repeated samples." (Carseyand Harden, 2013)

Resampling simulation draws multiple simulated samples from the researcher’s actual sample of data. According to Casey and Harden (2013), ordinary least squares (OLS) can be used for simulation. OLS assumes that the dependent variable is a linear function of independent variables where the relationship is represented by parameters labeled βs and some random stochastic factor which is labeled as ε. (Carsey and Harden, 2013)

In this study, after the generation of the multiple linear regression model from the survey sample, the model were used to generate simulated data to infer conclusions about the population.

The initial multiple linear regression model was created from the main data which was composed of 137 cases. The independent variables of the main data were selected individually and after selecting all of the independent variables, the variables were analyzed using the initial multiple linear regression model to predict the simulated dependent variable ROI.

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k \quad \text{(Eq.3)}$$

This process was repeated 100,000 times and these simulated cases were analyzed with IBM Statistical Package for the Social Sciences (SPSS) Statistics version 25.

3.4.8 Model Validation

When developing a predictive model, there is a risk of modeling the noise in the given data rather than modeling the relationship between the dependent and independent variables. Cross-validation technique is very helpful in ensuring if the model is reflecting the true relationship between the dependent and independent variables. For cross-validation, the data is divided into two sample subsets. The first portion of the data is used to build the model which is referred to as the training set and the second data which is held out referred to as the validation set. The model is built using the training data, and then the model is applied to the validation data to monitor how well it performs in the given model. (Grayson, Gardner and Stephens, 2015) In this study, cross-validation was performed by randomly splitting the data in a 50% - 50% ratio using the Statistical Package for the Social Sciences (SPSS) software.

CHAPTER 4 RESULTS AND DISCUSSION

This chapter presents the results of the data collected in this study.

4.1 Responses to Survey Questions

In this section, responses to survey questions are presented.

4.1.1 Question 1

The first question of the survey was: Do you implement BIM technology in your projects? The response options were:

- Yes
- No

A total of 181 respondents answered the question, and one respondent skipped the question. Among the remaining 175 respondents answered the question as Yes, and the other 6 respondents answered the question as No. The responses to question 1 are presented in Table 4 and Figure 3.

ANSWER CHOICES	RESPONSES	PERCENT
YES	175	96.69%
NO	6	3.31%
TOTAL	181	

Table 4: Responses to Question-1

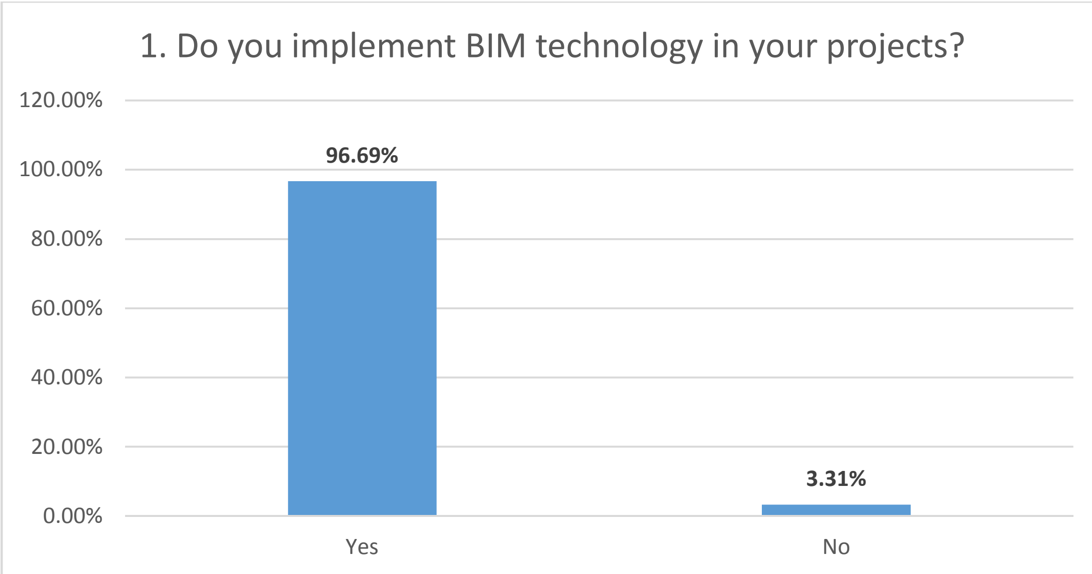

Figure 3: Responses to Question-1

4.1.2 Question 2

The second question of the survey was: Please select the project type that you generally do the most? The response options were:

- Building (residential, commercial, industrial)
- Non-building (infrastructure)

All of the respondents answered the question. In total 170 respondents selected Building (residential, commercial, industrial) option and the remaining 18 respondents selected Non-building option and a small number of respondents (6) of the respondents selected both options. Responses for question 2 are presented in Table 5 and Figure 4.

ANSWER CHOICES	RESPONSES	PERCENT
Building	170	93.41%
Non-Building	18	9.89%
TOTAL	182	

Table 5: Responses to Question-2

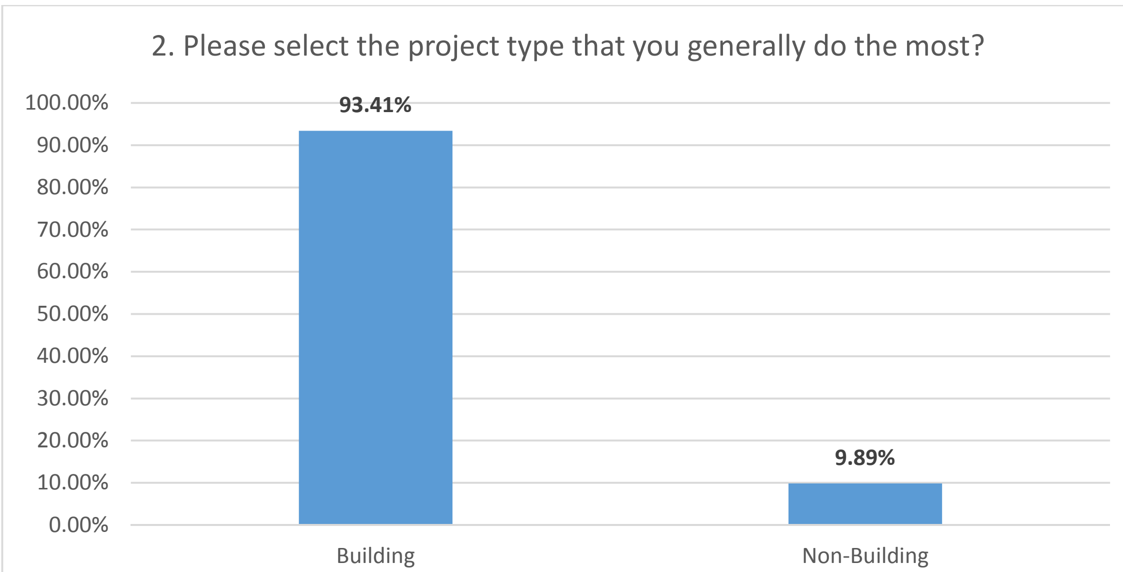

Figure 4: Responses to Question-2

4.1.3 Question 3

The third question of the survey was: Please select the sector type that you generally operate in most? The response options were:

- Public
- Private

All of the respondents answered this question. There was an even split between the two options; 96 respondents selected Public option and the remaining 100 responded to

Private option. The remaining 13 respondents selected both options. The responses to question 3 are presented in Table 6 and Figure 5.

ANSWER CHOICES	RESPONSES	PERCENT
Public	95	52.20%
Private	100	54.95%
TOTAL	182	

Table 6: Responses to Question-3

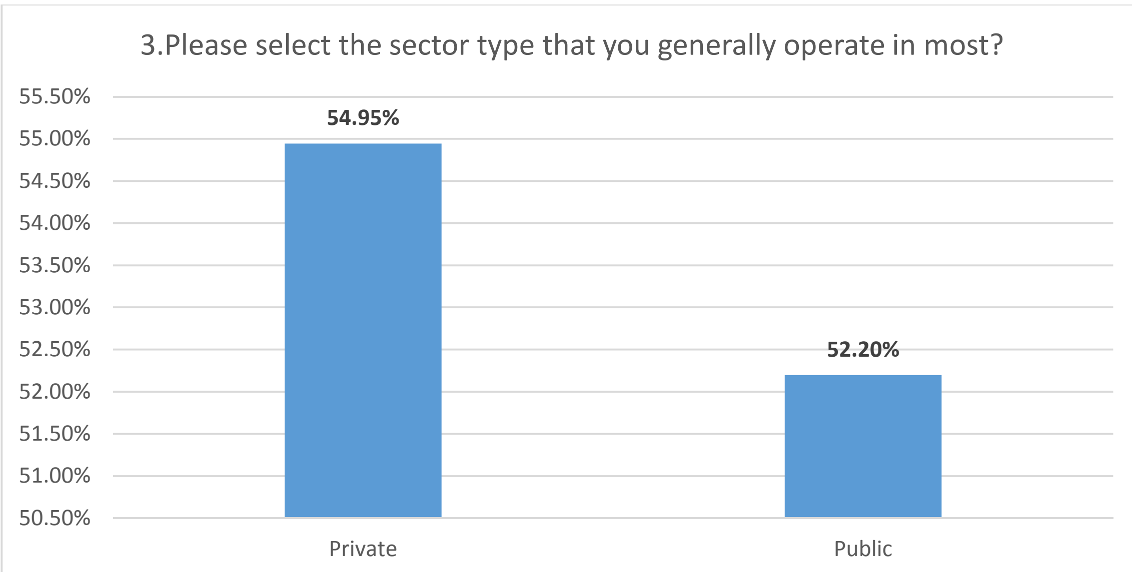

Figure 5: Responses to Question-3

4.1.4 Question 4

The fourth question of the survey was: Which of the following best defines your company role in construction projects? The response options were:

- Owner
- Contractor
- Design and Engineering Firm
- Other (please specify)

All of the 182 respondents answered this question. 38 respondents selected Owner, 47 selected contractor, while 80 respondents selected Design Firm. The remaining 17 respondents selected the "Other (please specify)" option. The responses to results of question 4 are presented in Table 7 and Figure 6.

ANSWER CHOICES	RESPONSES	PERCENT
Owner	38	20.88%
Contractor	47	25.82%
Design Firm	80	43.96%
Other	17	9.34%
TOTAL	182	

Table 7: Responses to Question-4

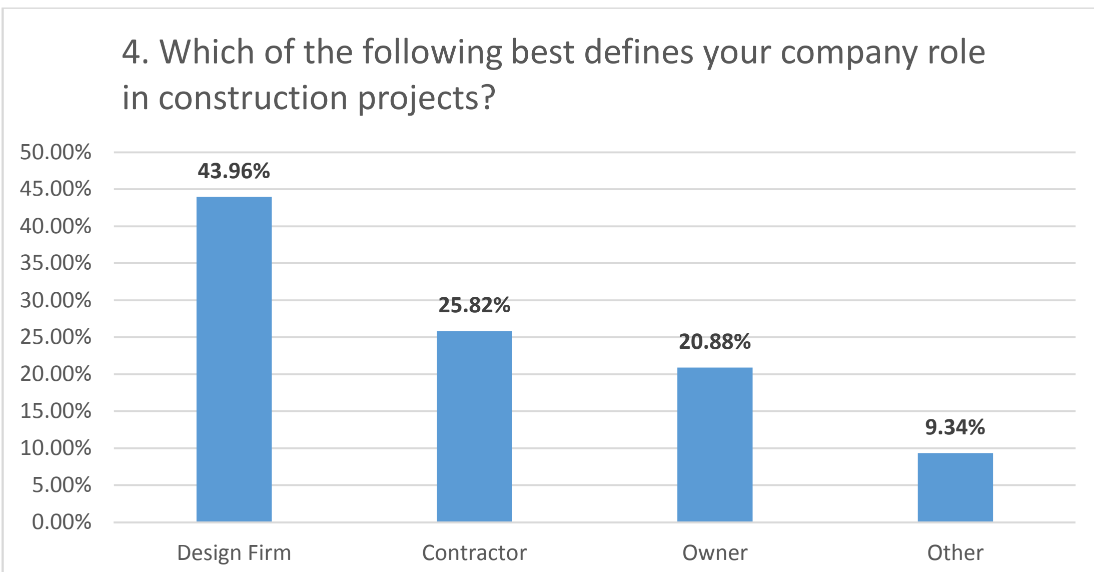

Figure 6: Responses to Question-4

4.1.5 Question 5

The fifth question of the survey was: Which role best defines your current position in your company? The response options were:

- Owner

- Principal/Director/VP
- Project Manager
- BIM Manager
- Designer/Engineer
- Other (please specify)

A sum of 180 respondents answered this question, and 2 of the respondents skipped the question. Among all the respondents, a total of 8 respondents selected Owner, 41 respondents selected Principal/Director/VP, 30 respondents selected Project Manager, 55 respondents selected BIM Manager, 29 respondents selected Designer/engineer and the remaining 17 respondents selected "Other (please specify)" option. The responses to question 5 are presented in Table 8 and Figure 7.

ANSWER CHOICES	RESPONSES	PERCENT
Owner	8	4.44%
Designer/Engineer	29	16.11%
Project Manager	30	16.67%
Principal/Director/VP	41	22.78%
BIM Manager	55	30.56%
Other	17	9.44%
TOTAL	180	

Table 8: Responses to Question-5

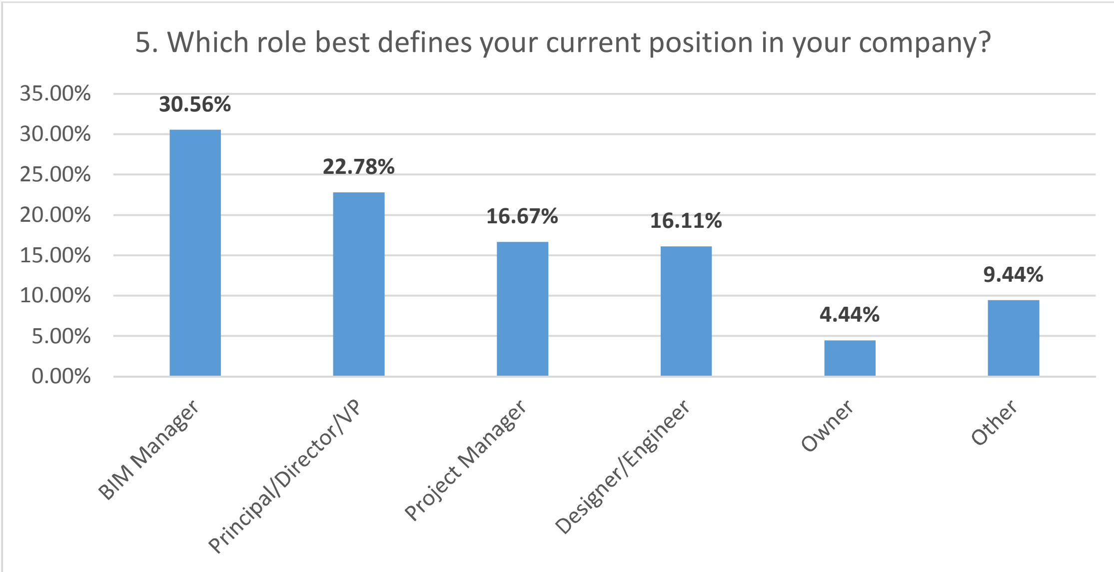

Figure 7: Responses to Question-5

4.1.6 Question 6

The sixth question of the survey was: What functions of BIM technology do you use in your projects? (Please check all that apply). The response options were:

- Early design coordination
- Creation and visualization of 3D models
- Production of coordinated drawings and construction documents
- Automated quantity take-off
- Cost estimating
- Scheduling and project planning
- Clash detection and conflict resolution
- Support on site construction management
- Simulation & analysis
- Other (please specify)

A total of 147 respondents answered this question, and 35 respondents skipped the question. Among the respondents that answered the question, 117 of them selected Early design coordination, 126 of them selected Creation and visualization of 3D models, 129 of them selected Production of coordinated drawings and construction documents, 53 of them selected Automated quantity take-off, 44 of them selected Cost estimating, 55 of them selected Scheduling and project planning, 125 of them selected Clash detection and conflict resolution, 70 of them selected Support on-site construction management, 53 of them selected Simulation & analysis, and 19 of them selected “Other (please specify)” option. According to the results, Early design coordination; Creation, and visualization of 3D models; Production of coordinated drawings and construction documents; and Clash detection and conflict resolution options had the highest response rate. The responses to question 6 are presented in Table 9 and Figure 8.

ANSWER CHOICES	RESPONSES	PERCENT
Cost estimating	44	29.93%
Automated quantity take-off	53	36.05%
Simulation & analysis	53	36.05%
Scheduling and project planning	55	37.41%
Support on site construction management	70	47.62%
Early design coordination	117	79.59%
Clash detection and conflict resolution	125	85.03%
Creation and visualization of 3D models	126	85.71%
Production of coordinated drawings and construction documents	129	87.76%
Other	19	12.93%
TOTAL	147	

Table 9: Responses to Question-6

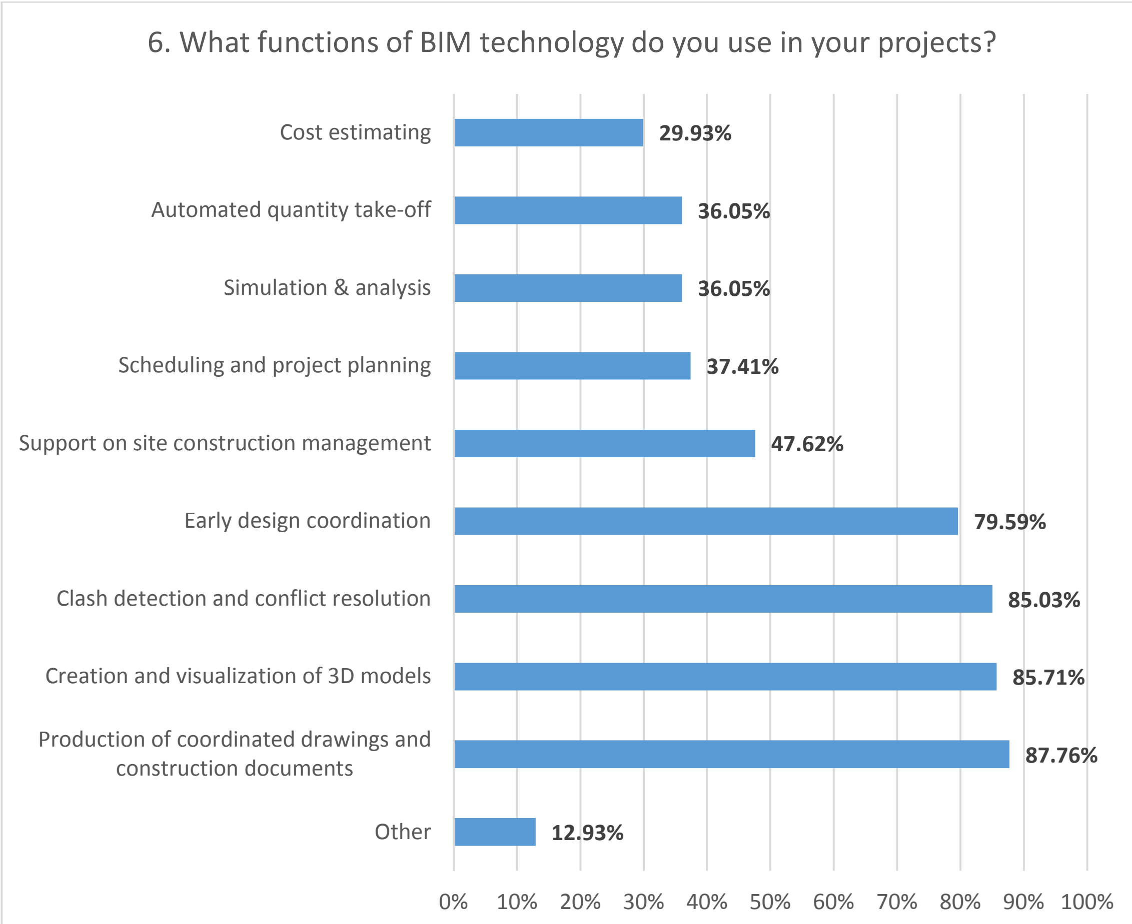

Figure 8: Responses to Question-6

4.1.7 Question 7

The seventh question of the survey was: What is the budget range of your usual projects? The response options were:

- Less than $500K
- +$500K - $2M
- +$2M - $5M
- +$5M - $10M
- +$10M - $25M
- More than $25M

All of the respondents answered this question and the response distribution was: 9 respondents selected Less than $500K, 22 respondents selected +$500K - $2M, 12 respondents selected +$2M - $5M, 16 respondents selected +$5M - $10M, 41 respondents selected +$10M - $25M and 82 respondents selected More than $25M option. The majority of the responses had project budgets more than $25M. The responses to question 7 is presented in Table 10 and Figure 9.

ANSWER CHOICES	RESPONSES	PERCENT
Less than $500K	9	4.95%
+$500K - $2M	22	12.09%
+$2M - $5M	12	6.59%
+$5M - $10M	16	8.79%
+$10M - $25M	41	22.53%
More than $25M	82	45.05%
TOTAL	182	

Table 10: Responses to Question-7

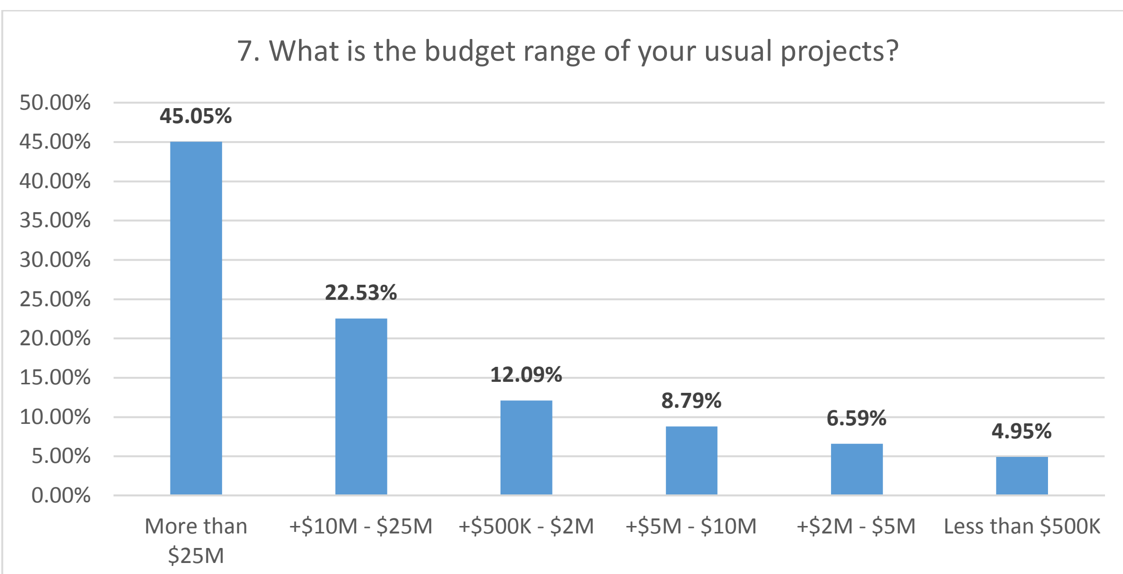

Figure 9: Responses to Question-7

4.1.8 Question 8

The eighth question of the survey was: In general, what type of project delivery system do you use for your project? The response options were:

- Design-Bid-Build
- Design-Build
- Construction Management at Risk
- Integrated Project Delivery
- Other (please specify)

This question was answered by 180 respondents and skipped by 2 respondents. A total of 58 respondents selected Design-Bid-Build, 28 respondents selected Design-Build, 59 respondents selected Construction Management at Risk, 16 respondents selected Integrated Project Delivery and 19 respondents selected "Other (please specify)" option. The responses to question 8 are presented in Table 11 and Figure 10.

ANSWER CHOICES	RESPONSES	PERCENT
Integrated Project Delivery	16	8.89%
Design-Build	28	15.56%
Design-Bid-Build	58	32.22%
Construction Management at Risk	59	32.78%
Other	19	10.56%
TOTAL	180	

Table 11: Responses to Question-8

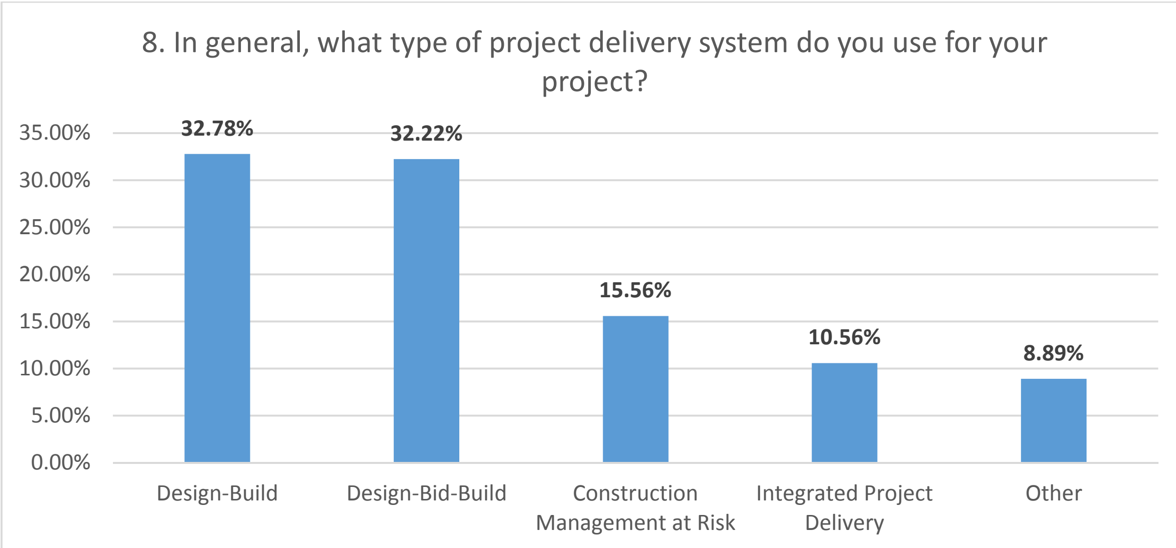

Figure 10: Responses to Question-8

4.1.9 Question 9

The ninth question of the survey was: How would you rate your company's BIM maturity level? The response options were:

- Level 0 - BIM is not implemented.
- Level 1 - 3D model created and basic data generation from the model, such as 2D plans, elevations, sections, quantity take offs are obtained. Automated and coordinated views are created.
- Level 2 - Information exchange between partners is accomplished. Clashes are detected between disciplines. Models are exported and imported into disconnected systems. Time (4th dimension) and Cost (5th dimension) dimensions are added to the model.
- Level 3 - A single source of model is established and stored in company database. The model is accessible to all project contributors. Complex analyses are performed. Synchronized communications between partners are achieved.

All of the respondents answered this question, 12 respondents selected Level 0, 39 respondents selected Level 1, 77 respondents selected Level 2, and 54 respondents selected Level 3. The responses to question 9 are presented in Table 12 and Figure 11.

ANSWER CHOICES	RESPONSES	PERCENT
Level 0	12	6.59%
Level 1	39	21.43%
Level 2	77	42.31%
Level 3	54	29.67%
TOTAL	182	

Table 12: Responses to Question-9

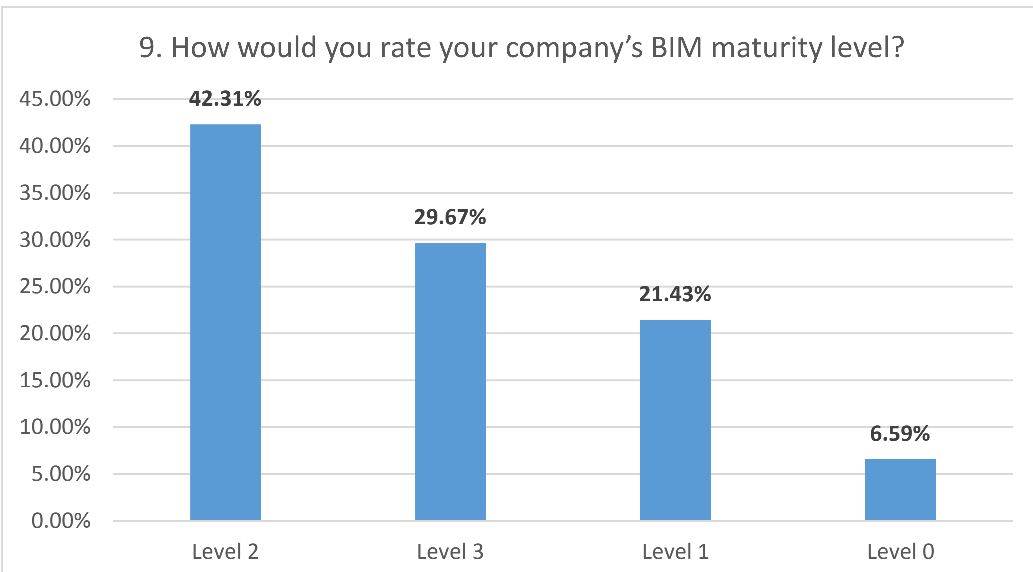

Figure 11: Responses to Question-9

4.1.10 Question 10

The tenth question of the survey was: How long has your company been working with BIM? The response options were:

- < 1 year

- 1-3 years
- +3-5 years
- > 5 years

Among the 182 respondents, 149 of them answered, and 33 of them skipped this question. The response distribution of the question is: 7 respondents selected less than 1 year, 16 respondents selected 1 to 3 years, 23 respondents selected more than 3 to 5 years, and 103 respondents selected more than 5 years option. The majority of the respondent has more than 5 years of BIM experience. The responses to question 10 are presented in Table 13 and Figure 12.

ANSWER CHOICES	RESPONSES	PERCENT
< 1 year	7	4.70%
1-3 years	16	10.74%
+3-5 years	23	15.44%
> 5 years	103	69.13%
TOTAL	149	

Table 13: Responses to Question-10

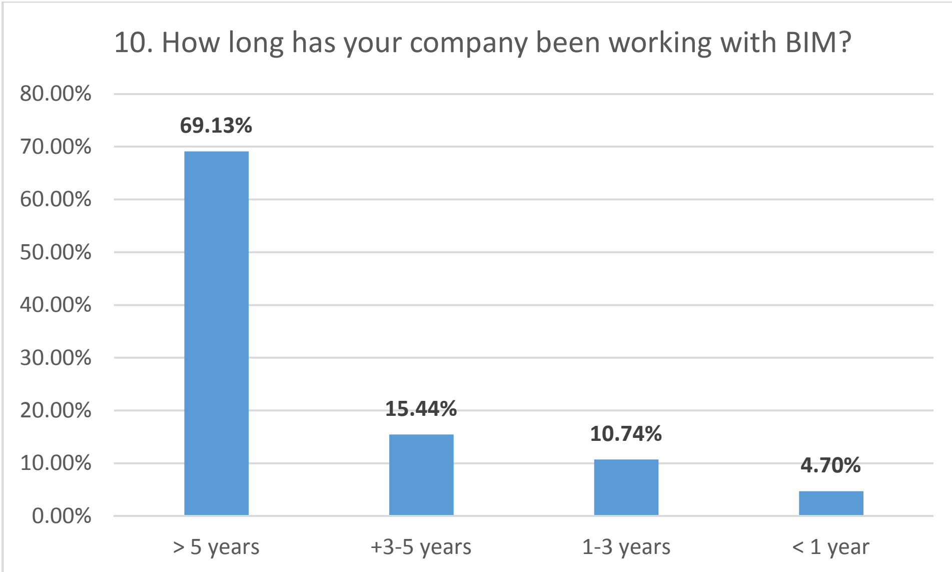

Figure 12: Responses to Question-10

4.1.11 Question 11

The eleventh question of the survey was: How often does your project team manually re-enter project data from other project parties' applications to your company applications because of incompatibility between systems? The response options were:

- Never
- Sometimes
- Always

A total of 179 respondents answered that question, and 3 respondents skipped the question. 32 respondents selected Never option, 122 respondents selected Sometimes option and the remaining 25 respondents selected Always option. According to the answers to this question, the majority of the respondent's project teams *sometimes* manually re-enter project data from the other project parties' applications to their company applications because of incompatibility between systems. The response results of the question 11 are presented in Table 14 and Figure 13.

ANSWER CHOICES	RESPONSES	PERCENT
Never	32	17.88%
Sometimes	122	68.16%
Always	25	13.97%
TOTAL	179	

Table 14: Responses to Question-11

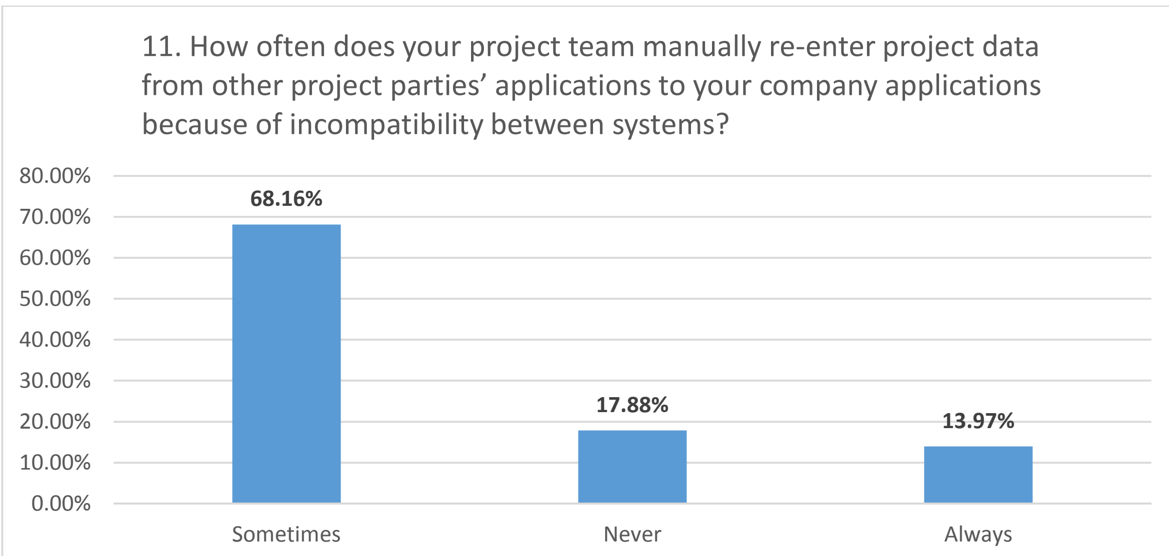

Figure 13: Responses to Question-11

4.1.12 Question 12

The twelfth question of the survey was: How often does your project team spend a considerable amount of time to check that they are working with the correct version of documents, drawings, plans, revisions, etc. because of software incompatibility issues or poor coordination? The response options were:

- Never
- Sometimes

- Always

This question was answered by 180 respondents, and skipped by 2 respondents. A total of 34 respondents selected Never, 112 respondents selected Sometimes and 34 respondents selected Always option. According to responses for this question, the majority of the respondent's project teams *sometimes* spend a considerable amount of time to check that they are working with the correct version of documents, drawings, plans, revisions, etc. because of software incompatibility issues or poor coordination. The responses to question 12 are presented in Table 15 and Figure 14.

ANSWER CHOICES	RESPONSES	PERCENT
Never	34	18.89%
Sometimes	112	62.22%
Always	34	18.89%
TOTAL	179	

Table 15: Responses to Question-12

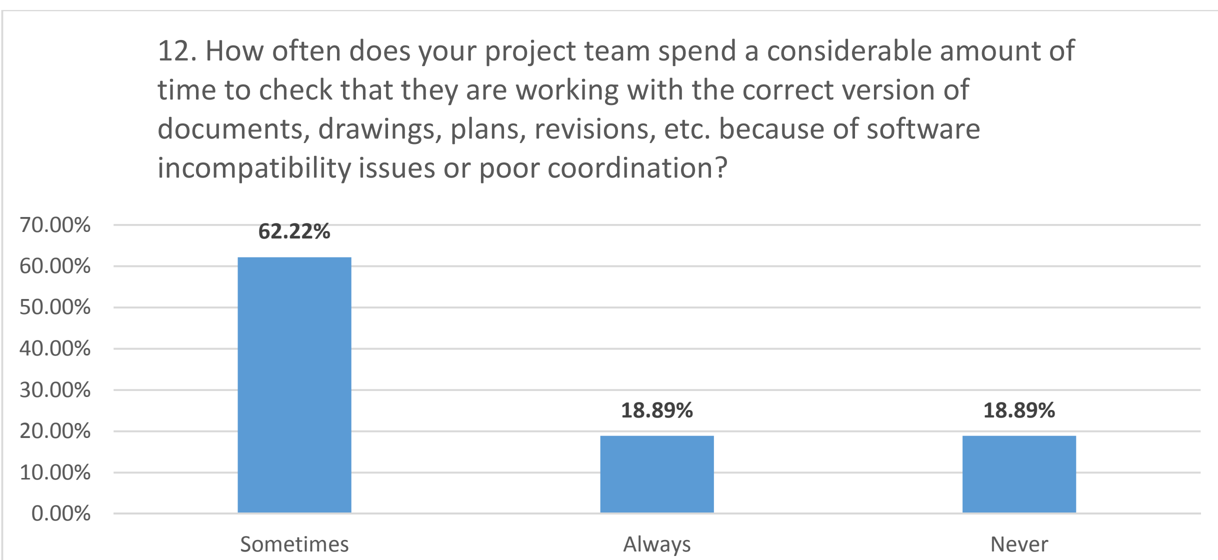

Figure 14: Responses to Question-12

4.1.13 Question 13

The thirteenth question of the survey was: How often do you have rework issues due to using the incorrect version of the project document, plans, drawings, revisions, etc.? The response options were:

- Never
- Sometimes
- Always

Among the 179 respondents who answered this question, 50 respondents selected Never, 117 respondents selected Sometimes and 12 respondents selected Always option. The remaining 3 respondents skipped this question. Based on the responses to this question, the majority of the respondents *sometimes* have rework issues due to using the incorrect version of the project document, plans, drawings, revisions, etc. The responses to question 13 are presented in Table 16 and Figure 15.

ANSWER CHOICES	RESPONSES	PERCENT
Never	50	27.93%
Sometimes	117	65.36%
Always	12	6.70%
TOTAL	179	

Table 16: Responses to Question-13

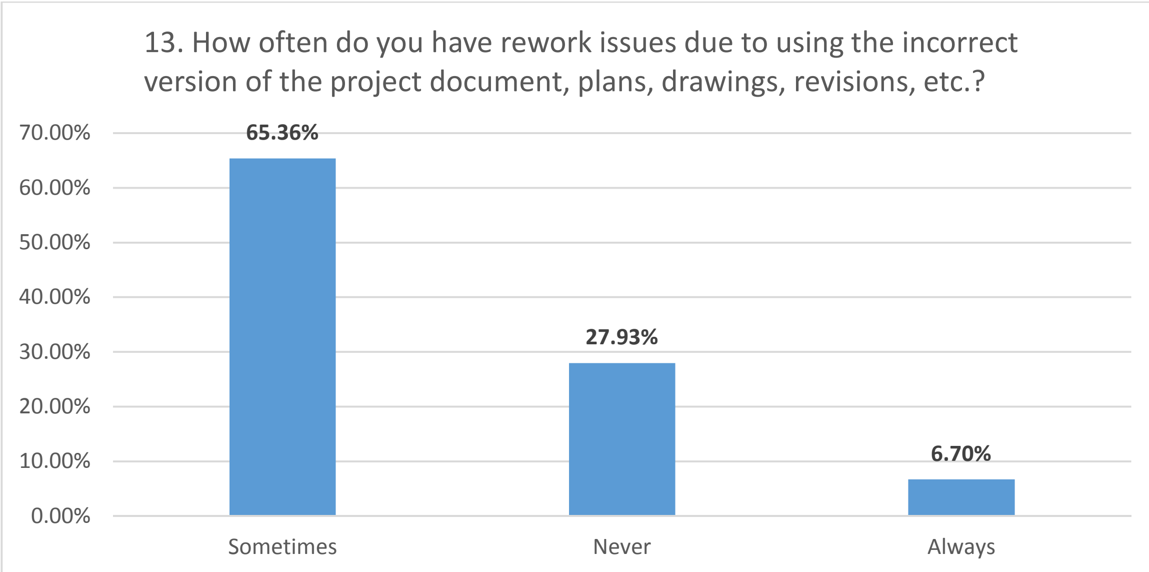

Figure 15: Responses to Question-13

4.1.14 Question 14

The fourteenth question of the survey was: Which one of the potential benefits of BIM implementation presented below contributes to cost savings if any? (Please check all that apply). The response options were:

- Improved understanding of the design
- Improved understanding of the scope
- Better project coordination
- Better document coordination
- Improved quality of the design
- Improved accuracy of construction cost estimating
- Improved constructability
- Reduced number of issues by clash detection
- Reduced number of rework issues
- Reduced amount of waste in time and material

- Reduced amount of claims
- Better planning of construction and design phases
- Improved communication between project team
- Improved overall quality of the project
- Reduced project duration
- Reduced number of Request for Information (RFI)
- Reduced number of submittals
- Reduction in time required to respond RFIs
- Reduction in time for submittal processes
- Better project outcomes
- Other (please specify)

Among the 147 respondents who answered this question, 119 respondents selected Increased understanding of the design, 83 respondents selected Improved understanding of the scope, 136 respondents selected Better project coordination, 108 respondents selected Better document coordination, 82 respondents selected Improved quality of the design, 62 respondents selected Improved accuracy of construction cost estimating, 89 respondents selected Improved constructability, 123 respondents selected Reduced number of issues by clash detection, 92 respondents selected Reduced number of rework issues, 64 respondents selected Reduced amount of waste in time and material, 48 respondents selected Reduced amount of claims, 75 respondents selected Better planning of construction and design phases, 105 respondents selected Improved communication between project teams, 86 respondents selected Improved overall quality of the project, 47 respondents selected Reduced project duration, 62 respondents selected Reduced number of Request for Information (RFI), 23 respondents selected Reduced number of submittals, 55 respondents selected Reduction in time required to respond RFIs, 27 respondents selected Reduction in time for submittal processes, 81 respondents selected Better project outcomes, and 14 respondents selected “Other (please specify)” option. The remaining 35 respondents skipped the question.

The results show that, Understanding of the design, Better project coordination, Better document coordination, Reduced number of issues by clash detection and Improved communication between project team were selected as the potential benefits of BIM by more than 75% of the respondents. The responses to question 14 is presented in Table 17 and Figure 16.

ANSWER CHOICES	RESPONSES	PERCENT
Reduced number of submittals	23	15.65%
Reduction in time for submittal processes	27	18.37%
Reduced project duration	47	31.97%
Reduced amount of claims	48	32.65%
Reduction in time required to respond RFIs	55	37.41%
Reduced number of Request for Information (RFI)	62	42.18%
Improved accuracy of construction cost estimating	62	42.18%
Reduced amount of waste in time and material	64	43.54%
Better planning of construction and design phases	75	51.02%
Better project outcomes	81	55.10%
Improved quality of the design	82	55.78%
Improved understanding of the scope	83	56.46%
Improved overall quality of the project	86	58.50%
Improved overall quality of the project	86	58.50%
Improved constructability	89	60.54%
Reduced number of rework issues	92	62.59%
Improved communication between project team	105	71.43%
Better document coordination	108	73.47%
Improved understanding of the design	119	80.95%
Reduced number of issues by clash detection	123	83.67%
Better project coordination	136	92.52%
Other (please specify)	14	9.52%
TOTAL	147	

Table 17: Responses to Question-14

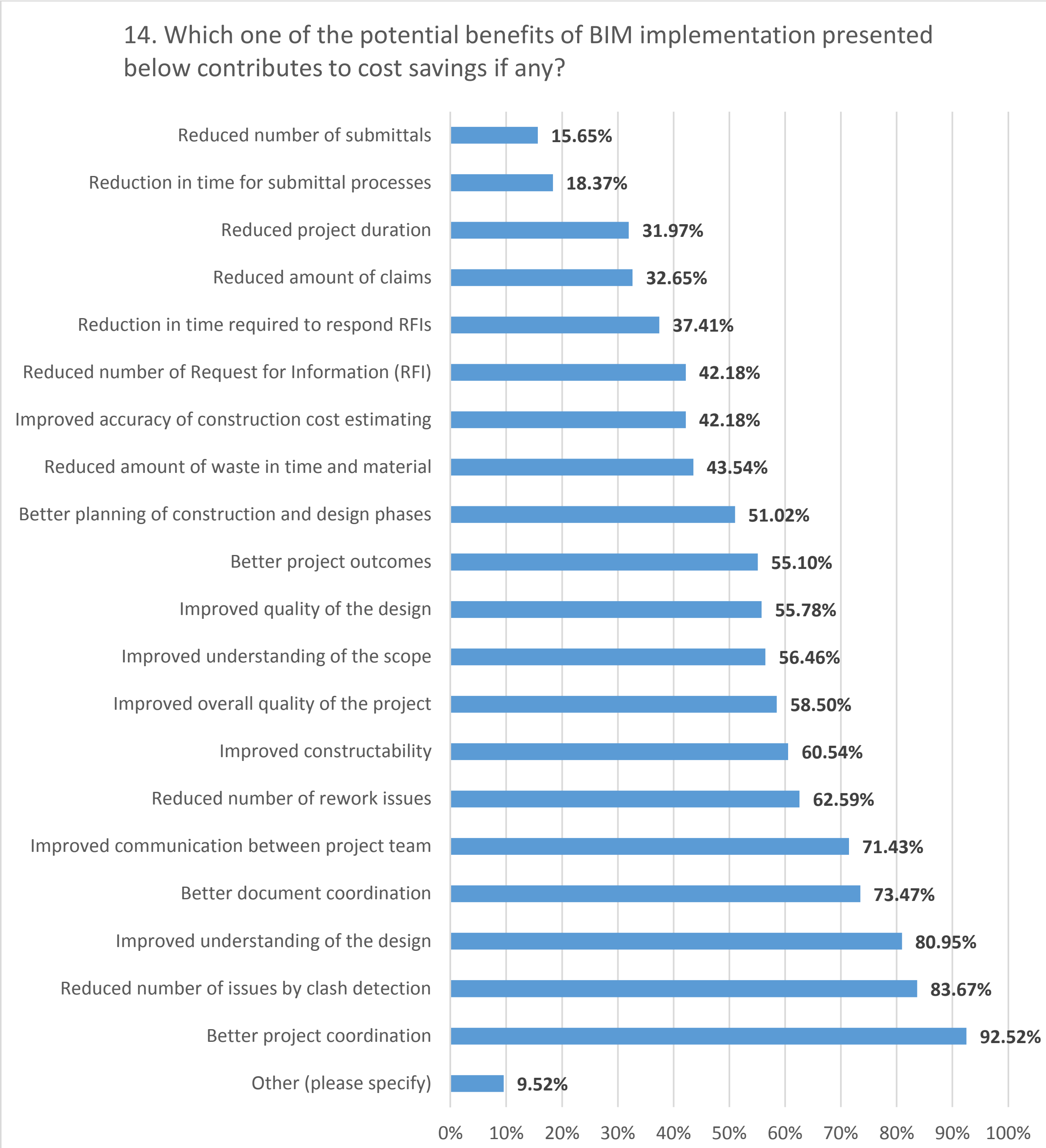

Figure 16: Responses to Question-14

4.1.15 Question 15

The fifteenth question of the survey was: Which of the cost items listed below add up to your total BIM investment cost? (Please check all that apply). The response options were:

- Software cost
- Training & consultancy costs
- Cost for interoperability (seamless exchange and management of electronic information between project participants) solutions
- Hardware cost
- Other (please specify)

A total of 144 respondents answered this question, and the remaining 38 respondents skipped the question. The answer distribution of this question is: 121 respondents selected Software cost, 114 respondents selected Training & consultancy costs, 71 respondents selected Cost for interoperability, 85 respondents selected Hardware cost, and 24 respondents selected "Other (please specify)" option. More than 75% of the respondents selected Software cost and Training and consultancy costs as BIM investment costs. The responses to question 15 are presented in Table 18 and Figure 17.

ANSWER CHOICES	RESPONSES	PERCENT
Software cost	121	84.03%
Training & consultancy costs	114	79.17%
Hardware cost	85	59.03%
Cost for interoperability	71	49.31%
Other	24	16.67%
TOTAL	144	

Table 18: Responses to Question-15

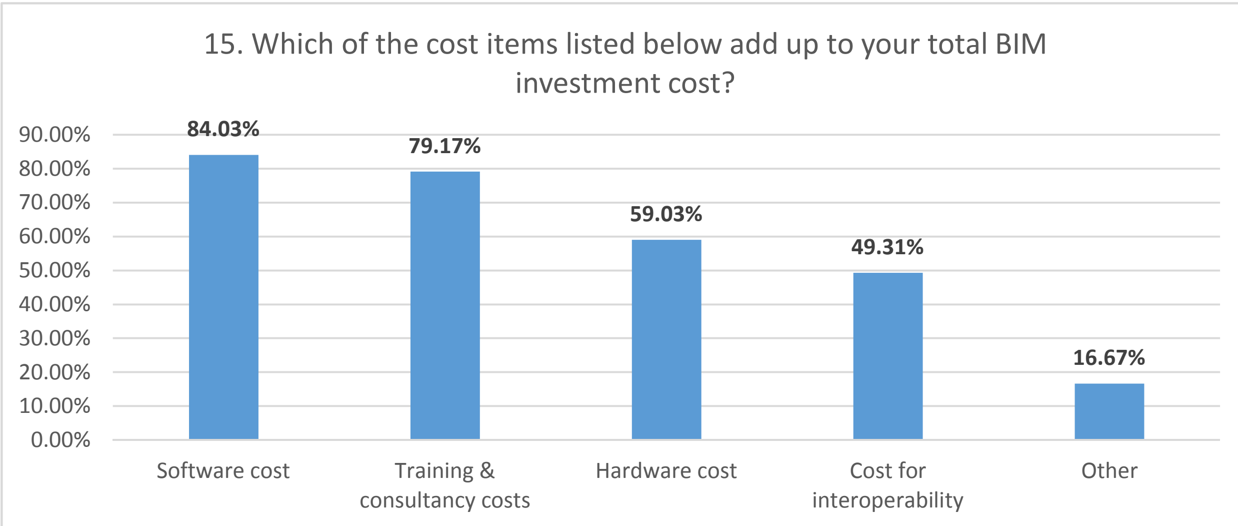

Figure 17: Responses to Question-15

4.1.16 Question 16

The sixteenth question of the survey was: ROI can be defined as the ratio of the net benefits produced by an investment divided by the cost of the investment and then multiplying the ratio with 100. Based on your previous answers on cost & benefits of BIM implementation, which one of the category below is your best estimate of ROI of BIM implementation for your company? The response options were:

- Low: ROI ≤ 0 (negative impact; at best no positive impact)
- Medium-Low: 1% ≤ ROI < 25% (some positive experience)
- Medium: 25 % ≤ ROI < 50% (satisfaction with BIM experience and there is room to grow)
- Medium-High: 50% ≤ ROI < 75% (reasonable degree of satisfaction with opportunities to get better)
- High: 75% ≤ ROI (positive impact confirmed, high degree of satisfaction with BIM experience)

All of the respondents answered this question. Among the respondents who answered this question, 9 of them selected Low, 27 of them selected Medium-Low, 64 of them selected Medium, 51 of them selected Medium-High, and the remaining 31 respondents selected High ROI option. The responses to question 16 are presented in Table 19 and Figure 18.

ANSWER CHOICES	RESPONSES	PERCENT
Low	9	4.95%
Medium-Low	27	14.84%
Medium	64	35.16%
Medium-High	51	28.02%
High	31	17.03%
TOTAL	182	

Table 19: Responses to Question-16

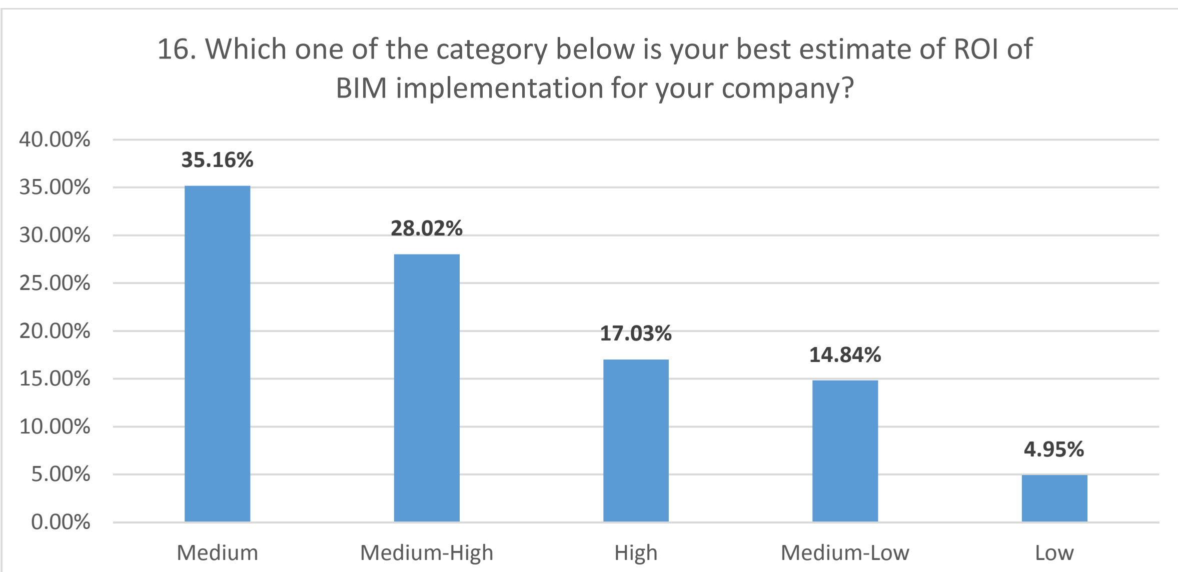

Figure 18: Responses to Question-16

CHAPTER 5 RESULTS AND DISCUSSION

This chapter presents the results of the statistical analyses.

5.1 Modeling

As explained in the methodology section of this dissertation 182 responses were collected. After the data screening process, this number was reduced to 137. The sample population was composed of owners, contractors, and design firms. The data was analyzed using IBM Statistical Package for the Social Sciences (SPSS) Statistics version 25.

Results of the modeling section is composed of two parts: the initial model and simulated model. The initial model was obtained from a multiple linear regression analysis of the main data. The simulated model was obtained from a multiple linear regression analysis of the main data and the simulated data combined together.

5.1.1 Initial Model

The initial model was obtained from the main data comprised of 137 cases. Frequency distributions for the main data were obtained and analyzed. The frequency distributions are presented in tables and graphical formats and narrative formats.

A multiple linear regression model was created to determine the combined effect of the key independent variables on the dependent variable return on investment (ROI). An analysis of variance (ANOVA) for the overall model was conducted to test whether the combined effect of all independent variables explained a statistically significant amount of variability in the dependent variable. Validation of the model was performed using a cross-validation technique to ensure the model reflected the true relationship between the dependent and independent variables. Finally, a correlation matrix was produced to examine correlations between independent variables. Results of the correlation analysis are presented and discussed.

5.1.1.1 Frequency Distributions

In this section, the frequency distributions of the dependent and independent variables were presented and described. The independent variables were: project type, project sector, project team member, project budget, project delivery system, interoperability, BIM maturity level and interoperability.

5.1.1.1.1 Project Type

Project type is an independent variable that aimed to show the effect of different project types on ROI of BIM. The distribution of project types was analyzed for the 137 cases included in the initial model. There were considerably more building project types compared to non-building project types in the main data. Building project type comprised 93% of all the cases whereas non-building project type comprised 7% of the cases. The frequency distributions for project type are presented in Table 20 and Figure 19.

PROJECT TYPE

	FREQUENCY	PERCENT	CUMULATIVE PERCENT
BUILDING	128	93%	93%
NON-BUILDING	9	7%	100%
TOTAL	137	100%	

Table 20: Initial Model Project Type Frequency and Percent Distribution

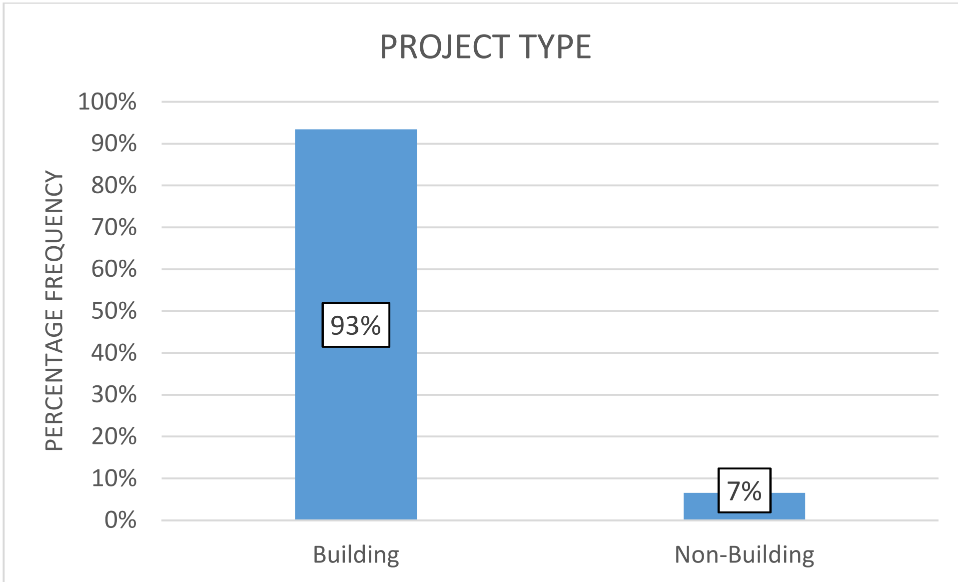

Figure 19: Initial Model Project Type Percent Frequency Distribution Graph

5.1.1.1.2 Project Sector

Project sector was an independent variable that described whether a project was public or private. It was entered into the model to assess the effect of project sector type on ROI of BIM. The frequency distribution for project sector was obtained for the 137 cases in the initial model. There were relatively more private sector projects, compared to public sector projects. Forty-seven percent of the cases involved public sector projects whereas 53% of the projects were located in the private sector. Frequency distributions for project sector are presented in Table 21 and Figure 20.

PROJECT SECTOR

	FREQUENCY	PERCENT	CUMULATIVE PERCENT
Public	64	47%	47%
Private	73	53%	100%
Total	137	100%	

Table 21 : Initial Model Project Sector Frequency and Percent Distribution

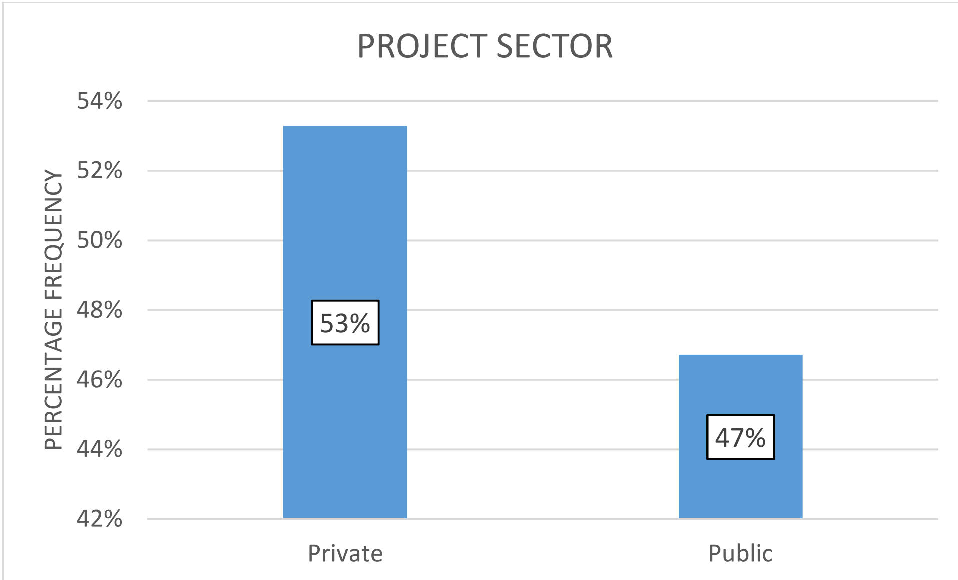

Figure 20: Initial Model Project Sector Percent Frequency Distribution Graph

5.1.1.1.3 Project Team Members

The third independent variable was project team members which could be either owners, contractors, or design firms. The distribution of project team members is presented for the 137 cases. There were relatively more design firms compared to owners and contractors, in the initial model data. Also, there were relatively fewer owners compared to design firms and contractors.

Owners were 20% of the project team members while contractors were 30%. Design firms were 50% of project team members. The frequency distributions for project team members are presented in Table 22 and Figure 21.

TEAM MEMBER TYPE

	FREQUENCY	PERCENT	CUMULATIVE PERCENT
OWNER	27	20%	20%
CONTRACTOR	41	30%	50%
DESIGN FIRM	69	50%	100%
TOTAL	137	100%	

Table 22: Initial Model Team Member Type Frequency and Percent Distribution

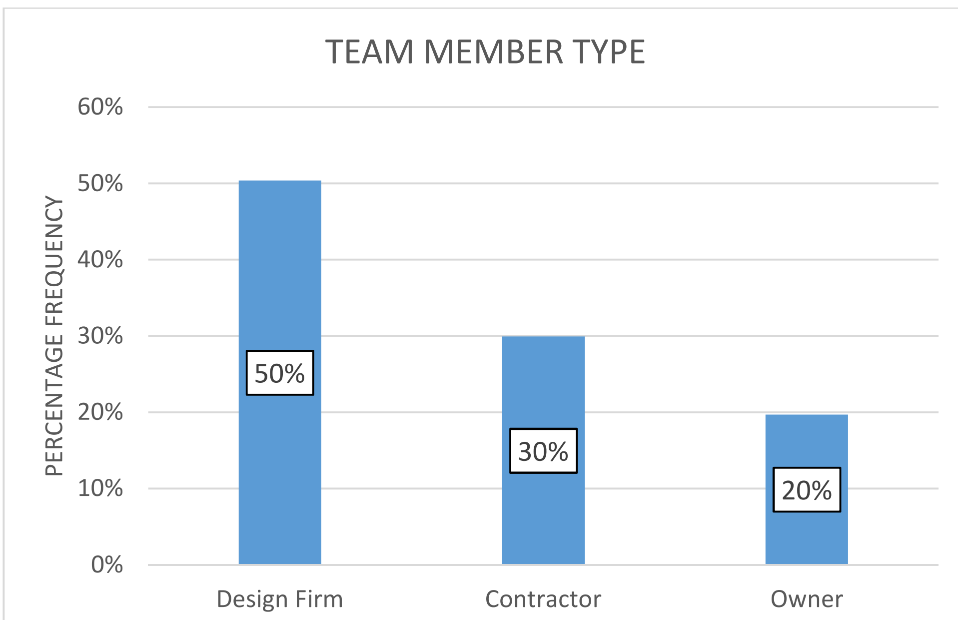

Figure 21: Initial Model Team Member Type Percent Frequency Distribution Graph

5.1.1.1.4 Project Budget

Another independent variable was project budget which describes a dollar value range for the project budget. The frequency distribution for this variable is presented for the 137 cases in the initial model. Project budgets between $10M and $25M were most frequent accounting for 24% of the cases. Project budgets between $500K and $2M were the second most frequent project budget size comprising 12% of the cases. Few project budgets were between 2M and 5M (7%) or between $5M and $10M (8%). The frequency distributions for project budget are presented in Table 23 and Figure 22.

PROJECT BUDGET

	FREQUENCY	PERCENT	CUMULATIVE PERCENT
Less than $500K	8	6%	6%
+$500K - $2M	17	12%	18%
+$2M - $5M	9	7%	25%
+$5M - $10M	11	8%	33%
+$10M - $25M	33	24%	57%
More than $25M	59	43%	100%
TOTAL	137	100%	

Table 23: Initial Model Project Budget Frequency and Percent Distribution

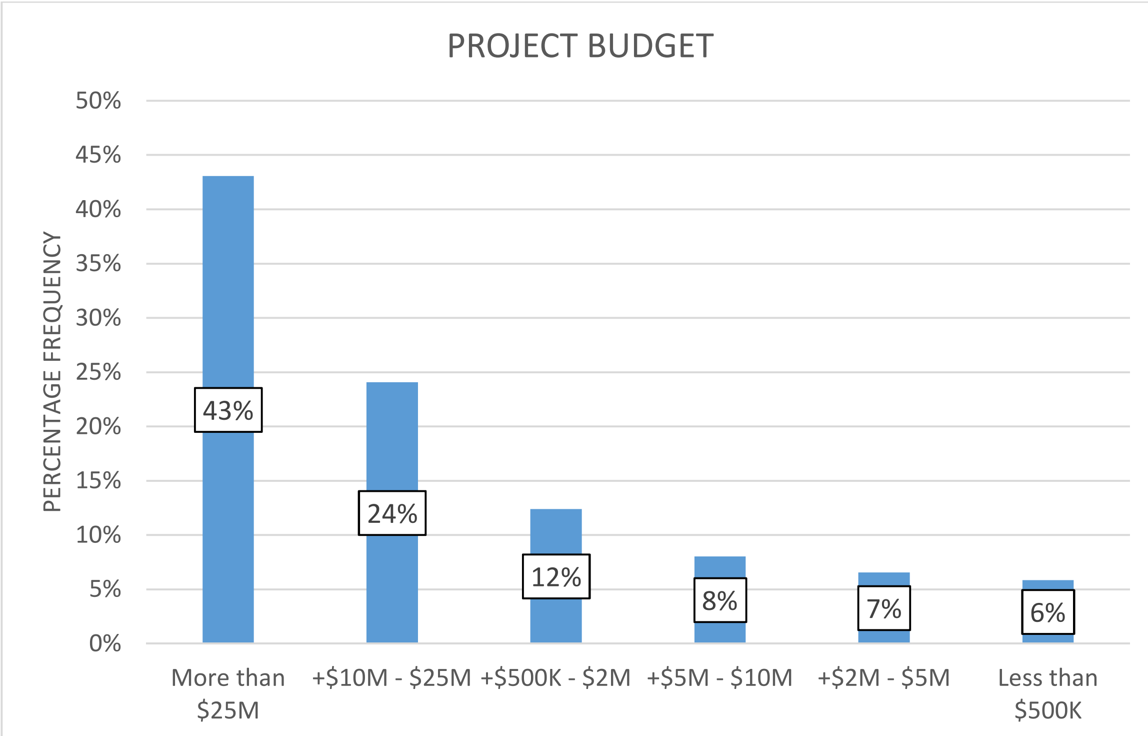

Figure 22: Initial Model Project Budget Percent Frequency Distribution Graph

5.1.1.1.5 Project Delivery System

Another independent variable was project delivery system which was a potentially important factor contributing to ROI of BIM. The frequency distribution for this variable for the 137 cases was obtained. There were relatively more design-build and design-bid-build project delivery systems in the main data.

Design-build and design-bid-build projects accounted for 56% of the project delivery systems. Construction management at risk project were 33% of the project delivery systems. Eleven percent of the projects had integrated project delivery systems. Frequency distributions for project delivery system are presented in Table 24 and Figure 23.

PROJECT DELIVERY SYSTEM

	FREQUENCY	PERCENT	CUMULATIVE PERCENT
Design-Build + Design-Bid-Build	77	56%	56%
Construction Management at Risk	45	33%	89%
Integrated Project Delivery	15	11%	100%
TOTAL	137	100%	

Table 24: Initial Model Project Delivery System Frequency and Percent Distribution

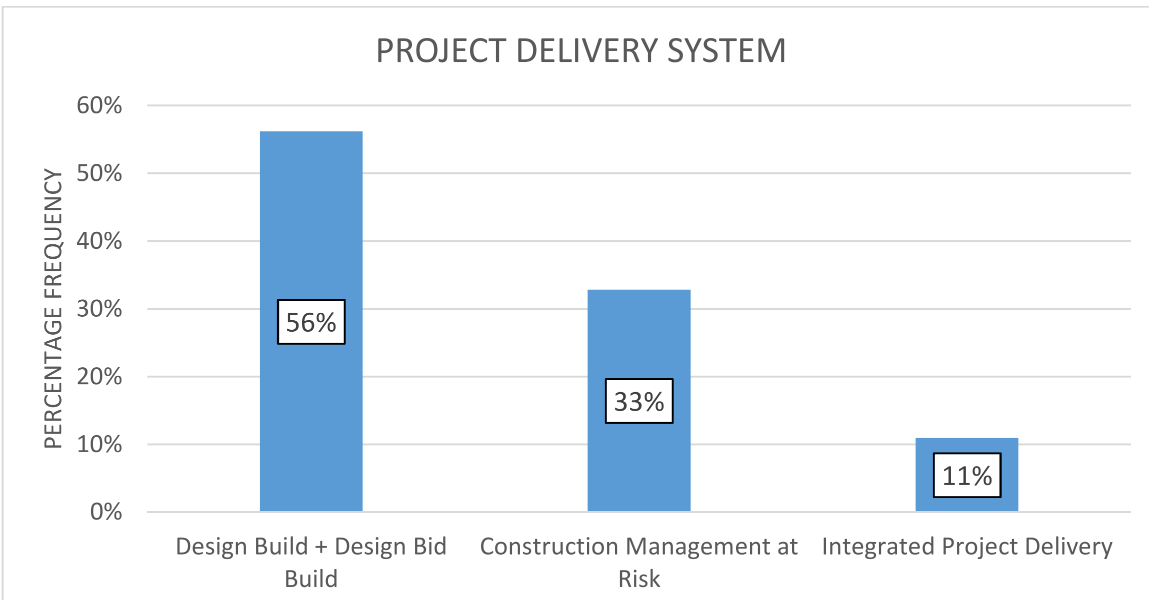

Figure 23: Initial Model Project Delivery System Percent Frequency Distribution Graph

5.1.1.1.6 BIM Maturity Level

The distribution of BIM maturity level was analyzed for the 137 cases in the main data. BIM maturity level 2 projects were most common. BIM maturity level 1 projects were found in 24% of the cases, whereas level 2 projects occurred in 46% of the cases. Level 3 BIM maturity level projects were 30% of the projects included in the initial model data.

Frequency distributions for BIM maturity level are presented in Table 25 and Figure 24.

BIM MATURITY LEVEL

	FREQUENCY	PERCENT	CUMULATIVE PERCENT
Level 1	33	24%	24%
Level 2	63	46%	70%
Level 3	41	30%	100%
TOTAL	137	100%	

Table 25: Initial Model BIM Maturity Level Frequency and Percent Distribution

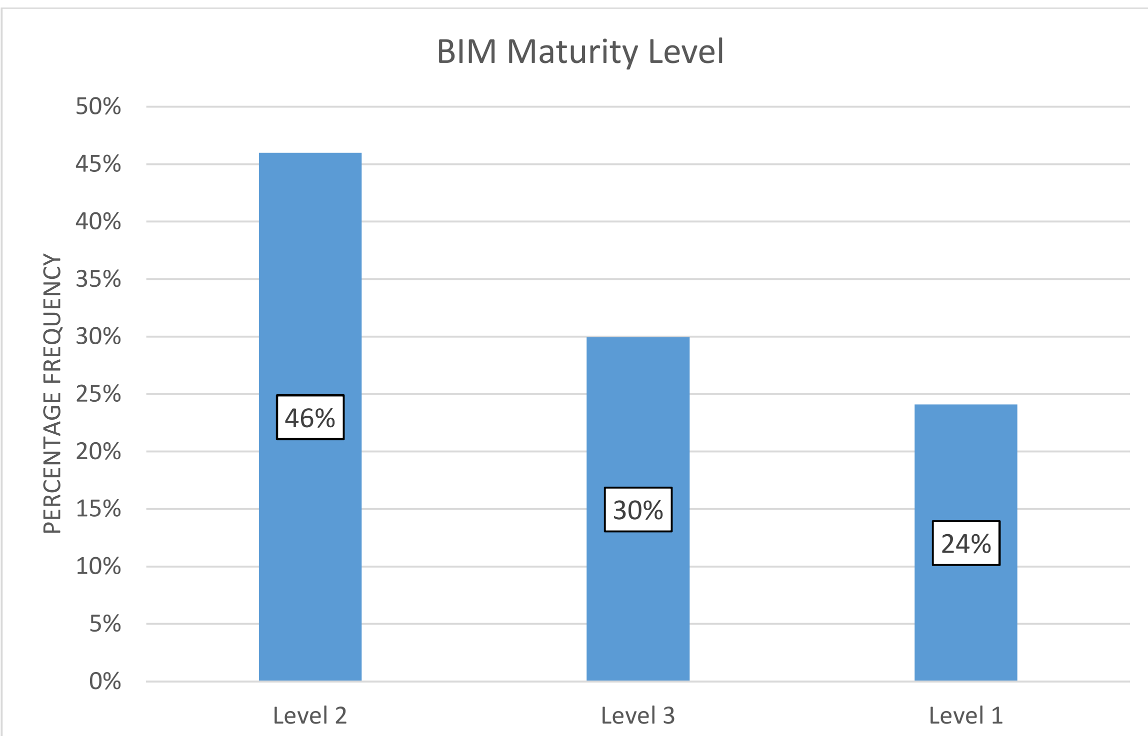

Figure 24: Initial Model BIM Maturity Level Percent Frequency Distribution Graph

5.1.1.1.7 Interoperability

The distribution of BIM interoperability was analyzed for the 137 cases. Medium interoperable projects had the highest distribution whereas low interoperable projects had the lowest distribution. Low interoperable projects constituted 15% of the total data. Medium interoperable projects were 64% of the total data and high interoperable projects occurred in 21% of the data. The frequency distributions of BIM interoperability independent variable are presented in Table 26 and Figure 25.

INTEROPERABILITY

	FREQUENCY	PERCENT	CUMULATIVE PERCENT
Low	21	15%	15%
Medium	87	64%	79%
High	29	21%	100%
TOTAL	137	100%	

Table 26: Initial Model Interoperability Frequency and Percent Distribution

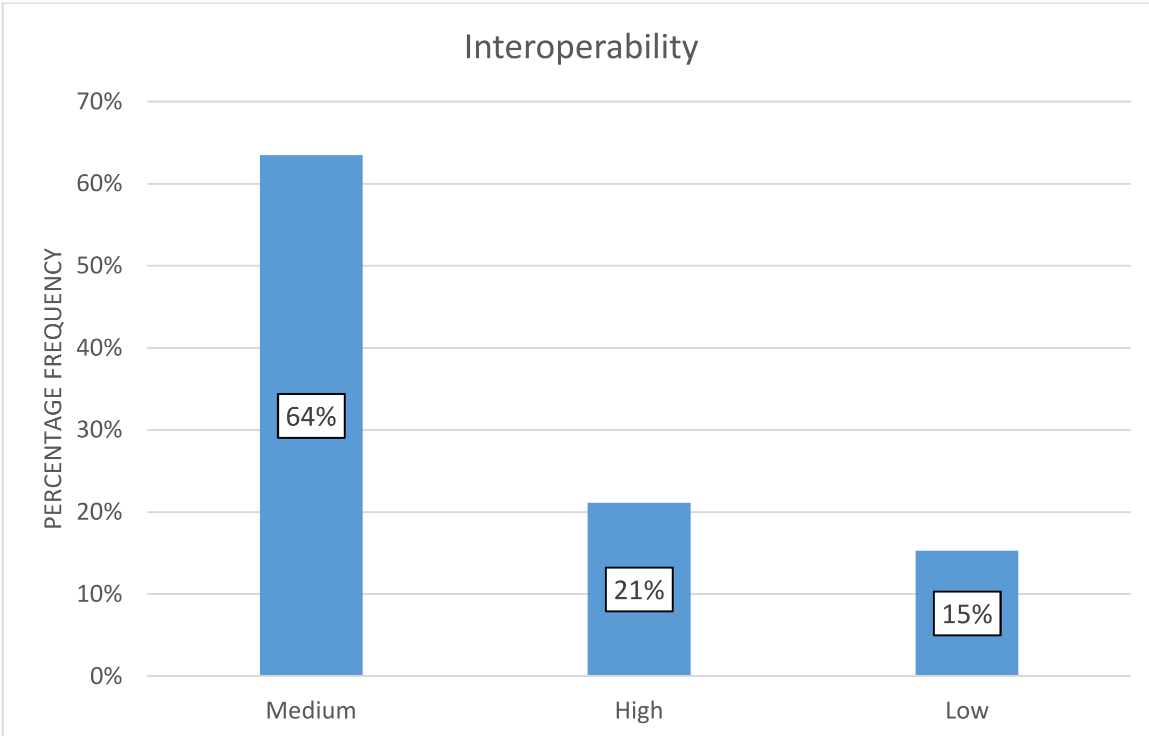

Figure 25: Initial Model Interoperability Percent Frequency Distribution Graph

5.1.1.1.8 Return on Investment

Return on investment (ROI) is the key dependent variable. The distribution of ROI was analyzed among 137 cases. It was found that projects having medium ROI had the highest distribution, whereas projects having low ROI had the lowest distribution. Only one percent of the projects had a low ROI. Medium-low ROI projects were 15% of total project while medium ROI projects were 37%, medium-high ROI projects were 28%, and high ROI were 19% of the total project. Frequency distributions for ROI are presented in Table 27 and Figure 26.

RETURN ON INVESTMENT (ROI)

	FREQUENCY	PERCENT	CUMULATIVE PERCENT
Low	2	1%	1%
Medium-Low	20	15%	16%
Medium	51	37%	53%
Medium-High	38	28%	81%
High	26	19%	100%
TOTAL	137	100%	

Table 27: Initial Model Return on Investment Frequency and Percent Distribution

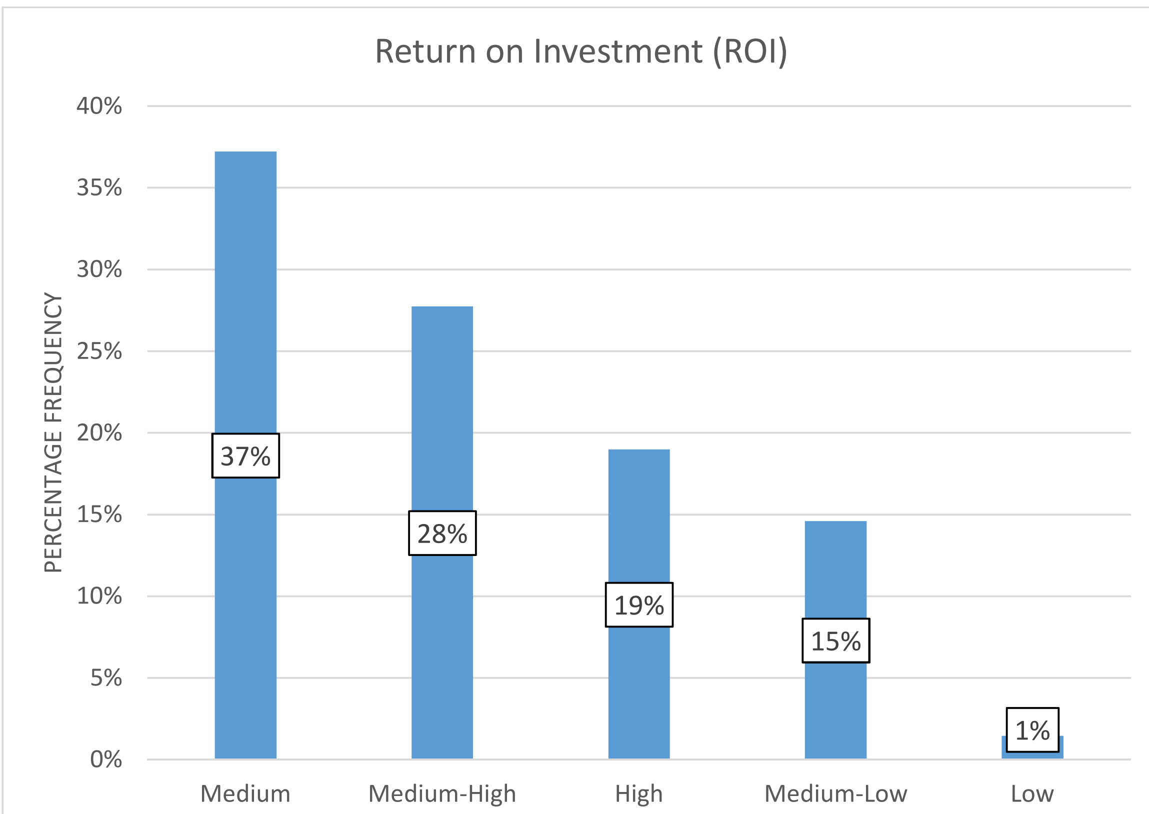

Figure 26: Initial Model Return on Investment Percent Frequency Distribution Graph

5.1.1.2 Analysis of Initial Model

In this section, the modeling and analysis of the main data are discussed. The main data included 137 cases which were entered into the initial multiple linear regression model. The multiple linear regression model was conducted to understand the combined effects of the independent variables; namely project type, project sector, project team member, project budget, project delivery system, interoperability, BIM maturity level and interoperability, on the dependent variable ROI of BIM.

The multiple correlation coefficient R = 0.488 indicates a moderately strong correlation between the dependent and independent variables. R^2 =0.238 represents the percentage of variability in ROI that can be explained by the independent variables in this model. In this model, 23.8% of variance in the dependent variable can be explained by changes in the independent variables. The initial model summary is presented in Table 28.

Initial Model Summary				
Model	**R**	**R^2**	**Adjusted R^2**	**Standard Error of the Estimate**
Initial	0.488	0.238	0.184	0.911

Table 28: Initial Model Summary

An analysis of variance (ANOVA) was included in the initial model to determine if the combined effect of all independent variables was statistically significant enough to explain variability in the dependent variable. The ANOVA p-value was less than 0.05 indicating the independent variables significantly predicted variation of ROI of BIM. The details of the initial model ANOVA are presented in Table 29.

ANOVA						
Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig**
Initial	Regression	32.876	9	3.653	4.404	0.000
	Residual	105.329	127	0.829		
	Total	138.204	136			

Table 29: Initial Model ANOVA

Unstandardized β (Beta) coefficients were examined to determine the combined effects of the independent variables on the dependent variable. Variables with β(Beta) coefficients with p-values less than 0.05 were considered to have a statistically significant effect on the dependent variable ROI, in this initial model. The coefficients table for the initial model is presented in Table 30.

Coefficients						
Mode l		Unstandardized B	Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
Initial	(Constant)	2.658	0.562		4.734	0
	PTYB	-0.351	0.333	-0.087	-1.053	0.295
	PSCPB	-0.108	0.166	-0.053	-0.649	0.518
	STYC	-0.262	0.252	-0.12	-1.041	0.3
	STYDE	-0.155	0.245	-0.077	-0.634	0.527
	PDSCM	-0.047	0.204	-0.022	-0.229	0.82
	PDSIPD	0.684	0.264	0.213	2.591	0.011
	Project Budget	-0.1	0.052	-0.163	-1.931	0.056
	BIM Maturity Level	0.407	0.112	0.297	3.63	0
	Interoperability	0.448	0.136	0.268	3.303	0.001

Table 30: Initial Model Coefficients

The interpretation of the initial model coefficients presented in Table 31.

Variable Kept on Model Background	Variable	B	Interpretation
Non-Building Projects	Building Projects	-0.351	Building projects result in a lesser ROI value when compared to Non-building projects
Private Sector	Pubic Sector	-0.108	Public Sector projects result in a lesser ROI value when compared to Private Sector Projects
Owner	Contractor	-0.262	Contractor BIM implementation result in a lesser ROI value when compared to Owner
Owner	Design-Engineering Firm	-0.155	Design and Engineering Firm BIM implementation result in a lesser ROI value when compared to Owner
DBB&DB	CM at Risk	-0.047	CM at Risk BIM implementation result in a lesser ROI value when compared to DBB & DB
DBB&DB	Integrated Project Delivery	0.684	Integrated Project Delivery BIM implementation result in a higher ROI value when compared to DBB & DB
NA	Project Budget	-0.1	As Project Budget level increases, ROI value decreases
NA	BIM Maturity Level	0.407	As BIM Maturity level increases, ROI value increases
NA	Interoperability	0.448	As BIM Interoperability level increases, ROI value increases

Table 31: Initial Model Coefficients Interpretation

5.1.1.3 Model Validation

In this study, cross-validation was performed by randomly splitting the data in a 50% - 50% ratio using the Statistical Package for the Social Sciences (SPSS) software. The first data filter variable was set to 0 randomly by SPSS, and the second data filter variable was set to 1. The first half of the data containing filter variable 0 was used for multiple linear model generation. The standard error of the estimate was calculated as 0.955 for the first model in this study.

The independent variable values of the second half of the data were analyzed using the multiple linear regression model that was generated from the first data, to predict the dependent variables of the second half of the data. The error between the actual dependent variable of the second half of data vs the predicted dependent variables of the second-half data was calculated, and the error was computed as 0.899. The error value of 0.955 for the first model and the error value of 0.899 for the second model were close to each other, which verifies the model.

5.1.1.4 Independent Variable Pearson Correlations

A correlation matrix was produced to determine the correlation of independent variables. The purpose of this is to examine how strongly independent variables are related to each other. The Pearson Correlations between the independent variables were examined. The correlation matrix and Pearson correlation coefficients are presented in Table 32.

Pearson Correlations							
	PT	PS	PTM	PB	PDS	BML	INT
Project Type (PT)	1.000	-0.165	0.123	0.063	-0.083	0.059	-0.222
Project Sector (PS)	-0.165	1.000	0.106	-0.087	0.108	-0.065	0.042
Project Team Member (PTM)	0.123	0.106	1.000	-0.285	-0.247	0.045	0.009
Project Budget (PB)	0.063	-0.087	-0.285	1.000	0.098	0.086	-0.081
Project Delivery System (PDS)	-0.083	0.108	-0.247	0.098	1.000	0.082	0.064
BIM Maturity Level (BML)	0.059	-0.065	0.045	0.086	0.082	1.000	0.025
Interoperability(INT)	-0.222	0.042	0.009	-0.081	0.064	0.025	1.000

Table 32: Independent Variables Pearson Correlation Coefficients

A positive correlation between the two variables indicated that when one variable increases the other variable increases. On the other hand, a negative correlation between two variables indicated that when one variable increase the other variable decreases. According to Hinkle, Wiersma, & Jurs (2003), there is a rule for interpreting the strength of a correlation coefficient. They state that: correlation coefficients from 0.90 to 1.00 (−0.90 to −1.00) have strong positive (negative) correlation; correlation coefficients from 0.70 to 0.90 (−0.70 to −0.90) have moderately high positive (negative) correlation;

correlation coefficients from 0.50 to 0.70 (−0.50 to −0.70) have moderate positive (negative) correlation, correlation coefficients from 0.30 to 0.50 (−0.30 to −0.50) have low positive (negative) correlation and correlation coefficients from 0.00 to 0.30 (0.00 to −0.30) have negligible correlation. The rule for interpreting the size (i.e. strength) of a correlation coefficient is presented in Table 33. In this study, the strongest correlation coefficient between the independent variables was -0.285, thus all of the independent variable to independent variable correlations were considered negligible.

Size of Correlation	Interpretation
.90 to 1.00 (−.90 to −1.00)	Very high positive (negative) correlation
.70 to .90 (−.70 to −.90)	High positive (negative) correlation
.50 to .70 (−.50 to −.70)	Moderate positive (negative) correlation
.30 to .50 (−.30 to −.50)	Low positive (negative) correlation
.00 to .30 (.00 to −.30)	Negligible correlation

Table 33: Correlation Coefficient Interpretation

5.1.2 Simulated Model

The multiple linear regression model of the main data included the initial sample cases. To generalize the patterns observed from the sample data and draw conclusions about the larger population (from which the repeated samples were taken from), a simulation study was performed. Simulated data was obtained by performing three steps. The first step was sampling the independent variables from the main data. This can be done because there were negligible correlations between independent variables. In the second step, selected independent variables were processed by using the initial regression model to predict the simulated dependent variable for each case. About

100,000 cases were incorporated in the simulation process. In the third step, the main data and simulated data called the final data were analyzed by multiple linear regression.

The simulated model was validated, frequency distributions for the final data were obtained, a multiple linear regression model for the final data was created, and the overall ANOVA of the simulated model was studied. These results are presented in this section. Additionally, an overall ANOVA for the model, and one-way ANOVA between each independent variable and the dependent variable was processed. One-way ANOVAs were run to evaluate potential differences in mean ROI by categories of independent variables For significant findings, Post Hoc tests were run to understand which category means were statistically significant which were not.

5.1.2.1 Simulated Model Validation

Multiple linear coefficients of the simulated model were expected to be between the initial model's sum of regression β plus its standard error and regression β minus its standard error. This provided information about the consistency of the simulation model with the original model. The β coefficients of the simulated model were checked to see if they were in the allowable range of the initial model β coefficients. All of the β coefficients of the simulation model were within the range of the initial model allowable β range, which completed the validation of the simulation model. The β coefficient validation results are presented in Table 34.

	Original Model Unstandardized Coefficients		Original Model B Range		Simulated Model Unstandardized Coefficients	Simulated Model Coefficient in Original Model B Range
	B	Std. Error	B - Std. Error	B + Std. Error	B	
(Constant)	2.658	0.562	2.097	3.220	2.551	YES
Project Type Building	-0.351	0.333	-0.684	-0.018	-0.339	YES
Project Sector Public	-0.108	0.166	-0.273	0.058	-0.100	YES
Team Member Contractor	-0.262	0.252	-0.514	-0.010	-0.219	YES
Team Member Design Firm	-0.155	0.245	-0.400	0.090	-0.113	YES
Project Delivery System CM at Risk	-0.047	0.204	-0.250	0.157	-0.023	YES
Project Delivery System IDP	0.684	0.264	0.420	0.948	0.654	YES
Project Budget	-0.100	0.052	-0.152	-0.048	-0.100	YES
BIM Maturity Level	0.407	0.112	0.295	0.520	0.439	YES
Interoperability	0.448	0.136	0.313	0.584	0.452	YES

Table 34: Simulation Model Validation

5.1.2.2 Frequency Distributions

In this section, the frequency distribution of independent variables of the final data is presented. The simulated model frequency distributions were same as the main model frequency distributions for all independent variables.

5.1.2.2.1 Project Type

The distribution of project types was analyzed for the 100,137 cases. There were considerably more building project types compared to non-building project types in the data. Building project type comprised 93% of all the cases whereas non-building project type comprised 7% of the cases. The frequency distributions for project type are presented in Table 35 and Figure 27.

PROJECT TYPE

	FREQUENCY	PERCENT	CUMULATIVE PERCENT
BUILDING	93589	93%	93%
NON-BUILDING	6548	7%	100%
TOTAL	100137	100%	

Table 35: Simulated Model Project Type Percent Frequency and Percent Distribution

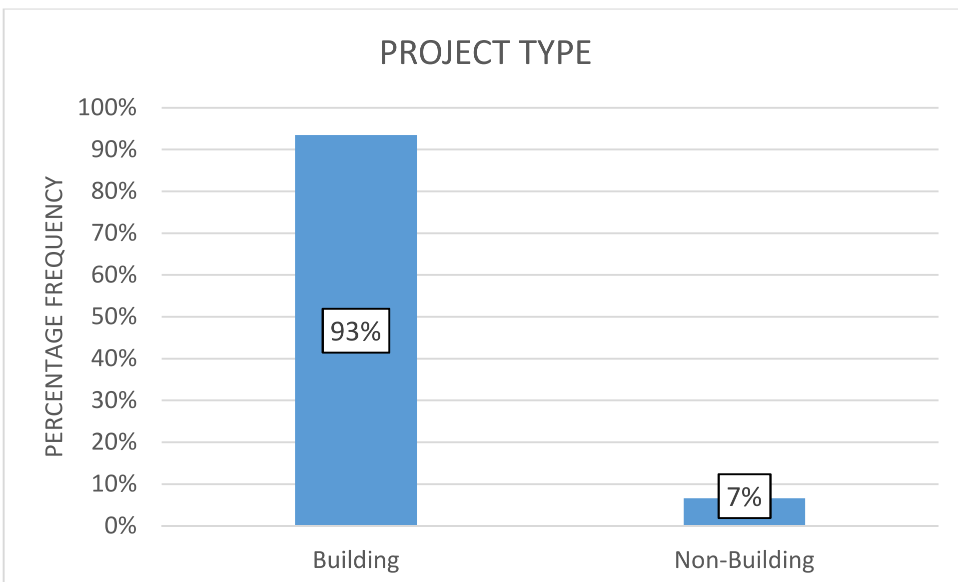

Figure 27: Simulated Model Project Type Percent Frequency Distribution Graph

5.1.2.2.2 Project Sector

The frequency distribution for project sector was obtained for the 100,137 cases in the model. There were relatively more private sector projects, compared to public sector projects. Forty-seven percent of the cases involved public sector projects whereas 53%

of the projects were located in the private sector. Frequency distributions for project sector are presented in Table 36 and Figure 28.

PROJECT SECTOR

	FREQUENCY	PERCENT	CUMULATIVE PERCENT
Public	47082	47%	47%
Private	53055	53%	100%
Total	100137	100%	

Table 36: Simulated Model Project Sector Frequency and Percent Distribution

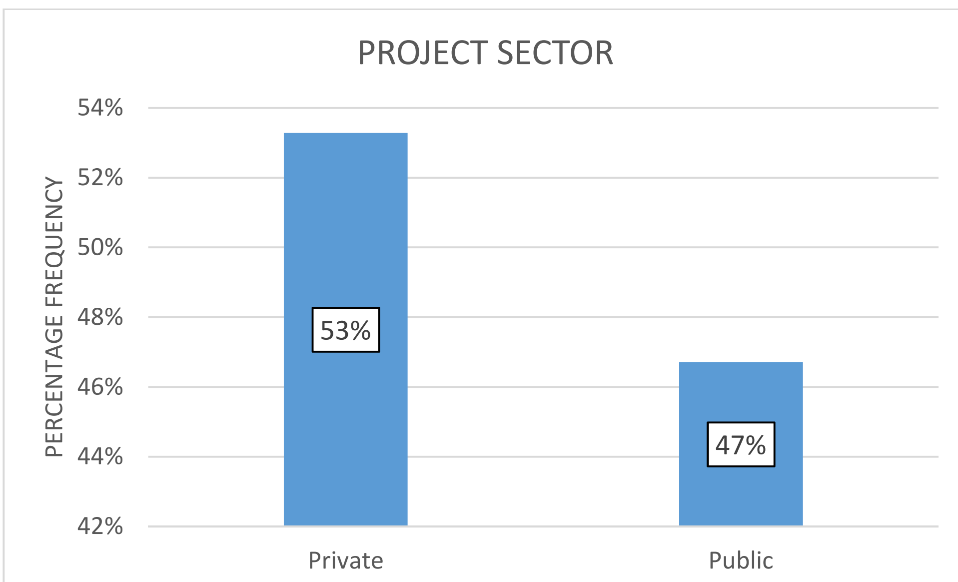

Figure 28: Simulated Model Project Sector Percent Frequency Distribution Graph

5.1.2.2.3 Project Team Members

The distribution of project team members is presented for the 100,137 cases. There were relatively more design firms compared to owners and contractors, in the model data. Also, there were relatively fewer owners compared to design firms and contractors.

Owners were 20% of the project team members while contractors were 30%. Design firms were 50% of project team members. The frequency distributions for project team members are presented in Table 37 and Figure 29.

TEAM MEMBER TYPE

	FREQUENCY	PERCENT	CUMULATIVE PERCENT
Owner	19859	20%	20%
Contractor	29691	30%	49%
Design & Engineering Firm	50587	50%	100%
Total	100137	100%	

Table 37: Simulated Model Team Member Type Frequency and Percent Distribution

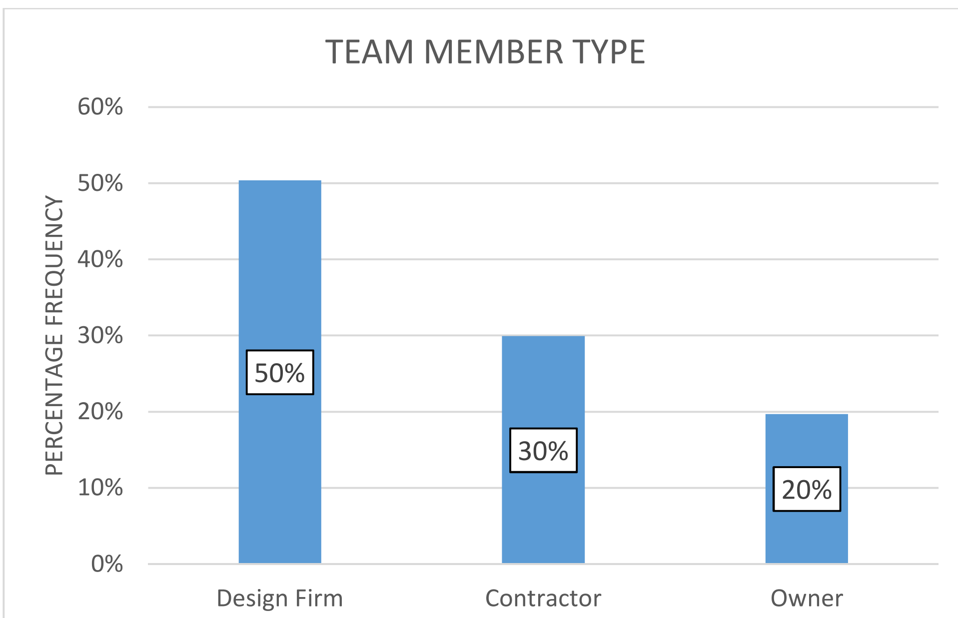

Figure 29: Simulated Model Team Member Type Percent Frequency Distribution Graph

5.1.2.2.4 Project Budget

The frequency distribution for this variable is presented for the 100,137 cases in the model. Project budgets between $10M and $25M were most frequent accounting for 24% of the cases. Project budgets between $500K and $2M were the second most frequent project budget size comprising 12% of the cases. Few project budgets were between 2M and 5M (7%) or between $5M and $10M (8%). The frequency distributions for project budget are presented in Table 38 and Figure 20.

PROJECT BUDGET

	FREQUENCY	PERCENT	CUMULATIVE PERCENT
Less than $500K	5977	6%	6%
+$500K - $2M	12328	12%	18%
+$2M - $5M	6683	7%	25%
+$5M - $10M	8061	8%	33%
+$10M - $25M	24104	24%	57%
More than $25M	42984	43%	100%
Total	100137	100%	

Table 38: Simulated Model Project Budget Frequency and Percent Distribution

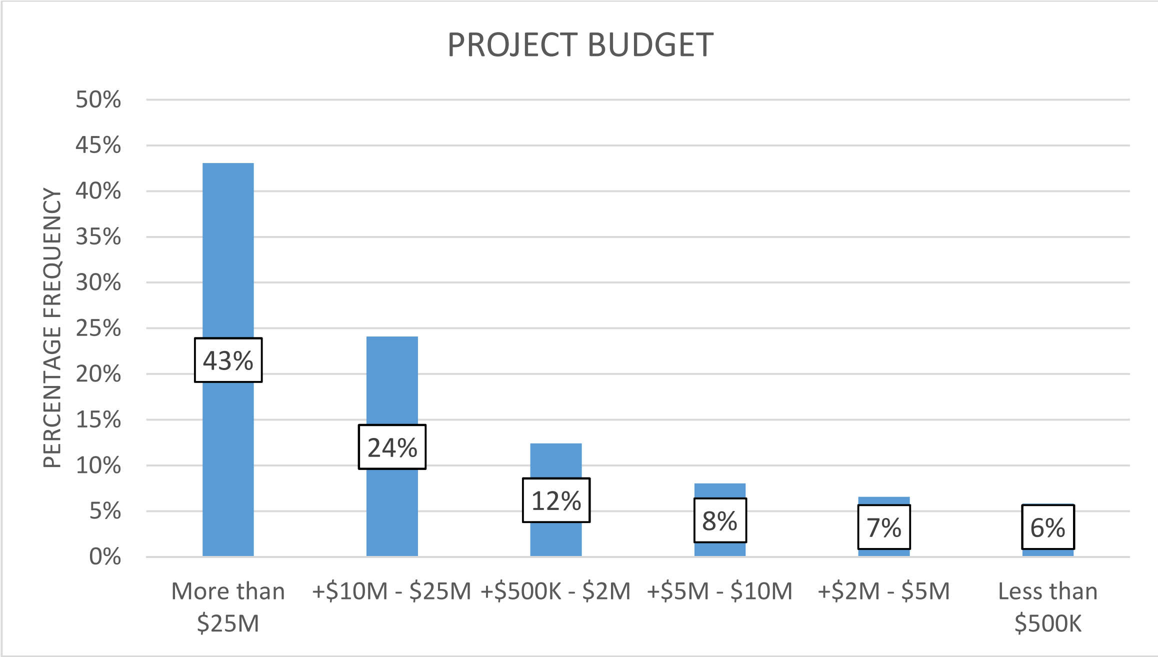

Figure 30: Simulated Model Project Budget Percent Frequency Distribution Graph

5.1.2.2.5 Project Delivery System

The frequency distribution for this variable for the 100,137 cases was obtained. There were relatively more design-build and design-bid-build project delivery systems in the data. Design-build and design-bid-build projects accounted for 56% of the project delivery systems. Construction management at risk project were 33% of the project delivery systems. Eleven percent of the projects had integrated project delivery systems. Frequency distributions for project delivery system are presented in Table 39 and Figure 31.

PROJECT DELIVERY SYSTEM

	FREQUENCY	PERCENT	CUMULATIVE PERCENT
Design-Build + Design-Bid-Build	56525	56%	56%
Construction Management at Risk	32728	33%	89%
Integrated Project Delivery	10884	11%	100%
TOTAL	100137	100%	

Table 39: Simulated Model Project Delivery System Frequency and Percent Distribution

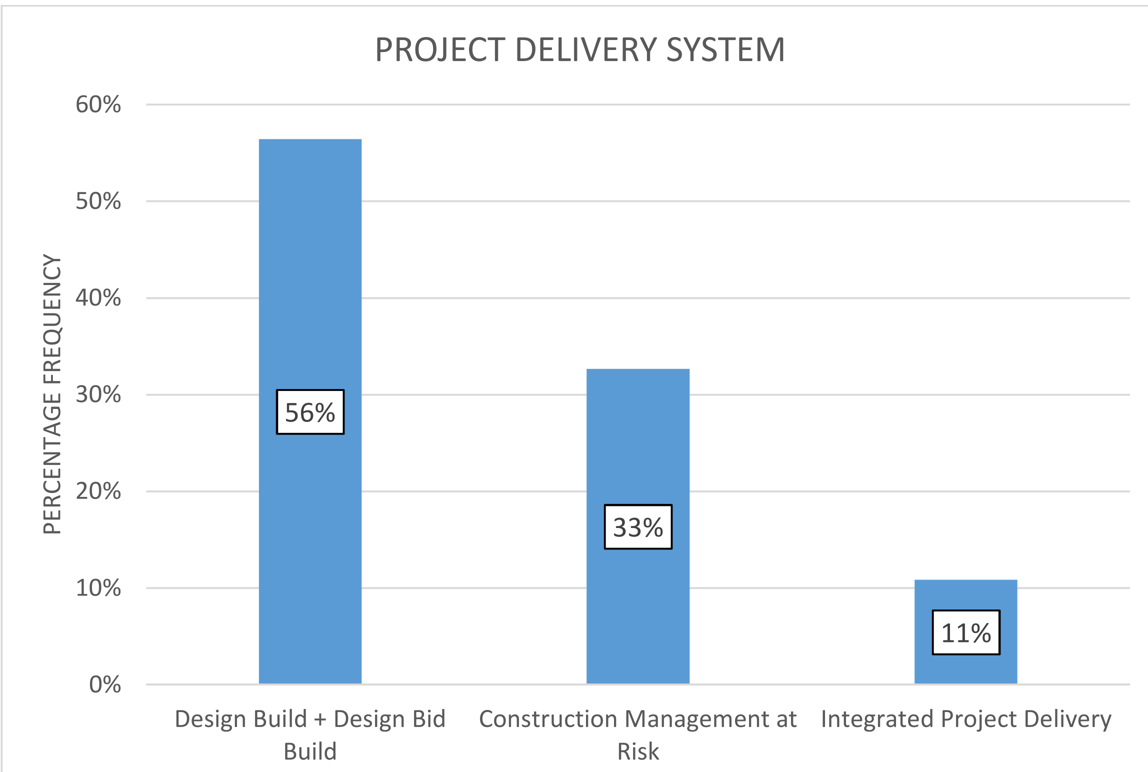

Figure 31: Simulated Model Project Delivery System Percent Frequency Distribution Graph

5.1.2.2.6 BIM Maturity Level

The distribution of BIM maturity level was analyzed for the 100,137 cases in the data. BIM maturity level 2 projects were most common. BIM maturity level 1 projects were found in 24% of the cases, whereas level 2 projects occurred in 46% of the cases. Level 3 BIM maturity level projects were 30% of the projects included in the model data.

Frequency distributions for BIM maturity level are presented in Table 40 and Figure 32.

BIM MATURITY LEVEL

	FREQUENCY	PERCENT	CUMULATIVE PERCENT
Level 1	24108	24%	24%
Level 2	45920	46%	70%
Level 3	30109	30%	100%
TOTAL	100137	100%	

Table 40: Simulated Model BIM Maturity Level Frequency and Percent Distribution

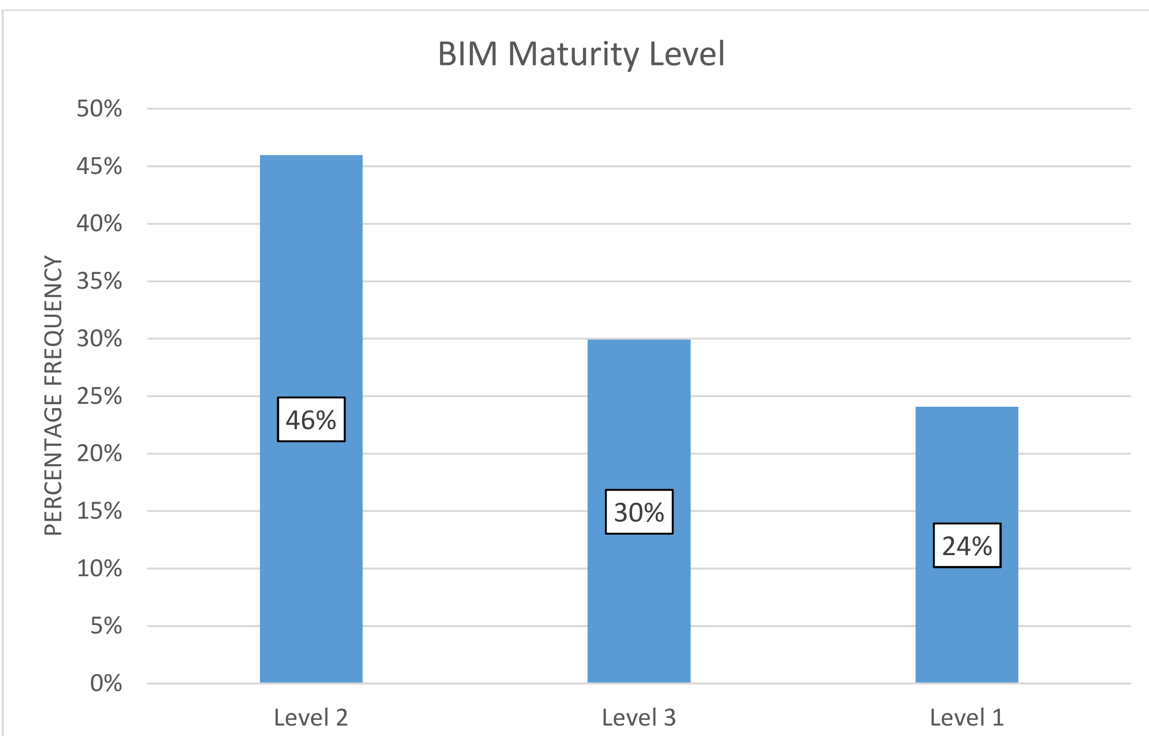

Figure 32: Simulated Model BIM Maturity Level Percent Frequency Distribution Graph

5.1.2.2.7 Interoperability

The distribution of BIM interoperability was analyzed for the 100,137 cases. Medium interoperable projects had the highest distribution whereas low interoperable projects had the lowest distribution. Low interoperable projects constituted 15% of the total data. Medium interoperable projects were 64% of the total data and high interoperable projects occurred in 21% of the data. The frequency distributions of BIM interoperability independent variable are presented in Table 41 and Figure 33.

INTEROPERABILITY

	FREQUENCY	PERCENT	CUMULATIVE PERCENT
Low	15210	15%	15%
Medium	63750	64%	79%
High	21177	21%	100%
TOTAL	100137	100%	

Table 41: Simulated Model Interoperability Frequency and Percent Distribution

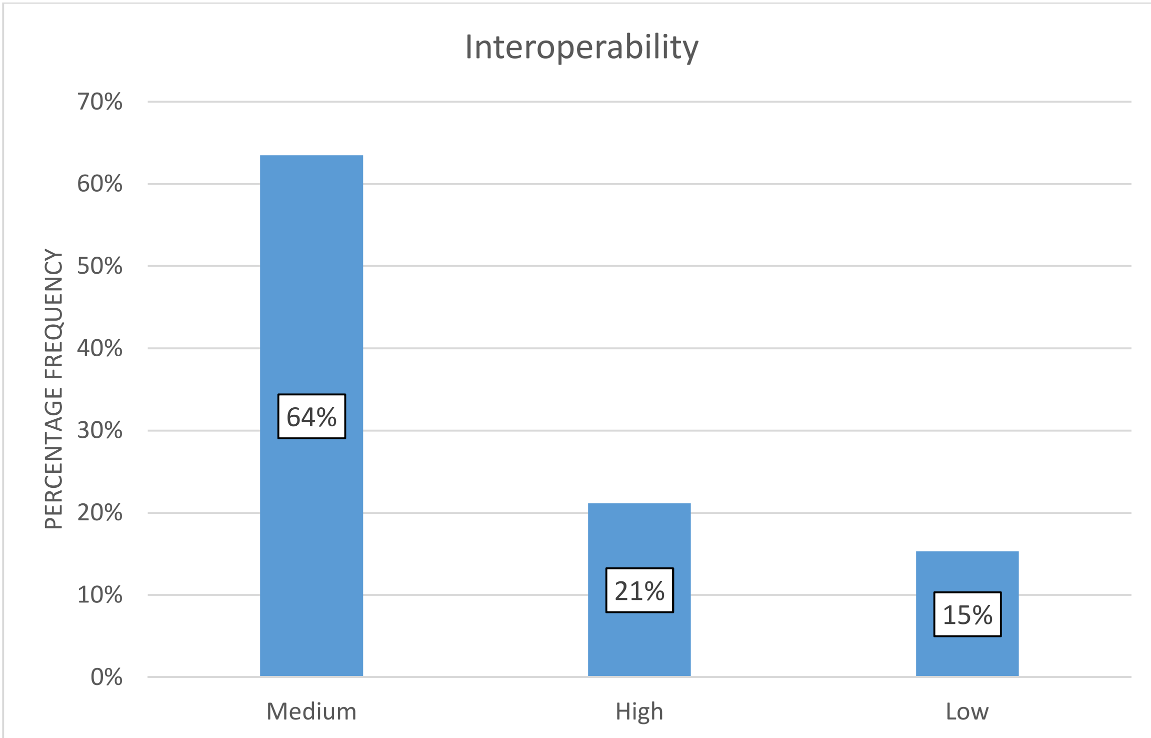

Figure 33: Simulated Model Interoperability Percent Frequency Distribution Graph

5.1.2.2.8 Return on Investment

The distribution of ROI was analyzed among 100,137 cases. It was found that projects having medium ROI had the highest distribution whereas projects having low ROI had the lowest distribution. Low ROI projects represented 0%, medium-low ROI projects represented 2%, medium ROI projects represented 49%, and medium-high ROI projects represented 46%, and high ROI projects represented 3% of the data. Frequency distribution of ROI dependent variable is presented in Table 42 and Figure 34.

RETURN ON INVESTMENT (ROI)

	FREQUENCY	PERCENT	CUMULATIVE PERCENT
Low	2	0%	0%
Medium-Low	1862	2%	2%
Medium	49278	49%	51%
Medium-High	46126	46%	97%
High	2869	3%	100%
TOTAL	100137	100%	

Table 42: Simulated Model Return on Investment Frequency and Percent Distribution

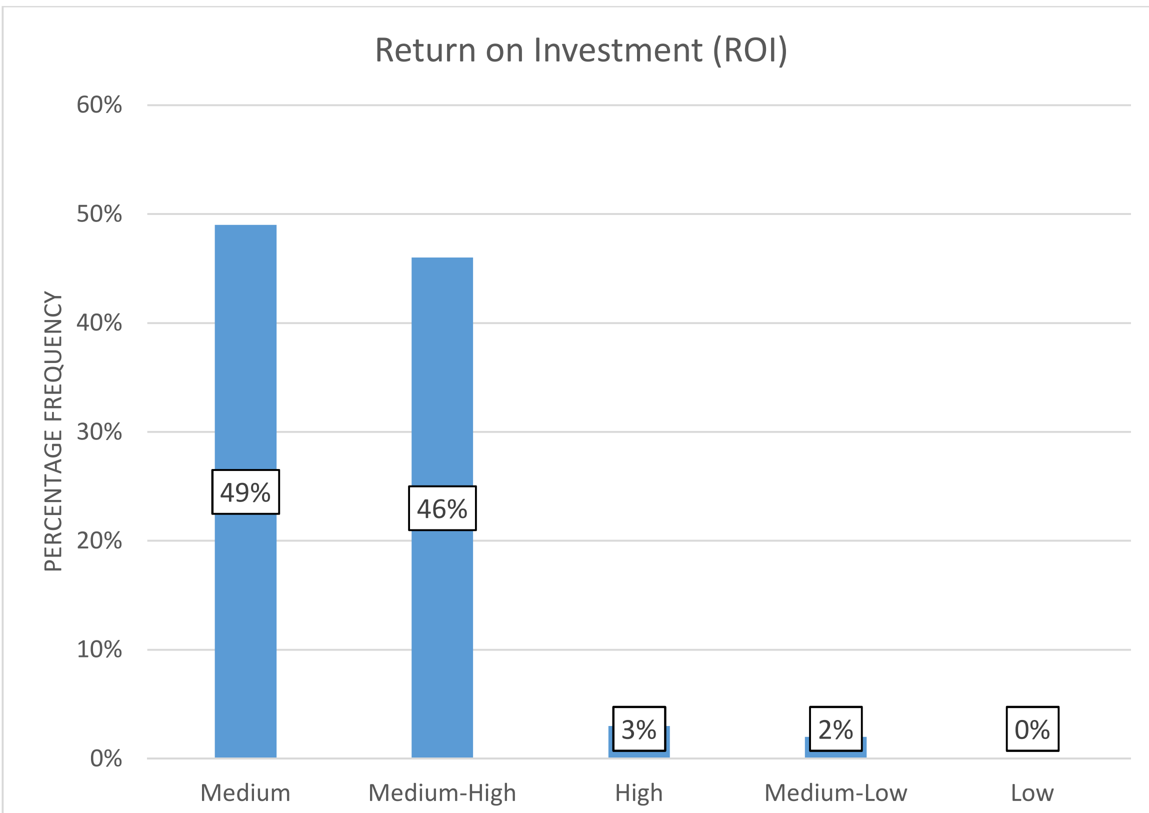

Figure 34: Simulated Model Return on Investment Percent Frequency Distribution Graph

5.1.3 Dependent - Independent Variable Interactions

The multiple linear regression model presents the combined statistical significance effect of all of the independent variables on the dependent variable. To test whether an independent variable by itself has a statistical significance on the dependent variable, a one-way ANOVA test was performed on each independent variable.

5.1.3.1.1.1 ANOVA on ROI and Project Type

The p-value of the ANOVA between dependent variable ROI and the independent variable project type was less than 0.05, which meant there was a difference in ROI by project type. Therefore, the null hypothesis was rejected:

H_{01}: $\beta_1 = 0$. There is no statistically significant relationship between project type and ROI of BIM.

The ROI and Project Type ANOVA table is presented in Table 43.

ANOVA					
Return on Investment					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	649.444	1	649.444	1920.686	0.000
Within Groups	33858.757	100135	0.338		
Total	34508.200	100136			

Table 43: ANOVA on ROI and Project Type

5.1.3.1.1.2 ANOVA on ROI and Project Sector

The p-value of the ANOVA between dependent variable ROI and independent variable project sector was less than 0.05, which meant that the project sector had a statistically significant effect on ROI. Therefore, the null hypothesis was rejected:

H_{02}: $\beta_2 = 0$. There is no statistically significant relationship between project sector and ROI of BIM.

The ROI and Project Sector ANOVA table was presented in Table 44.

ANOVA					
Return on Investment					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	232.420	1	232.420	679.003	0.000
Within Groups	34275.781	100135	0.342		
Total	34508.200	100136			

Table 44: ANOVA on ROI and Project Sector

5.1.3.1.1.3 ANOVA on ROI and Project Team Member

The p-value of the ANOVA between dependent variable ROI and independent variable project team member was less than 0.05, which meant that the project type had a statistically significant effect on ROI. Therefore, the null hypothesis was rejected:

H_{03}: $\beta_3 = 0$. There is no statistically significant relationship between team member category and ROI of BIM.

The ROI and Project Team Member ANOVA table is presented in Table 45.

ANOVA					
Return on Investment					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	579.902	2	289.951	855.744	0.000
Within Groups	33928.298	100134	0.339		
Total	34508.200	100136			

Table 45: ANOVA on ROI and Project Team Member

For independent variables which had a statistically significant effect on ROI and had more than two categories, Post Hoc tests were applied to understand where the significant differences were between categories of the independent variables.

When Tukey's HSD table was analyzed, contractors had a sample mean of 3.40, design firms had a sample mean of 3.51, and the owners had the highest sample mean which was 3.62. Project team member sample means are presented in Table 46.

Return on Investment				
Tukey HSD				
Project Team Member	N	Subset for alpha = 0.05		
		1	2	3
Contractor	29691	3.40		
Design & Engineering Firm	50587		3.51	
Owner	19859			3.62

Table 46: Sample Means of Project Team Member

When the multiple comparison table 47 were analyzed, it was found that there was a difference in mean ROI for all of the categories because the corresponding p-values were less than 0.05. The greatest difference in ROI was between owners and contractors. The difference between the two categories was 0.220. ROI and Project Team Member multiple comparison table is presented in Table 47.

Multiple Comparisons						
Dependent Variable:	Return on Investment					
Tukey HSD						
(I) Project Team Member		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Owner	Contractor	.220*	0.005	0.000	0.21	0.23
	Design & Engineering Firm	.118*	0.005	0.000	0.11	0.13
Contractor	Owner	-.220*	0.005	0.000	-0.23	-0.21
	Design & Engineering Firm	-.102*	0.004	0.000	-0.11	-0.09
Design & Engineering Firm	Owner	-.118*	0.005	0.000	-0.13	-0.11
	Contractor	.102*	0.004	0.000	0.09	0.11

Table 47: Member Multiple Comparison for ROI and Project Team Member

5.1.3.1.1.4 ANOVA on ROI and Project Budget

The p-value of the ANOVA between dependent variable ROI and independent variable project budget was less than 0.05, which meant that project team member had a statistically significant effect on ROI. Therefore, the null hypothesis was rejected:

H_{04}: $\beta_4 = 0$. There is no statistically significant relationship between project budget and ROI of BIM.

The ROI and Project Budget ANOVA table is presented in Table 48.

ANOVA					
Return on Investment					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2770.907	5	554.181	1748.439	0.000
Within Groups	31737.294	100131	0.317		
Total	34508.200	100136			

Table 48: ANOVA on ROI and Project Budget

When Tukey's HSD table was analyzed, project budgets less than $500K had the largest sample mean of 3.87, and this means decreased gradually and had the lowest sample mean value for the project with more than $25M budgets which were 3.37. Project budget sample means are presented in Table 49.

Return on Investment							
Tukey HSD							
		Subset for alpha = 0.05					
Project Budget	N	1	2	3	4	5	6
More than $25M	42984	3.37					
+$10M - $25M	24104		3.45				
+$5M - $10M	8061			3.51			
+$2M - $5M	6683				3.63		
+$500K - $2M	12328					3.79	
Less than $500K	5977						3.87

Table 49: Project Budget Sample Means

When the multiple comparison Table 50 was analyzed tables presented, all of the categories had a significant effect on ROI because the corresponding p-value was less than 0.05 and the categories had statistically significant difference from each other. The greatest mean difference was between Less than $500K and More than $25M categories. The difference between the two categories was 0.497.

Also, it was observed that as ROI value increases the project budget value decreases. ROI and Project Budget multiple comparison table is presented in Table 50.

Multiple Comparisons						
Dependent Variable:		Return on Investment				
Tukey HSD						
(I) Project Budget		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Less than $500K	+$500K - $2M	.074*	0.009	0.000	0.05	0.10
	+$2M - $5M	.235*	0.010	0.000	0.21	0.26
	+$5M - $10M	.357*	0.010	0.000	0.33	0.38
	+$10M - $25M	.420*	0.008	0.000	0.40	0.44
	More than $25M	.497*	0.008	0.000	0.47	0.52
+$500K - $2M	Less than $500K	-.074*	0.009	0.000	-0.10	-0.05
	+$2M - $5M	.161*	0.009	0.000	0.14	0.19
	+$5M - $10M	.283*	0.008	0.000	0.26	0.31
	+$10M - $25M	.346*	0.006	0.000	0.33	0.36
	More than $25M	.423*	0.006	0.000	0.41	0.44
+$2M - $5M	Less than $500K	-.235*	0.010	0.000	-0.26	-0.21
	+$500K - $2M	-.161*	0.009	0.000	-0.19	-0.14
	+$5M - $10M	.122*	0.009	0.000	0.10	0.15
	+$10M - $25M	.185*	0.008	0.000	0.16	0.21
	More than $25M	.261*	0.007	0.000	0.24	0.28
+$5M - $10M	Less than $500K	-.357*	0.010	0.000	-0.38	-0.33
	+$500K - $2M	-.283*	0.008	0.000	-0.31	-0.26
	+$2M - $5M	-.122*	0.009	0.000	-0.15	-0.10
	+$10M - $25M	.063*	0.007	0.000	0.04	0.08
	More than $25M	.140*	0.007	0.000	0.12	0.16

+$10M - $25M	Less than $500K	-.420*	0.008	0.000	-0.44	-0.40
	+$500K - $2M	-.346*	0.006	0.000	-0.36	-0.33
	+$2M - $5M	-.185*	0.008	0.000	-0.21	-0.16
	+$5M - $10M	-.063*	0.007	0.000	-0.08	-0.04
	More than $25M	.076*	0.005	0.000	0.06	0.09
More than $25M	Less than $500K	-.497*	0.008	0.000	-0.52	-0.47
	+$500K - $2M	-.423*	0.006	0.000	-0.44	-0.41
	+$2M - $5M	-.261*	0.007	0.000	-0.28	-0.24
	+$5M - $10M	-.140*	0.007	0.000	-0.16	-0.12
	+$10M - $25M	-.076*	0.005	0.000	-0.09	-0.06

Table 50: Member Multiple Comparison for ROI and Project Budget

5.1.3.1.1.5ANOVA on ROI and Project Delivery System

The p-value of the ANOVA between dependent variable ROI and independent variable project delivery system was less than 0.05, which meant that the project delivery system had a statistically significant effect on ROI. Therefore, the null hypothesis was rejected.

H_{05}: $\beta_5 = 0$. There is no statistically significant relationship between project delivery method and ROI of BIM.

The ROI and Project Delivery System ANOVA is presented in Table 51.

ANOVA					
Return on Investment					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4390.646	2	2195.323	7298.949	0.000
Within Groups	30117.554	100134	0.301		
Total	34508.200	100136			

Table 51: ANOVA on ROI and Project Delivery System

When Tukey's HSD table was analyzed, construction management at risk had a sample mean of 3.41, design-bid-build and design-build had a sample mean of 3.43 and integrated project delivery had the highest sample mean which was 4.10. Project delivery system sample means are presented in Table 52.

Return on Investment				
Tukey HSD				
Project Delivery System	N	Subset for alpha = 0.05		
		1	2	3
Construction Management at Risk	32728	3.41		
Design Build + DBB	56525		3.43	
Integrated Project Delivery	10884			4.10

Table 52: Sample Means of Project Delivery System

When the multiple comparison Table 53 was analyzed, all of the categories had a significant effect on ROI because the corresponding p-value was less than 0.05 and the categories were significantly different from each other. The greatest mean difference was between integrated project delivery and construction management categories. The difference between the two categories was 0.687. ROI and Project Delivery System multiple comparison is presented in Table 53.

Multiple Comparisons						
Dependent Variable:		Return on Investment				
Tukey HSD						
(I) Project Delivery System		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Design Build + DBB	Construction Management at Risk	.024*	0.004	0.000	0.01	0.03
	Integrated Project Delivery	-.663*	0.006	0.000	-0.68	-0.65
Construction Management at Risk	Design Build + DBB	-.024*	0.004	0.000	-0.03	-0.01
	Integrated Project Delivery	-.687*	0.006	0.000	-0.70	-0.67
Integrated Project Delivery	Design Build + DBB	.663*	0.006	0.000	0.65	0.68
	Construction Management at Risk	.687*	0.006	0.000	0.67	0.70

Table 53: Member Multiple Comparison for ROI and Project Delivery System

5.1.3.1.1.6 ANOVA on ROI and BIM Maturity Level

The p-value of the ANOVA between dependent variable ROI and independent variable BIM maturity level was less than 0.05, which meant that BIM maturity level had a statistically significant effect on ROI. Therefore, the null hypothesis was rejected.

H_{06}: β_6= 0. There is no statistically significant relationship between BIM maturity level and ROI of BIM.

The ROI and BIM maturity level ANOVA is presented in Table 54.

ANOVA					
Return on Investment					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	10452.128	2	5226.064	21753.622	0.000
Within Groups	24056.072	100134	0.240		
Total	34508.200	100136			

Table 54: ANOVA on ROI and BIM Maturity Level

When Tukey's HSD table was analyzed, BIM maturity level 1 had a sample mean of 3.06, BIM maturity level 2 had a sample mean of 3.44 and BIM maturity level 3 had the highest sample mean which was 3.94. BIM maturity level sample means are presented in Table 55.

Return on Investment				
Tukey HSD				
BIM Maturity Level	N	Subset for alpha = 0.05		
		1	2	3
Level 1	24108	3.06		
Level 2	45920		3.44	
Level 3	30109			3.94

Table 55: Sample Means of BIM Maturity Level

When the multiple comparison Table 56 was analyzed, all of the categories had a significant effect on ROI because the corresponding p-value was less than 0.05 and the categories are significantly different from each other. Also, it was observed that BIM maturity level 3 had the highest ROI value whereas BIM maturity level 1 had the lowest ROI value. The mean difference between the two categories was 0.871. ROI and BIM maturity level comparison is presented in Table 56.

Multiple Comparisons						
Dependent Variable:		Return on Investment				
Tukey HSD						
(I) BIM Maturity Level		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Level 1	Level 2	-.376*	0.004	0.000	-0.39	-0.37
	Level 3	-.871*	0.004	0.000	-0.88	-0.86
Level 2	Level 1	.376*	0.004	0.000	0.37	0.39
	Level 3	-.495*	0.004	0.000	-0.50	-0.49
Level 3	Level 1	.871*	0.004	0.000	0.86	0.88
	Level 2	.495*	0.004	0.000	0.49	0.50

Table 56: Member Multiple Comparison for ROI and BIM Maturity Level

5.1.3.1.1.7 ANOVA on ROI and Interoperability

The p-value of the ANOVA between dependent variable ROI and independent variable interoperability was less than 0.05, which meant that interoperability had a statistically significant effect on ROI. Therefore, the null hypothesis was rejected.

H_{07}: $\beta_7 = 0$. There is no statistically significant relationship between interoperability and ROI of BIM.

The ROI and Interoperability ANOVA is presented in Table 57.

ANOVA					
Return on Investment					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7437.274	2	3718.637	13755.053	0.000
Within Groups	27070.926	100134	0.270		
Total	34508.200	100136			

Table 57: ANOVA on ROI and Interoperability

When Tukey's HSD table was analyzed, low interoperability had a sample mean of 3.00, medium interoperability had a sample mean of 3.48, and high interoperability had the highest sample mean which was 3.91. Interoperability sample means are presented in Table 58.

Return on Investment				
Tukey HSD				
		Subset for alpha = 0.05		
Interoperability	N	1	2	3
Low	15210	3.00		
Medium	63750		3.48	
High	21177			3.91

Table 58: Sample Means of Interoperability

When the multiple comparison Table 59 was analyzed all of the categories had a significant effect on ROI because the corresponding p-value was less than 0.05 and the categories were significantly different from each other. Also, it was observed that high interoperability has the highest ROI value whereas low interoperability had the lowest ROI value. The mean difference between the two categories was 0.912. ROI and Interoperability comparison is presented in Table 59.

Multiple Comparisons						
Dependent Variable:		Return on Investment				
Tukey HSD						
(I) Interoperability		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Low	Medium	-.477*	0.005	0.000	-0.49	-0.47
	High	-.912*	0.006	0.000	-0.93	-0.90
Medium	Low	.477*	0.005	0.000	0.47	0.49
	High	-.435*	0.004	0.000	-0.44	-0.43
High	Low	.912*	0.006	0.000	0.90	0.93
	Medium	.435*	0.004	0.000	0.43	0.44

Table 59: Member Multiple Comparison for ROI and Interoperability

5.1.4 Analysis of Simulated Model

The final data which was comprised of 100,137 cases, was used for the creation of simulated multiple linear regression model. The multiple linear regression model was used to understand the combined effects of the independent variables on the dependent variable.

The multiple correlation coefficient R = 0.873 indicates the strength of the relationship between dependent and independent variables. R2 =0.762 represents the percentage of variability in ROI that can be explained by the independent variables in this model. This means that 76.2% of the variability in the dependent variable ROI can be explained by the combined effect of the independent variables. The simulated model summary is presented in Table 60.

Simulated Model Summary				
Model	**R**	**R^2**	**Adjusted R^2**	**Standard Error of the Estimate**
Initial	0.873	0.762	0.762	0.286

Table 60: Simulated Model Summary

ANOVA analysis for the whole model had a p-value of zero which was less than 0.05 and it indicated that the combined effect of the independent variables had statistical significance at predicting the ROI. The details of simulated model ANOVA presented in Table 61.

ANOVA						
Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig**
Initial	Regression	26295.282	9.000	2921.698	35619.596	0.000
	Residual	8212.919	100127.000	0.082		
	Total	34508.200	100136.000			

Table 61: Simulated Model ANOVA

The coefficients table of the model is presented below. Each independent variable had a p-value less than 0.05 which means that all of the independent variables had statistical significance in explaining the variability of the dependent variable. The coefficients of the simulated model is presented in Table 62.

Coefficients						
Model		Unstandardized B	Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
Simulation	(Constant)	2.552	0.006		405.669	0.000
	(Constant)	-0.337	0.004	-0.142	-92.039	0.000
	Project Type Building	-0.099	0.002	-0.084	-54.455	0.000
	Project Sector Public	-0.218	0.003	-0.170	-83.086	0.000
	Team Member Contractor	-0.113	0.002	-0.096	-47.180	0.000
	Team Member Design Firm	-0.020	0.002	-0.016	-9.941	0.000
	Project Delivery System CM at Risk	0.660	0.003	0.350	220.043	0.000
	Project Delivery System IDP	-0.101	0.001	-0.282	-182.783	0.000
	Project Budget	0.438	0.001	0.547	354.886	0.000
	BIM Maturity Level	0.451	0.002	0.461	298.705	0.000

Table 62: Simulated Model Coefficients

The interpretation of the coefficients for the simulated model is presented in Table 63.

Variable Kept on Model Background	Variable	B	Interpretation
Non-Building Projects	Building Projects	-0.337	Building projects result in a lesser ROI value when compared to Non-building projects
Private Sector	Pubic Sector	-0.099	Public Sector projects result in a lesser ROI value when compared to Private Sector Projects
Owner	Contractor	-0.218	Contractor BIM implementation result in a lesser ROI value when compared to Owner
Owner	Design-Engineering Firm	-0.113	Design and Engineering Firm BIM implementation result in a lesser ROI value when compared to Owner
DBB&DB	CM at Risk	-0.020	CM at Risk BIM implementation result in a lesser ROI value when compared to DBB & DB
DBB&DB	Integrated Project Delivery	0.660	Integrated Project Delivery BIM implementation result in a higher ROI value when compared to DBB & DB
NA	Project Budget	-0.101	As Project Budget level increases, ROI value decreases
NA	BIM Maturity Level	0.438	As BIM Maturity level increases, ROI value increases
NA	Interoperability	0.451	As BIM Interoperability level increases, ROI value increases

Table 63: Simulated Model Coefficients Interpretation

CHAPTER 6 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This study was undertaken to analyze factors influencing the return on investment of building information modeling. A survey was distributed to construction industry professionals; namely owners, contractors and design firms. 182 responses were obtained and a data screening process was performed to increase reliability of the survey results. After data screening process a total of 137 survey responses were analyzed and used for generation of initial model. Frequencies were obtained and examined for all the variables to understand the distribution of the data. A multiple linear regression model was developed to determine the group effect of all independent variables on the dependent variable Return on Investment of Building Information Modeling. An analysis of variance (ANOVA) for the overall model was conducted to test whether or not the combined effect of all independent variables explained a statistically significant amount of variability in the dependent variable. Validation of the model was performed by cross-validation technique to ensure that the model is reflecting the true relationship between the dependent and independent variables. Finally, a correlation analysis was conducted to examine relationships between the independent variables.

After the generation of the initial multiple linear regression model, the model was used to generate simulated data to infer broader conclusions about the population. A simulated multiple linear regression model was developed and the overall ANOVA of the simulated model was studied. Additional to overall ANOVA for the model, one-way ANOVA between each independent variable and the dependent variable was conducted to evaluate the mean differences between independent variable categories to decide if the mean differences were statistically significant in explaining the variances in the dependent variable. For independent variables which had a statistically significant effect on ROI and had more than two categories, additional Post Hoc tests were applied to understand which category means were statistically significant which were not.

The simulated multiple linear regression analysis showed the independent variables did have a significant effect on the dependent variable ROI of BIM.

Non-building projects had a higher ROI compared to building projects. BIM has been used more extensively in building projects so the building project teams have extensive experience and advancement in BIM compared to non-building project teams. The study results did not show alignment with the BIM adoption difference between building projects and non-building projects. A total number of 137 cases, building projects were reflected in 128 of the cases whereas non-building projects represented only nine cases. The skewed nature of this data could have decreased the validity of findings for infrastructure projects.

The findings also reflected private sector projects had a higher ROI compared to public sector projects. This was an expected result because private sector BIM adoption has accelerated more than in public projects. The private sector has more experience on BIM and its concepts which brings more cost saving in return. However, BIM adoption in the public sector is increasing as well. According to the McGraw Hill Smart Market Report (2012), public owners are increasingly focusing on lowering total lifecycle cost of buildings and BIM implementation is necessary for that purpose. As the public sector increases BIM implementation, the ROI gap between public and private sector is expected to close.

Findings also reflect that owners had a higher ROI compared to contractors and design firms. For contractors, BIM implementation allowed for better planning, reduction in errors, and fewer conflicts which results in cost savings. For design firms, benefits were incurred from consistency in drawings, enhanced visualization, automating spatial interference checking, interfacing analysis, and reliable cost analysis. In short, design firms benefited from the design stage cost savings of BIM whereas contractors benefited from construction stage cost savings. Owner benefited from both of the stages, so it was a natural result that owners had the highest cost benefit from BIM. Owners also had additional savings from building higher quality and better performing buildings on the facility management phase.

The initial expectation for this study was that projects with larger budgets (larger projects) would have a higher ROI on BIM implementation because the number of design errors, RFIs, and RFCs were expected to be higher in those projects. BIM can provide solutions to a large number of problems, leading to more savings. But the results showed just the opposite result. This may be due to project complexity. A project with a higher budget may get fewer benefits compared to extremely complex smaller budgeted projects.

For project delivery type, integrated project delivery had the highest ROI value compared to other project delivery systems. This may be because both BIM and IPD require the early involvement of project team members. Furthermore, BIM requires collaboration between disciplines which is the core competency of integrated project delivery. With design-bid-build, design-build and CM at risk delivery systems, the contractual relationships between parties may diversely affect the communication, integration, and information exchange between project parties which may result a lesser investment returns when compared to IDP.

Interoperability also was examined. As the level of interoperability increased, ROI of BIM also increased. This is most likely because interoperability allows project parties to share, exchange, and manage electronic information easily resulting in information integration and collaboration. Integration and collaboration are the core concepts of BIM which increase the efficiency of the system and bring more cost savings as a result.

The results of this study suggested that as BIM maturity level increases, BIM ROI values increase as well. As BIM adoption capability experience increases, the process gives way to better integration and collaboration between project disciplines, higher quality projects, and in a more efficient way, which results in cost saving.

LIMITATIONS OF THE STUDY

It was desired to obtain as many responses as possible from the industry professionals who had BIM expertise. A major challenge of this study was obtaining a large number of responses survey responses because of the limited time respondents' usually have to answer the survey questions. However, the sample size for the study turned out to be adequate for obtaining statistically significant results.

Recruiting infrastructure companies that implement BIM to participate in the survey was particularly difficult. This is because BIM technologies are used in building construction industry at a wider scale than the infrastructure industry.

A total number of 137 cases, building projects were reflected in 128 of the cases whereas non-building projects represented only nine cases. The skewed nature of this data could have decreased the validity of findings for infrastructure projects.

Furthermore, simply looking at the project budgets may not be enough when assessing the effects of budget on ROI. Project budget and complexity should be evaluated together to understand the real effect of the budget on ROI. It is important to realize that some projects with more limited budgets can still have levels of complexities from a BIM implementation perspective.

Finally, this study focused on the BIM benefits from conceptual design to handover of the project. The facility management was outside the scope of this study, however it is believed that the consideration of facility management increases the ROI value when life-cycle cost are considered.

STUDY ASSUMPTIONS

The following assumptions were made for this study:

- All respondents had sufficient technical knowledge about BIM implementation.
- All respondents had reasonable understanding of the financial aspects of BIM investment.
- All answers were aligned with the respondents' experience with BIM.
- Survey respondents adequately represented the construction industry in a way that allowed for the generalizations of the results to the larger populations.

APPENDIX A: SURVEY INTRODUCTION LETTER

Thank you for taking part in this research survey.

This survey is administered by Civil and Environmental Engineering Department of Wayne State University. The survey is designed for construction industry design & engineering firms, general contractors and owners that implement Building Information Modelling (BIM) technology on their projects. The aim of the survey is to find out the factors affecting Return on Investment (ROI) of BIM. Information gathered from this survey will be written up as a Ph.D. dissertation. It will take approximately 5 minutes to complete this survey. All the answers you provide will be kept in strictest confidentiality.

We appreciate your valuable input and your time for taking the survey,

Best Regards,

APPENDIX B: RESEARCH SURVEY

1. Do you implement BIM technology in your projects? The response options were:
   - Yes
   - No
2. Please select the project type that you generally do the most?
   - Building (residential, commercial, industrial)
   - Non-building (infrastructure)
3. Please select the sector type that you generally operate in most?
   - Public
   - Private
4. Which of the following best defines your company role in construction projects?
   - Owner
   - Contractor
   - Design and Engineering Firm
   - Other (please specify)
5. Which role best defines your current position in your company?
   - Owner
   - Principal/Director/VP
   - Project Manager
   - BIM Manager
   - Designer/Engineer
   - Other (please specify)

6. What functions of BIM technology do you use in your projects? (Please check all that apply).
   - Early design coordination
   - Creation and visualization of 3D models
   - Production of coordinated drawings and construction documents
   - Automated quantity take-off
   - Cost estimating
   - Scheduling and project planning
   - Clash detection and conflict resolution
   - Support on site construction management
   - Simulation & analysis
   - Other (please specify)
7. What is the budget range of your usual projects? Less than $500K
   - +$500K - $2M
   - +$2M - $5M
   - +$5M - $10M
   - +$10M - $25M
   - More than $25M
8. In general, what type of project delivery system do you use for your project?
   - Design-Bid-Build
   - Design-Build
   - Construction Management at Risk
   - Integrated Project Delivery

- Other (please specify)

9. How would you rate your company's BIM maturity level?

    - Level 0 - BIM is not implemented.
    - Level 1 - 3D model created and basic data generation from the model, such as 2D plans, elevations, sections, quantity take offs are obtained. Automated and coordinated views are created.
    - Level 2 - Information exchange between partners is accomplished. Clashes are detected between disciplines. Models are exported and imported into disconnected systems. Time (4th dimension) and Cost (5th dimension) dimensions are added to the model.
    - Level 3 - A single source of model is established and stored in company database. The model is accessible to all project contributors. Complex analyses are performed. Synchronized communications between partners are achieved.

10. How long has your company been working with BIM?

    - < 1 year
    - 1-3 years
    - +3-5 years
    - > 5 years

11. How often does your project team manually re-enter project data from other project parties' applications to your company applications because of incompatibility between systems? The response options were:

    - Never

- Sometimes
- Always

12. How often does your project team spend a considerable amount of time to check that they are working with the correct version of documents, drawings, plans, revisions, etc. because of software incompatibility issues or poor coordination? The response options were:
    - Never
    - Sometimes
    - Always
13. How often do you have rework issues due to using the incorrect version of the project document, plans, drawings, revisions, etc.?
    - Never
    - Sometimes
    - Always
14. Which one of the potential benefits of BIM implementation presented below contributes to cost savings if any? (Please check all that apply).

- Improved understanding of the design
- Improved understanding of the scope
- Better project coordination
- Better document coordination
- Improved quality of the design
- Improved accuracy of construction cost estimating
- Improved constructability

- Reduced number of issues by clash detection
- Reduced number of rework issues
- Reduced amount of waste in time and material
- Reduced amount of claims
- Better planning of construction and design phases
- Improved communication between project team
- Improved overall quality of the project
- Reduced project duration
- Reduced number of Request for Information (RFI)
- Reduced number of submittals
- Reduction in time required to respond RFIs
- Reduction in time for submittal processes
- Better project outcomes
- Other (please specify)

15. Which of the cost items listed below add up to your total BIM investment cost? (Please check all that apply).
    - Software cost
    - Training & consultancy costs
    - Cost for interoperability (seamless exchange and management of electronic information between project participants) solutions
    - Hardware cost
    - Other (please specify)

16. The sixteenth question of the survey was: ROI can be defined as the ratio of the net benefits produced by an investment divided by the cost of the investment and then multiplying the ratio with 100.

$$\text{ROI} = \frac{\text{Gain from Investment} - \text{Cost of Investment}}{\text{Cost of Investment}} \text{ x } 100$$

Based on your previous answers on cost & benefits of BIM implementation, which one of the category below is your best estimate of ROI of BIM implementation for your company?

- Low: ROI ≤ 0 (negative impact; at best no positive impact)
- Medium-Low: 1% ≤ ROI < 25% (some positive experience)
- Medium: 25 % ≤ ROI < 50% (satisfaction with BIM experience and there is room to grow)
- Medium-High: 50% ≤ ROI < 75% (reasonable degree of satisfaction with opportunities to get better)
- High: 75% ≤ ROI (positive impact confirmed, high degree of satisfaction with BIM experience)

REFERENCES

1. Autodesk. (2007). "BIM's return on investment."
2. Azhar, S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. Leadership and management in engineering, 11(3), 241-252.
3. Azhar, S., Hein, M., & Sketo, B. (2008). Building information modeling: Benefits,
4. Barlish, K., & Sullivan, K. (2012). How to measure the benefits of BIM—A case study approach. Automation in construction, 24, 149-159.
5. Bazjanac, V. (2006). Virtual building environments (VBE)-applying information modeling to buildings. August, 29, 2009.
6. Cakan, H., Kazan, E., & Usmen, M. (2014). Investigation of Factors Contributing to Fatal and Nonfatal Roofer Fall Accidents. International Journal of Construction Education and Research, 10(4), 300-317.
7. Carmona, J., & Irwin, K. (2007). BIM: who, what, how and why. Building Operating Management, 54(10), 37-39.
8. Chatterjee, S., & Simonoff, J. S. (2013). Handbook of regression analysis (Vol. 5). John Wiley & Sons.
9. Construction, M. H. (2012). The business value of BIM for infrastructure: Addressing America's infrastructure challenges with collaboration and technology. Smart Market Report.
10. Construction, M. H. (2012). The Business Value of BIM for Infrastructure. Smart MarketReport.

11. Construction, M. H. (2014). The Business Value of BIM for Construction in Major Global Markets: How contractors around the world are driving innovations with Building Information Modelling. Smart MarketReport.
12. Construction, M. H. (2014). The Business Value of BIM for Owners. Smart MarketReport.
13. Dalcher, D. (1993). The new project management mindset for the 21st century. In Procs 1st British Project Management Colloquium.
14. Eastman, C. M., Eastman, C., Teicholz, P., & Sacks, R. (2011). BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors. John Wiley & Sons.
15. Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2008). BIM handbook: A guide to building information modeling for owners, managers, designers. ISBN: 978-0-470-18528-5.
16. El Asmar, M. (2012). Modeling and Benchmarking Performance for the Integrated Project Delivery (IPD) System. Dissertation Abstracts International, 74(01).
17. Feibel, B. J. (2003). Investment performance measurement (Vol. 116). John Wiley & Sons.
18. Friedlob, G. T., & Plewa Jr, F. J. (1996). Understanding return on investment. John Wiley & Sons.
19. GCR, N. (2004). Cost analysis of inadequate interoperability in the US capital facilities industry. National Institute of Standards and Technology (NIST).
20. Gidado, K. I. (1996). Project complexity: The focal point of construction production planning. Construction Management & Economics, 14(3), 213-225.

21. Giel, B. K., & Issa, R. R. (2011). Return on investment analysis of using building information modeling in construction. Journal of Computing in Civil Engineering, 27(5), 511-521.
22. Giel, B. K., Issa, R. R. A., & Olbina, S. (2009). Return on investment analysis of building information modeling in construction. Florida: University of Florida.
23. Gilligan, B., & Kunz, J. (2007). VDC use in 2007: significant value, dramatic growth, and apparent business opportunity. TR171, 36.
24. Grace-Martin, K., & Sweet, S. (2012). Data analysis with SPSS: a first course in applied statistics.
25. Gravetter, F. J., & Wallnau, L. B. (2016). Statistics for the behavioral sciences. Cengage Learning.
26. Gravetter, F. J., & Wallnau, L. B. (2016). Statistics for the behavioral sciences. Cengage Learning.
27. Grayson, J., Gardner, S., & Stephens, M. (2015). Building better models with JMP Pro. SAS Institute.
28. Grilo, A., & Jardim-Goncalves, R. (2010). Value proposition on interoperability of BIM and collaborative working environments. Automation in Construction, 19(5), 522-530.
29. Hale, D. R., Shrestha, P. P., Gibson Jr, G. E., & Migliaccio, G. C. (2009). Empirical comparison of design/build and design/bid/build project delivery methods. Journal of Construction Engineering and Management, 135(7), 579-587.
30. Hardin, B., & McCool, D. (2015). BIM and construction management: proven tools, methods, and workflows. John Wiley & Sons.

31. Hinkle, Wiersma, & Jurs (2003). Applied Statistics for the Behavioral Sciences (5th ed.).
32. Ho, R. (2013). Handbook of univariate and multivariate data analysis with IBM SPSS. Chapman and Hall/CRC.
33. Holness, G. V. (2006). Building information modeling. ASHRAE journal, 48(8), 38.
34. Holness, G. V. (2006). Building information modeling. ASHRAE journal, 48(8), 38.
35. Holness, G. V. (2008). BIM Gaining Momentum.
36. How To Adopt BIM Workflow for Civil Projects | Autodesk. (2018, October), How to adopt and adapt to a BIM workflow for civil projects. Retrieved from: https://www.autodesk.com/solutions/bim/how-to-adopt-bim-workflow-for-civil-projects
37. Construction Surveys - Wage and Hour Division (WHD) - U.S. Department of Labor, (2013, April). Retrieved from: https://www.dol.gov/whd/programs/dbra/Survey/surveys.htm
38. Huang, X. (2011). An analysis of the selection of project contractor in the construction management process. International Journal of Business and Management, 6(3), 184.
39. Kassel, D. S. (2016). Managing public sector projects: A strategic framework for success in an era of downsized government. Taylor & Francis.
40. Khosrowshahi, F., & Arayici, Y. (2012). Roadmap for implementation of BIM in the UK construction industry. Engineering, Construction and Architectural Management, 19(6), 610-635.

41. Konchar, M., & Sanvido, V. (1998). Comparison of US project delivery systems. Journal of construction engineering and management, 124(6), 435-444.
42. Korkmaz, S., Riley, D., & Horman, M. (2010). Piloting evaluation metrics for sustainable high-performance building project delivery. Journal of Construction Engineering and Management, 136(8), 877-885.
43. Meyers, L. S., Gamst, G. C., & Guarino, A. J. (2013). Performing data analysis using IBM SPSS. John Wiley & Sons.
44. Mollaoglu, S., Syal, C. M., & CPC, C. (2015). Adoption of Building Information Modeling in Small Size Home-Building-Businesses.
45. Mukaka, M. M. (2012). A guide to appropriate use of correlation coefficient in medical research. Malawi Medical Journal, 24(3), 69-71.
46. of the 44th Annual Conference of the Associated Schools of Construction (ASC)
47. Oyetunji, A. A., & Anderson, S. D. (2006). Relative effectiveness of project delivery and contract strategies. Journal of Construction Engineering and Management, 132(1), 3-13.
48. Perkins, E. A. (2007). Building Information Modeling Implementation in the Construction Industry.
49. Phillips, P. P., & Phillips, J. J. (2006). Return on investment (ROI) basics. American Society for Training and Development.
50. Porwal, A., & Hewage, K. N. (2013). Building Information Modeling (BIM) partnering framework for public construction projects. Automation in Construction, 31, 204-214.

51. Remington, K., & Pollack, J. (2007). Tools for complex projects. Gower Publishing, Ltd.

52. Rhemtulla, M., Brosseau-Liard, P. É., & Savalei, V. (2012). When can categorical variables be treated as continuous? A comparison of robust continuous and categorical SEM estimation methods under suboptimal conditions. Psychological methods, 17(3), 354.

53. risks and challenges. In T. Sulbaran, & C. Sterling (Eds.), International Proceedings

54. Schachner, L. (1973). Return on investment--Its values, determination and uses. The CPA Journal (pre-1986), 43(000004), 277.

55. Schafer, J. L. (1999). Multiple imputation: a primer. Statistical methods in medical research, 8(1), 3-15.

56. Succar, B. (2009). Building information modelling framework: A research and delivery foundation for industry stakeholders. Automation in construction, 18(3), 357-375.

57. Succar, B., Sher, W., & Williams, A. (2012). Measuring BIM performance: Five metrics. Architectural Engineering and Design Management, 8(2), 120-142.

58. Succar, B. (2010, May). The five components of BIM performance measurement. In CIB World Congress (pp. 2-50).

59. Taxén, L., & Lillieskӧld, J. (2008). Images as action instruments in complex projects. International Journal of Project Management, 26(5), 527-536.

60. Tse, T. C. K., Wong, K. D. A., & Wong, K. W. F. (2005). The utilisation of building information models in nD modelling: a study of data interfacing and adoption barriers. Journal of Information Technology in Construction (ITcon), 10(8), 85-110.
61. Weiss, D. J. (2006). Analysis of Variance and Functional Measurement: A Practical Guide Includes CD-ROM (Vol. 1). Oxford University Press.
62. Welkowitz, J., Cohen, B. H., & Lea, R. B. (2011). Introductory statistics for the behavioral sciences. John Wiley & Sons.
63. Wiley, J. F., & Pace, L. A. (2012). Beginning R. Apress: Imprint: Apress,.
64. Williams, Terry M. "The need for new paradigms for complex projects." International journal of project management 17.5 (1999): 269-273.
65. Zhang, Y., & Wang, G. (2009, September). Cooperation between building information modeling and integrated project delivery method leads to paradigm shift of AEC industry. In Management and Service Science, 2009. MASS'09. International Conference on (pp. 1-4). IEEE.

ABSTRACT

ANALYSIS OF FACTORS INFLUENCING RETURN ON INVESTMENT (ROI) FOR BUILDING INFORMATION MODELING (BIM) IMPLEMENTATION

by

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A research study was conducted to investigate and understand factors influencing Return on Investment of Building Information Modeling (BIM).

Research data was collected from 182 industry professionals (design firms, contractors and owners) using a survey instrument. The research data were evaluated by examining frequency distributions and running statistical analyses including an analysis of variance with post hoc tests and a multiple linear regression analysis. Furthermore, a simulation study was conducted to infer conclusions about the larger population from which the repeated samples were taken. The research findings revealed that the factors contributing to Return on Investment of BIM implementation were: project type, project sector, project team members, project budget, project delivery systems, interoperability, and BIM maturity level.

AUTOBIOGRAPHICAL STATEMENT

Tugce Kulaksiz graduated from Middle East Technical University, Turkey in 2009 with a B.S. degree in civil engineering. She graduated from Middle East Technical University, Turkey in 2012 with a M.S. degree in industrial engineering – engineering management. She was awarded a performance award – most successful student in the Master of Science of Engineering Management Department. She joined the Wayne State University Civil Engineering Department at 2016 to pursue her Ph.D. studies specializing in the Construction Management area with a minor in Industrial Engineering.

Tugce Kulaksiz worked in top international firms, and she has been involved in all aspects of project management in the construction industry, namely leading cross-functional teams, schedule management, cost management, risk management, contract management, investment feasibility analysis, ERP architecture, program workload planning, market research and strategical planning. She teaches the Engineering Economy course at the Wayne State University Civil and Environmental Engineering Department. She served as a Graduate Teaching Assistant and Research Fellow at Wayne State University during her graduate education.