2016

The effect of Building Information Modeling on Design and Construction Industry

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THE EFFECT OF BUILDING INFORMATION MODELING ON DESIGN AND CONSTRUCTION INDUSTRY

by

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A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Civil, Environmental and Construction Engineering
in the College of Engineering and Computer Science
at the University of Central Florida
Orlando, Florida

Fall Term
2016

Major Professor: Amr Oloufa

ABSTRACT

Construction industry's evolution is, historically, in the lowest level, if compared to other industries, such as auto manufacturing. Construction is a multidisciplinary industry, considering that designers, contractors, and owners are all involved in the same project, each one seeking their own interests. The complex environment surrounding design and construction makes the decision-makers hesitate about adopting new methodology. Building Information Modeling (BIM) is a new method and technology, which can improve both the design and the construction processes. The adoption of BIM is increasing significantly over the last years, and its effects can be seen on real life projects.

In order to understand the effect of BIM on the design and construction industry, we have created a comprehensive survey, consisting of a general questionnaire and experts' interviews. The general questionnaire concentrated on most of BIM issues, while the interviews focused on specific points arisen from the general questionnaire. Most of the published papers in this area justify BIM adoption by focusing on BIM ROI, and the comparison between project with and without BIM. In this research, however, we tried first to understand BIM status at the AEC market, and then to measure its effects. Therefore, we have targeted all the players in the BIM field: engineers, architects, contractors, and owners.

Through the general questionnaire, we have measured the relationship between the independent variables and outcome variables. The independent variables are: motivations, concerns, investment needed, software, valuable benefits, success measures, and BIM uses. The outcome variables include: companies' role, sector, specialty, market level, level of

implementation, years of implementation, and experience. In the second part of the research, we have conducted a series of subject matter interviews to measure the effect of BIM uses and its intangible benefits. For the experts' interviews, we designed a structured interview which covers two major areas: BIM uses, and intangible benefits. Both areas derived from the general questionnaire, and we aimed to measure their effects on real life projects.

After analyzing the general questionnaire by using Person Chi-Square test, the results shown a significant relationship between independent variables and outcome variables. Participants' responses shown that they share common objectives when establishing BIM such as: increasing communication, reducing rework, increasing coordination and collaboration between parties, improving quality, and increasing productivity. We have found that the use of BIM is varied, and the large companies are taking advantage of BIM technology. In addition, the majority of the participants indicate that BIM has a positive ROI, and its adoption generates more business.

The experts' interviews uncovered the fact that AEC parties have common understanding about the intangible benefits, even though they perceive the benefits differently. The diverse views of intangibles' benefits were influenced by the distinct role of each party. Moreover, experts share information about BIM project, and the project outcomes are successful on the following metrics: cost, schedule, number of RFI, number of change orders, and quality.

This work is dedicated to my parents "Saleh" and "Jouharah", my wife "Mashal", my kids "Saleh" and "Janna", my brothers "Mansour", "Talal" and "Bader", and my sisters "Hind" and "Sara".

ACKNOWLEDGMENTS

I would like to express my gratitude to my professor Dr. Amr Oloufa for his guidance and support during my academic life in UCF. He spent a lot of time teaching me and guiding me to be a good researcher. Dr. Oloufa is the cause of every success I have accomplished during my PhD journey.

Also, I would like to thank my committee members, Dr. Omer Tatari, Dr. Nizam Uddin, Dr. Mustapha Mouloua, and Dr. Petros Xanthopoulos for their time and efforts during the research period. Their insightful comments have guided me to the right research direction.

Thanks to the Orland Revit Users Group (ORUG), and the Central Florida Contractors' BIM User Group (CFCBUG) for their help in providing me with information and data needed to conduct this research.

And finally, thanks to my parents, my wife, and the rest of my family, for their great support during my long years of education.

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LIST OF ABBREVIATIONS

3-D	Three Dimensions
4-D	Three Dimensions + Time
5-D	Four Dimensions + Money
AIA	American Institutes of Architects
AEC	Architecture/ Engineering/ Construction
AGC	Associated General Contractors of America
AEC	Architecture, Engineering and Construction
AECO	Architecture, Engineering, Construction, and Operation
ASCE	The American Society of Civil Engineering
ASCE-CI	ASCE Construction Institute
BIM	Building Information Modeling
BIS	Business Innovation and Skills
CAD	Computer Aided Design
CMM	Capability Maturity Model
CO	Change Order

CMAA	Construction Management Association of America
CIFE	Center of Integrated Facility Engineering
DE	Driving Power
DeP	Dependency Power
GC	General Contractor
GSA	General Services A0dministration
IB	Intangible Benefits
I-CMM	NBIMS Interactive Capability Maturity Model
ISM	Interpretive Structural Modeling
IT	Information Technology
KPI	Key performance Indicator
NAVFAC	Naval Facilities Engineering Command
NBIMS	National BIM Standard
NIST	National Institute of Standard and Technology
ROI	Return of Investment
RFI	Request for Information

SMEs	Subject Matter Experts
VDC	Virtual Design and Construction

CHAPTER 1: INTRODUCTION

1.1 Background

Historically, the evolution in construction industry is in the lowest level, when compared to other industries such as the auto manufacturing industry. A study conducted by the Center of Integrated Facility Engineering (CIFE) about construction industry labor productivity indicates that construction productivity "has declined 20% from 1964 to 2003," compared to manufacturing productivity's increase of 120% (Teicholz 2001). The 2004 report sustains that "poor interoperability and data management cost the construction industry approximately $15.8 billion" (GCR and NIST 2004, Suermann and Issa 2009).

Almost every construction projects face issues, such as change orders, which associated to contract adjustments cost the industry from 5 to 10% of its total value (Finke 1998, Schwartzkopf 2004, SERAG 2006). According to the Bureau (2015), the totality of construction works put in place in 2015 figured $1125 billion (Bureau 2015), meaning that construction problems might have cost the industry around $58 billion dollars in that year. In addition, the 2004 report indicates that "poor interoperability and data management cost the construction industry approximately $15.8 billion" (GCR and NIST 2004, Suermann and Issa 2009). The lack of quality in information exchange between the project's parties is one of the main causes of project overrun (Love, Edwards et al. 2011, Crotty 2013).

Reports showed that in the state of Massachusetts, *50%* of the road projects finished over budget, and *33%* of the projects were delayed (Ford 2011, Love, Simpson et al. 2013). Likewise, in Australia, Blake Waldron conducted a survey that covered infrastructure projects, and found the majority of these projects to be delivered late, over budget and with lower quality than expected (Waldron 2011). Moreover, the high cost, associated with the change orders due to the lack of design or specification during the construction progress, is another factor that increases expenditure on construction projects.

Building Information Modeling (BIM) is considered a new technology in design and the construction market. The advanced features of BIM allow the architecture, engineering and construction (AEC) professionals to create a shared digital model that can be used for the project's life cycle (Young, Jones et al. 2009). Autodesk describes BIM as "an intelligent model-base process that provides insight to help you plan, design, construct and manage buildings and infrastructure" (AutoDesk 2015). "The emergence of BIM, and the evolution of Virtual design and construction (VDC) in the architecture, engineering, and construction (AEC) industry are fundamentally changing the process by which buildings are designed and constructed" (Giel and Issa 2013).

BIM ensures the collaboration between the different parties in a project, and prevents common problems generated by the traditional method of design and information exchange. According to Deke Smith, "a basic premise of BIM is collaboration between different stakeholders at different phases of the life cycle of a facility to insert, extract, update, or modify information in the BIM to support and

reflect the roles of that stakeholder" (Suremann 2009). The nature of the AEC industry is that of a complex, multidisciplinary team working together in a mass interaction environment. Hence, the industry needs a strong communication platform to gather the project's components and reduce the risk of miscommunication between the parties.

1.2 Research Needs

1.2.1 Understanding how BIM is implemented in Design and Construction

BIM is a highly used term in design and construction industry; the reality indicates that AEC professionals are divided on BIM use and its potentialities. Design and construction industries interact, many disciplines are involved, and all affect each other's outcomes. It is important to understand how the different parties perceive BIM and what their expectations are. When analyzing designers and contractors, each have different views about BIM usage. Among the AEC professionals, some still believe in the traditional methods, while others insist that BIM is the method that will change the entire industry.

Adopting new methods or technologies tend to be costly in many aspects. Industry's parties such as owners, designers and contractors need solid evidence to justify the adoption of BIM. Market demand drives the companies to adopt such methods; for instance, in the UK, the government has mandated the use of BIM in public projects (NBS 2014). In the US, it happens in a different way. Public entities are not mandating the use of BIM yet; therefore, the project leaders do not have

enforcement motivation. Moreover, the adoption of new technologies is "limited to the large firms" (Eastman, Teicholz et al. 2011). One of the biggest issues in the BIM field and its applications is the lack of data and published case studies. The employment of BIM is increasing without sufficient empirical studies that support and justify its implementation (Suermann and Issa 2009).

In design, "BIM can be considered an epochal transition" (Eastman, Teicholz et al. 2011). BIM applications provide advanced tools for designing, managing data, visualizing, simulating, and other features that ensure the consistency of the project's drawings and reports. For instance, for architects and engineers, BIM 3D modeling reduces the design cycle time by 20 to 50% (Holness 2006). A report issued by the Massachusetts Port Authority (Massport) indicates that BIM has 51 different uses in analysis, design, construction, data management, waste reduction, facility management and other uses (Massport 2015). Hence, we need to understand which of these features are used, and how effective they are on projects' outcomes.

1.2.2 How BIM is effecting the Design and Construction industry

AEC parties measure the effect of BIM based on common metrics: cost, scheduling, safety, quality, communication, and project management. Project's parties tend to rank these metrics based on their project's objectives. A VDC scorecard report issued by Stanford University ranks cost as the number one objective (CIFE 2013). Cost is associated with many other aspects that affect the industry, such as change orders. Common sense suggests that companies tend to adopt new technology that will potentially maximize their return. In the AEC industry, we cannot assume that

designers and contractors have the same objectives when they decide to use BIM in a certain project.

Research suggest that Return of Investment (ROI) is the most effective measure for all parties when using BIM. A 2014 report indicates that 27% of the contractors perceive a moderately positive ROI, and 17% perceive a very positive ROI (Construction 2014). The report also indicates that 33% of the contractors regularly measure the ROI for at least 25% of their projects, while almost 67% measure it only occasionally, or never (Construction 2014). However, there is no sufficient evidence on the effects of BIM in all potentially measurable data. Also, immeasurable aspects such as intangibles, cost, and benefits should be calculated to understand the whole picture of BIM's effect.

1.3 Research Questions

The research examines the effects of BIM in design and construction industry, by conducting a survey questionnaire targeting BIM professionals. This step will be followed by personal interviews with selected BIM professionals based on the outcomes of the questionnaire. The following research question will be explored:

- How are the design and construction companies implementing the Building Information Modeling (BIM) approach?
- To what degree has BIM effected the designers and contractors?

- How is the Building Information Modeling (BIM) approach used in the Design and Construction Industry? And, are they using the same features? If not, what are the most significant features that both are using?
- Is BIM a good investment? If yes, how is BIM generating business and saving money to the designers and contractors?
- What makes BIM different from traditional methods? And how BIM solves the traditional problems?
- How the intangible benefits and BIM uses are contributing in the project success and money saving?

1.4 Research Objective

The main objective of this research is the following:

1. Determine how BIM is implemented in design and construction industry. The data collected from the survey's participants will be used to identify how the industry professionals perceived BIM.
2. Analyze the relationship between firms' roles, market level, experience, BIM level of implementation, and BIM's metrics, adoption motivations, concerns, investment needed, and uses.
3. Determine the effects of BIM features on design and construction. The data collected from the survey's participants will identify what are the features that are frequently used among the designers and contractors.

4. Test the effects of BIM features against common metrics such as cost, schedule, quality, safety, BIM managements and communication. Real life data from designers and constructors will be used to prove to non-BIM users how effective BIM is.
5. Determine the effects of the Intangible benefits of BIM on overall project success. Data was collected from the interviews with BIM experts who represent the AEC industry.

1.5 Scope of Work

The research is divided into two parts as follows:

General Survey: in this step we targeted BIM professionals in design and construction industry. The survey will covered private firms and public entities, taking into consideration the firms' size, experience, and level of BIM implementation. At the beginning of this step, BIM designers and contractors in Orlando, Florida, were reached through their professional groups. Then, BIM professionals around the world were targeted through the professional media channels, as discussed in chapter 3.

Interviews: in this step we focused on the experienced designers, contractors, and owners in the AEC industry. The interviews covered qualitative and quantitative measures. Targeted projects were 100% completed, and the projects could not be the first BIM experience for the companies. Projects were be tested against common

metrics. Also, we measured the effects of BIM based on two major aspects, the intangible benefits, and BIM uses.

1.6 Research Timeline

The start time and planned completion of the research are shown in Figure 1 below:

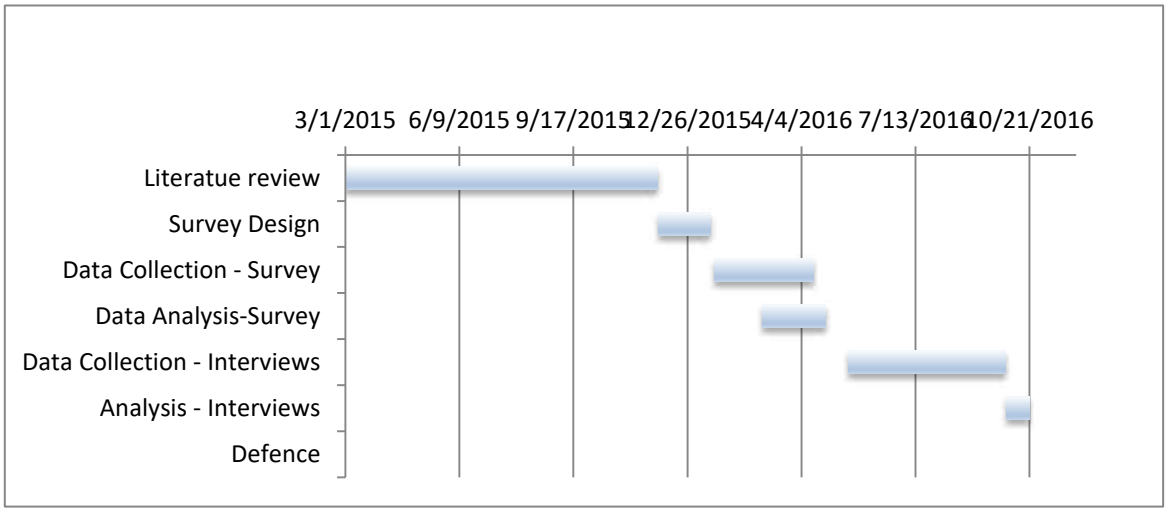


Figure 1. Research Timeline

1.7 Summary

The dissertation consists of five chapters. Chapter one includes the introduction to the research and then addresses the research need, research questions, objectives and scope.

Chapter 2 includes the literature review of previous published studies that cover all areas related to Building Information Modeling (BIM).

Chapter 3 includes the methodology followed in this research. It addresses the procedures of data collection in the general survey and the interviews. The chapter also discusses how the data was prepared and analyzed.

Chapter 4 includes the results and analysis of the data collected. The analysis of the general survey illustrated the perception of BIM; the statistical relationship between the BIM outcome variables, such as sector, role, firm's size, firm's experience; and the independent variables such as motivations, concerns, metrics, uses, and success measures. For the Interviews, we present the Interviews transcripts, and the practical significance derived from the interviews. Also, we present the results of the Interpretive Structural Modeling (ISM) analysis for the intangible benefits.

Chapter 5 highlights how this research is distinguished from previous studies in this area. It addresses the contribution of this research and makes recommendations for future research.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Building Information Modeling (BIM) is considered a new approach in Architecture, Engineering and Construction (AEC) industry. BIM can be seen as a design and visualization tool, but many AEC professionals believe that BIM will lead to a better, and more sustainable construction.

Construction industry is a multidisciplinary environment. Thus, the relationship between the involved parties is critical to the project's success. Every construction project is considered as a unique case, but all projects share the same type of problems such as delays, over cost, design mistakes, contractual conflicts, change orders etc. The parties involved in any construction project have distinct goals. For example, the owner's goal is to finish the project at the least cost and shortest duration, whereas the contractor goal is to make the highest possible profit. These two goals in many cases are contradictory, and may increase the potentiality of conflicts. Consequently, finding a new approach that assures the quality of the project, increases coordination between participants, and minimizes the possibility of conflicts between parties, is the ultimate goal for all participants.

Reviewing the related literature of BIM was not an easy mission. The perception of BIM varied among the AEC stakeholder. Therefore, we will try to synthesize these perspectives, based on the available published literature. This

literature review will focus on the broad concept of BIM, and how BIM utilization will affect the AEC industry.

2.2 AEC Industry

Historically, the evolution in construction industry is in the lowest level, when compared to other industries, such as the auto manufacturing industry. A study conducted by the Center of Integrated Facility Engineering (CIFE) about construction industry labor productivity indicates that construction productivity "has declined 20% from 1964 to 2003," compared to a manufacturing productivity increase of 120% (Teicholz 2001) as cited in (Chelson 2010). The 2004 report insists that "poor interoperability and data management costs the construction industry approximately $15.8 billion" (GCR and NIST 2004, Suermann and Issa 2009).

Construction problems such as change orders are recurrent in most projects. The contract modifications associated with these problems cost the industry from 5 to 10% of its total values (Finke 1998, Schwartzkopf 2004, SERAG 2006). The value of the construction works put in place at the end of 2015 was $1125 billion (Bureau 2015), which means that construction problems might have cost the industry around $58 billion dollars in 2015. In addition, the 2004 report indicates that "poor interoperability and data management cost the construction industry approximately $15.8 billion" (GCR and NIST 2004, Suermann and Issa 2009). The lack of quality in information exchange between the project's parties is one of the main causes of the project's overrun (Love, Edwards et al. 2011, Crotty 2013).

Reports showed that in the state of Massachusetts, *50%* of the road projects finished over budget, and *33%* of the projects were delayed (Ford 2011, Love, Simpson et al. 2013). Also, in Australia, Blake Waldron conducted a survey that covered infrastructure projects, and found that the majority of these projects were delivered late, over budget and in lower quality than required (Waldron 2011). Moreover, the high cost associated with the change orders due to the lack of design or specification during the construction progress, is another factor that causes an extra cost to construction projects.

2.3 Building Information Modeling (BIM)

The idea of Building Information Modeling came out between 1980s and 1990s (Eastman 1992, Linderoth 2010), and took almost 15 years until the positive outcomes of BIM could be seen (Jongeling and Olofsson 2007, Olofsson, Lee et al. 2008, Linderoth 2010). Some AEC professionals consider BIM as a 3D tool that is used for projects' visualization. The majority of AEC professionals, however, believe that BIM is not only a 3D tool, but a whole new approach that will potentially evolve the construction industry. The term Building information Modeling (BIM) "refers to an expensive knowledge domain within the design, construction and operation" (Succar, Sher et al. 2012). BIM is defined as a "set of interacting policies, process and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building life cycle" (Penttilä 2006, Succar 2009). This definition supports the idea that BIM is a compound method that consists of several functions leading to better management of the facility.

Other researchers defined BIM as a "shared digital representation of physical and functional characteristics of any built objects which form a reliable basis for decision" (ISOStandard 2010, Volk, Stengel et al. 2014). It means that BIM is a decision making tool, that allows the project's participants to make decisions based on the project 3D detailed model.

BIM technology allows users to construct a digital precise model. It also "offers a revolutionizing way to design, document and procure building" (Aranda-Mena, Crawford et al. 2009). The design functions integrate with other supportive functions, such as cost estimating and scheduling. This will result in a better understanding of the project, and assure the quality of the project outcomes (Eastman, Teicholz et al. 2011).

BIM has been seen from different points of view. The McGraw Hill report "The Business Value of BIM"; defined BIM as "The process of creating and using digital models for design, construction and/or operation of projects" (Young, Jones et al. 2009) cited in (Barlish and Sullivan 2012). This report sees BIM from the point of view of contractors, and portrays BIM as a design and documentation tool that can be used in construction and/or operation phase.

Barlish and Sullivan (2012) describe BIM as "an intelligent 3D virtual building model, that can be constructed digitally by combining all aspects of building information – into an intelligent format that can be used to develop optimized building solution, with reduced risk and increased values before committing to design proposal" (Woo, Wilsmann et al. 2010) cited in (Barlish and Sullivan 2012). In this

definition, Barlish and Sullivan insist that BIM is a risk-reducer and advanced tool that helps the projects' participants to make valuable changes by using the digital constructed model in the earlier stages of the project.

Also Autodesk describes BIM as "an intelligent model-base process that provides insight to help you plan, design, construct and manage buildings and infrastructure" (AutoDesk 2015). From Autodesk point of view, in Figure 1, BIM is a tool that "turn the information into insight" and will create a value to the project and enhance the productivity and the collaboration,

Figure 2. What is BIM, adopted from (AutoDesk 2015)

BIM represents the model's objects in different ways. The objects can be visualized as "geometric or non-geometric attributes with functional, semantic or topologic information" (Volk, Stengel et al. 2014). Costs or duration could represent the functional information; connectivity represents semantic information; and the object's location represents the topological information.

In addition, Volk, Stengel et al. (2014) differentiate between BIM processes for new and for existing buildings. For the new buildings, they indicate that BIM model can be created during different construction phases, and for different purposes. For existing buildings, the model can be updated if it's available, if not, a new model can be created by using the scanning technology. The two different processes are shown in Figure 3.

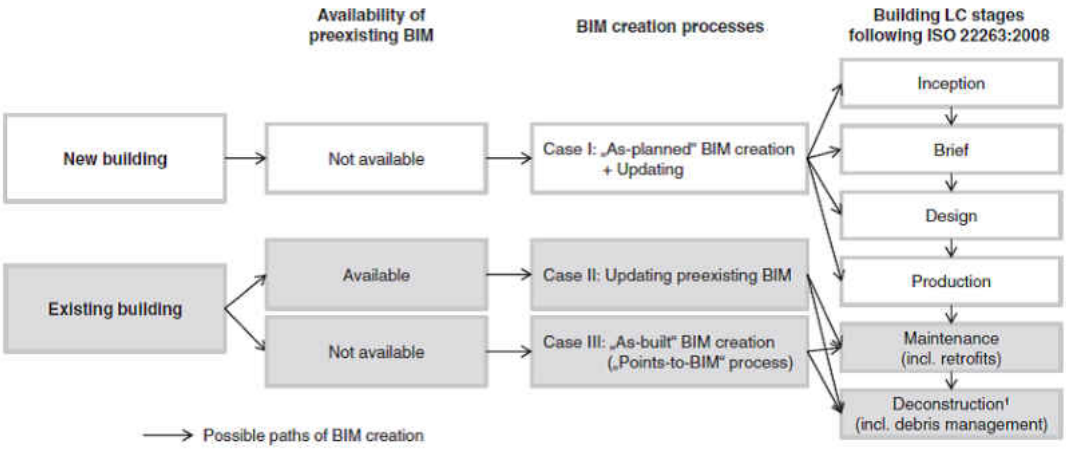


Figure 3. BIM model creation process for new and existing buildings, adopted from (Volk, Stengel et al. 2014)

Moreover, for the new projects, BIM technology allows the users to create a digital design model that is precise and accurate for multi purposes, such as visualization and documentation. This will give the users better control over the project throughout the construction progress (Eastman, Teicholz et al. 2011). The accurate geometric design, and the detailed project data that is stored in the BIM model, will help the owner in better decision-making during the operation and maintenance phases.

BIM has a "holistic nature" that synthesizes the design, information and the project management tools in one software (Bryde, Broquetas et al. 2013). And the different definitions of BIM prove that construction projects' participants look at BIM from different angles, which sometimes cause hesitation to using BIM, and doubt about its benefits.

2.3.1 BIM use and Adoption

BIM is considered as new approach in Architecture, Engineering, Construction and Operation (AECO). According to Giel and Issa (2014), the use of BIM is still considered low (Giel and Issa 2014). However, other researchers insist that BIM use is growing significantly (Keller, Gerjets et al. 2006, Eastman, Teicholz et al. 2011, Aibinu and Venkatesh 2014). In the present section we will discuss the adoption and use of BIM based on the available published surveys and reports.

2.3.1.1 Stanford's Center for Integrated Facility Engineering (CIFE)

In 2007, Brian Gilligan and John Kunz from the Center for Integrated Facility Engineering (CIFE) at Stanford University conducted a survey to study the growth and the use of the Virtual Design and Construction (VDC) and BIM, and the their business opportunities. CIFE uses the term VDC instead of BIM, and define it as "the use of integrated multi-disciplinary performance models of design-construction projects to support explicit and public business objectives" (Kunz and Fischer 2009). The definition indicates that the two terms are identical. CIFE's research surveyed 171 AEC professionals from different locations, backgrounds and types of projects.

The study came up with valuable results, and suggested that the use of BIM and VDC increased significantly.

In addition, the research indicates that the respondents did not quantify the value of VDC, but they felt that VDC and BIM have qualitative values during the construction progress, or at any construction phases (Gilligan and Kunz 2007). The rapid increase of VDC usage has been measured by comparing the respondents' use of VDC between 2006 and 2007. The results indicate that the number of non-users of VDC on their projects has been increasing significantly, which points to the fact that VDC had been advertised more, and the sample size has increased. Conversely, the number of users of 1 to 3 projects increased three times, and users of more than 4 projects increased by half, as shown in Figure 4.

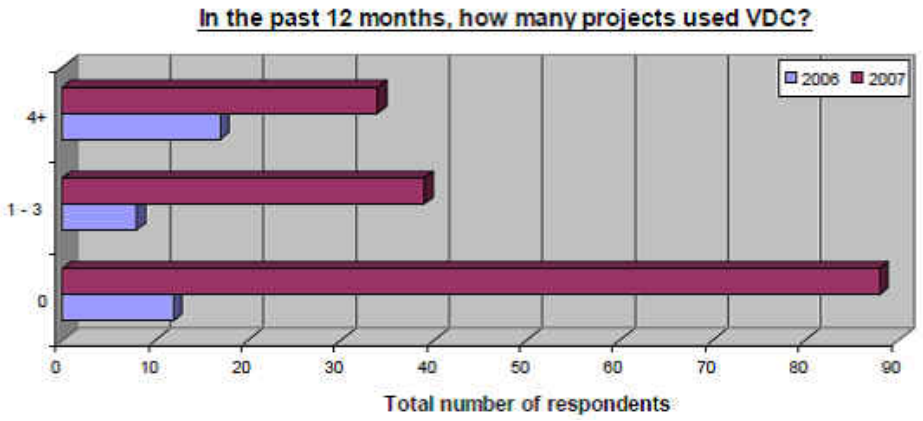


Figure 4. VDC survey results by CIFE: Comparison between no users of VDC and users of VDC between 2006 and 2007, adopted from (Gilligan and Kunz 2007)

In addition, CIFE report suggests that previous VDC users are willing to implement it in future works. The respondents' answers showed that the majority of

VDC users will implement VDC in more than 9 future projects, and the proportion of planning for 7 or more projects has doubled between 2006 and 2007, as shown in figure 4. The proportion of VDC users, who used VDC between 1 to 3 projects increased by 25%, whereas users who implemented VDC before, and are planning not to use it in future increased in almost 5%.

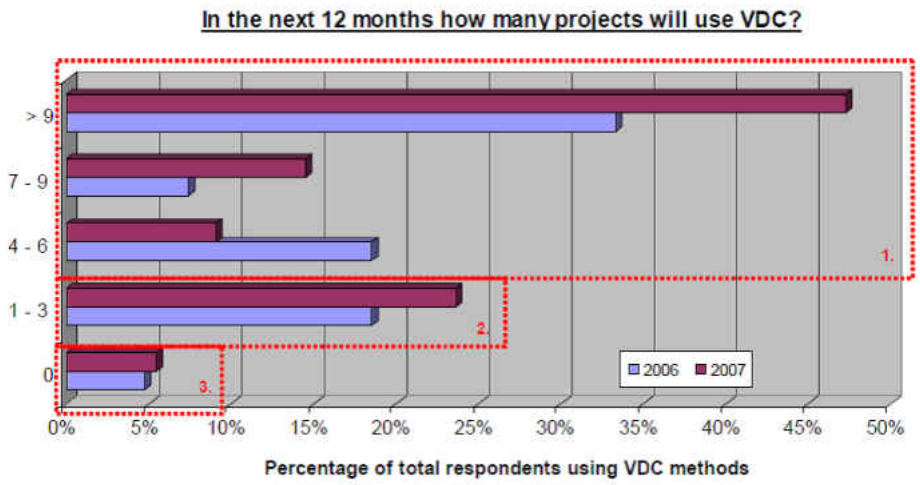


Figure 5. VDC survey results by CIFE: How many future projects will use VDC, adopted from (Gilligan and Kunz 2007)

Moreover, CIFE survey asked why the companies are not using VDC or BIM. The results showed that the majority of VDC non-users, which represent almost half of them, stated that the "lack of using VDC" is caused by "no need or owner not requesting" (Gilligan and Kunz 2007) as shown in Figure 5. The involved parties such as Engineers, Architects, and builders agreed that the lack of demand from the owners is the main reason of not using VDC.

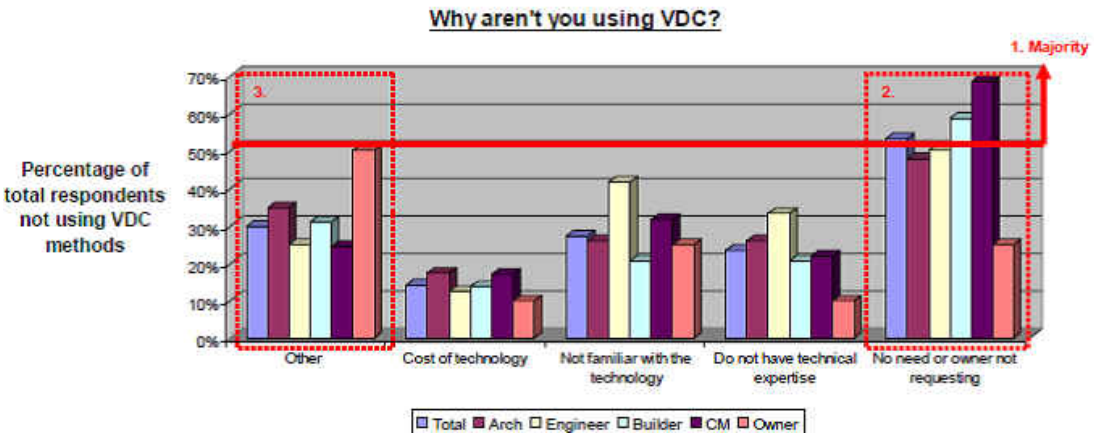


Figure 6. VDC survey results by CIFE: Reasons of not using VDC, adopted from (Gilligan and Kunz 2007).

In addition, the results in Figure 6 points to 15% of non-users who chose the "not familiar with technology" as a reason of not using VDC or BIM, where 12% stated that using VDC is costly (Gilligan and Kunz 2007).

The use of VDC or BIM varies from firm to firm, depending on the needs and the technological capability of the design crew. CIFE survey investigated the purpose of using VDC, and stated 14 different purposes, as shown in Figure 7. The results reveal that the majority of respondents used VDC for clash detection and architectural visualization. In figure 7, Gilligan and Kunz (2007) divide the business purposes into two phases: 1) Visualization, which represent the top four of the purposes, and 2) Integration and Automation, which represent the rest of the business purposes.

The vertical line in Figure 7 shows that the majority of the respondents chose the top four purposes, which falls into visualization phase, and this phase is considered as first step of VDC implementation. Also, the results showed that the

minority of users used the more advanced purposes of VDC which represent the Integration and Automation phase (Gilligan and Kunz 2007).

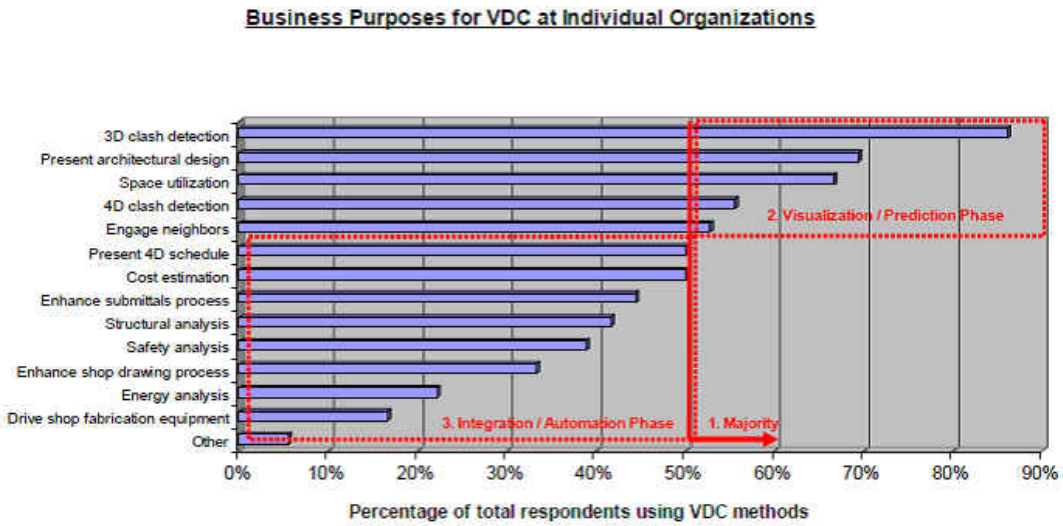


Figure 7. The Business purposes of using VDC (Gilligan and Kunz 2007)

2.3.1.2 McGraw Hill Smart Market Reports

McGraw Hill has issued several market reports based on extensive survey that cover most BIM issues. BIM Smart market report, published in 2009 and titled "The Business Value of BIM, Getting Building Information Modeling to the Bottom Line", surveyed thousands of AEC professionals in North America, and indicated that BIM "gained momentum that expected to continue in the coming years" (Young, Jones et al. 2009). In addition, the report shows that the use of BIM between 2007 and 2009 have been increasing from 28% to 48%.

Moreover, the report stated that 50% of the AEC industry is using BIM or "related tools", which indicates the significant growth in the use of BIM since 2007.

In the contractors' side, in 2009 the use of BIM has increased 400%, when compared to 2007. Furthermore, BIM became popular and useful for experts. Consequently, McGraw Hill survey results reveals that almost 66% of the experts are using BIM in more than 60% of their current projects. Also, 33% of the total BIM users are using BIM in more 60% of their current projects, representing 200% increase (Young, Jones et al. 2009). All of these statistics confirm that BIM is gaining popularity every year, and 66% of all respondents were implementing BIM in the recent three years, as shown in figure 8.

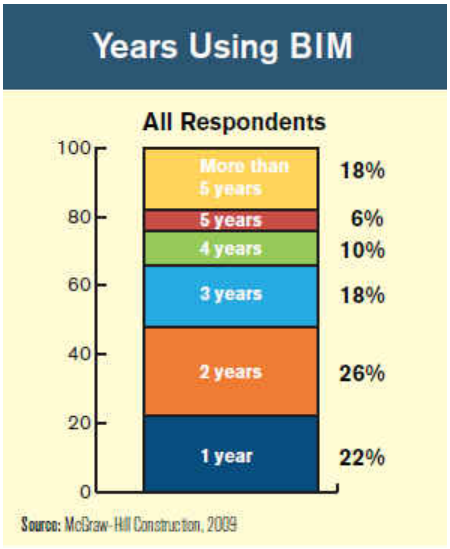


Figure 8. Years of Using BIM among the Respondents (Young, Jones et al. 2009).

AEC professionals have different motivations and goals, and these goals are connected to each other according to common interests. As stated before, contractors will not use BIM if the owners do not ask for it, and owners will not ask for it if it is

not monetarily beneficial for them. The survey tested the owners' demand and found out that 70% of owners "report positive Return of Investment (ROI) from BIM (Young, Jones et al. 2009). It means that the contractors will adopt BIM more, because owners will ask for it, once they perceive positive ROI.

In 2012, McGraw Hill had released the Smart Market report titled: "The Business Value of BIM in North America; Multi-Year Trend Analysis and User Ratings (2007-2012)". The report stands that BIM usage is increasing significantly, and the industry adoption reached 71% in 2012 (Construction 2012), Figure 9 shows the comparison of BIM usage between the years 2007, 2009 and 2012.

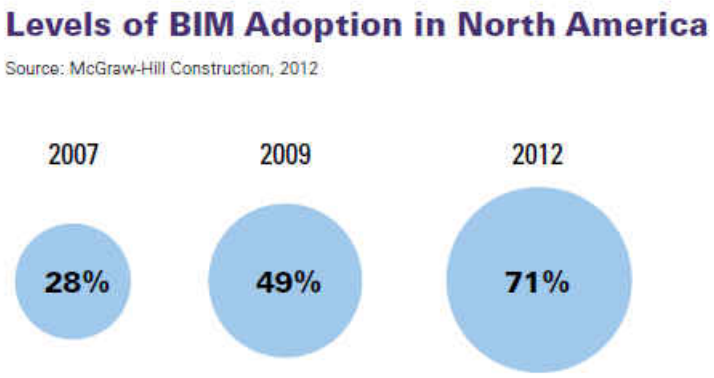


Figure 9. BIM Adoption rate in North America (Construction 2012)

The report confirms that, despite the economic crisis between 2009 and 2012, BIM usage "grew by 45%" (Construction 2012). Among the AEC, the contractors are responsible for the highest proportion of BIM adoption (74%) compared with 70% for the engineers, and 67% for the Architects. In addition, regions matter when it comes

to BIM adoption and use. In 2009, BIM adoption was in lowest level at the northeastern part of US (38%), where the west achieved the highest adoption rate (56%). The adoption variation between the regions may reflect the economic status. The statistics demonstrates that BIM usage is growing in all regions, though in different percentage, as seen in Figure 10 (Construction 2012).

The Northeastern region had the most significant growth among the regions, which might be a result of an economic stimulation. In 2012, the Western region still had the highest rate in BIM adoption, but in general, all the regions grew significantly. McGraw Hill Report claimed that BIM adoption increased because of the high number of the health care projects. The reason behind that is that health care projects are complicated, and need more collaboration between the project's team than other type of projects (Construction 2012).

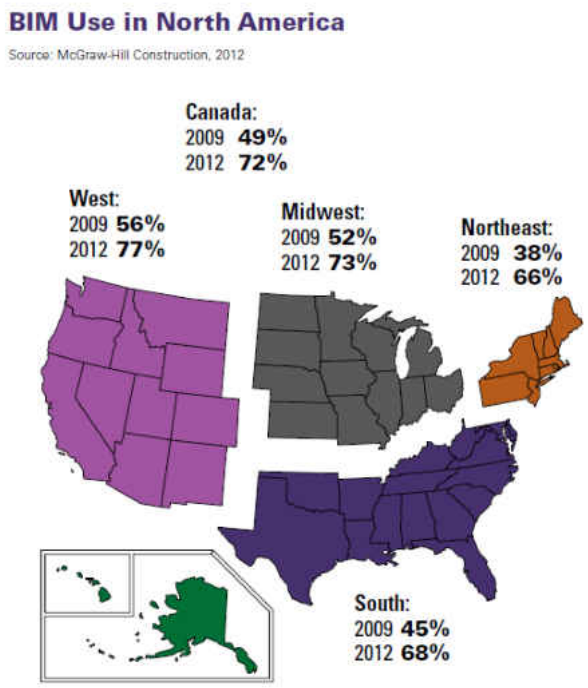


Figure 10. BIM Usage Growth between 2009 and 2012 in North America (Construction 2012)

The firm's size is also an important matter when it comes to BIM adoption (Construction 2012). The larger is the firm, the more it will adopt BIM. The report indicates that BIM usage rate among the small firms in 2009 was 25%, which is below the average, whereas the rate is 74% among large firms. Figure 10 shows the growth in BIM use based on the type and the size of the firms. Also, figure 11 shows that the use of BIM is increasing among the small firms, but the rate is still lower than the average.

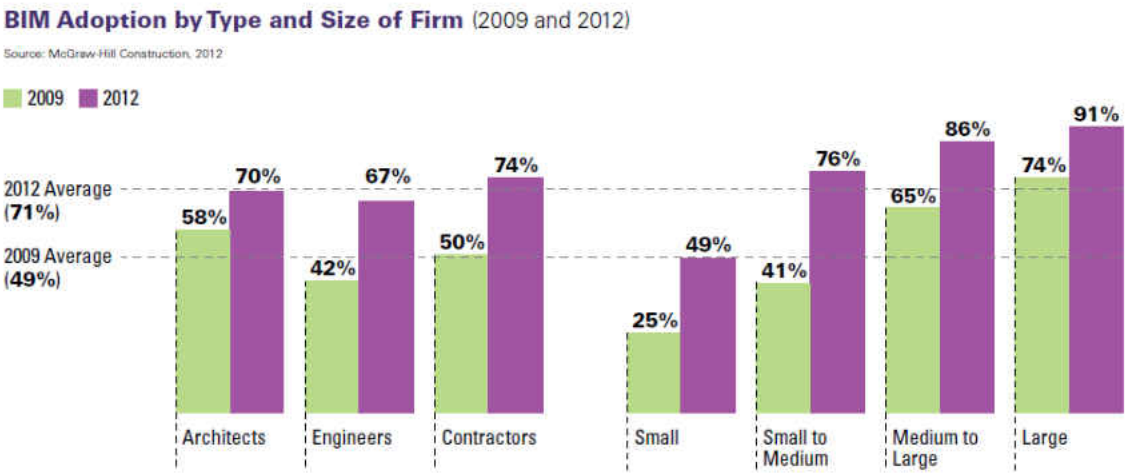


Figure 11. BIM adoption based on the size and the Type of the Firms between 2009 and 2012 (Construction 2012)

2.3.1.3 NBS National BIM Report 2014

NBS is an enterprise owned by the Royal Institute of British Architects (RIBA). NBS released the National BIM report, which addresses various issues related to BIM adoption and use. UK government will enforce BIM adoption in public funded projects which, in turn, will increase its knowledge and awareness (NBS 2014). NBS issued two BIM report in 2010 and 2014, and they compare the survey outcomes to measure the improvement in BIM use. In this section, we will cover the results from 2014 report.

NBS survey confirm that the majority of respondent at UK construction industry adopted BIM and used it "at least once last year" (NBS 2014). The survey tested "BIM usage and awareness", and the results show that BIM awareness among

the survey participants has jumped from 58% in 2010, to 95% in 2013, as shown in Figure 12.

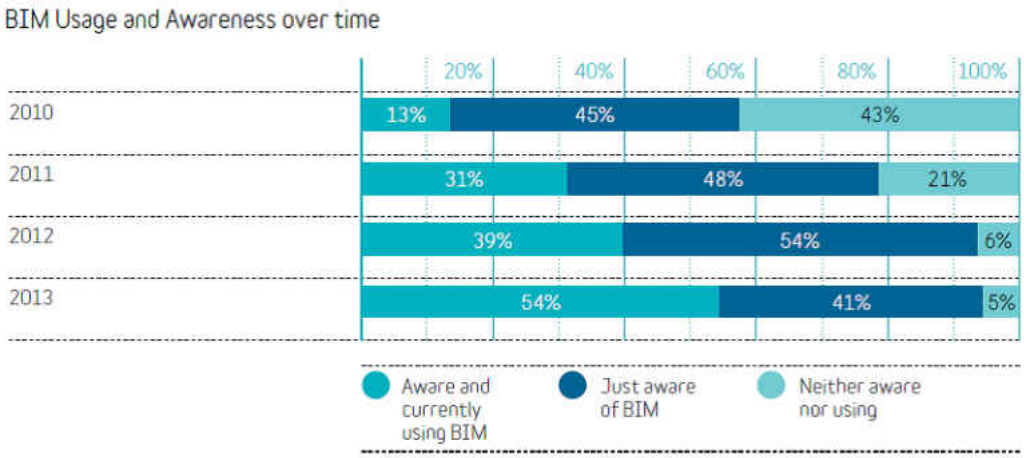


Figure 12. BIM usage and Awareness between 2010 and 2013 (NBS 2014)

NBS report indicates that being aware of BIM is the first step to adopt it. Therefore, it is important to find out how BIM is adopted among the participants who are aware of it. The results presented in Figure 13 indicate that 81% will use BIM in one year; 93% will use it in the next 3 years and 95% will use it in next 5 years. Since the UK government will enforce BIM in 2016 for public funded projects, BIM adoption will undoubtedly increase in the coming years.

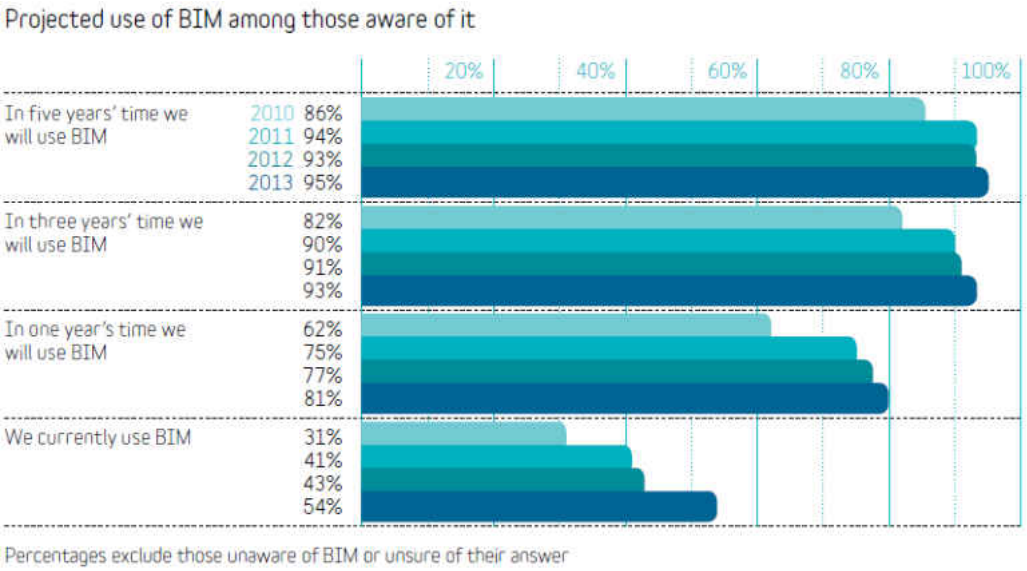


Figure 13. Projected use of BIM among those aware of it (NBS 2014)

The results shown in figure 13 represent the participants who aware of BIM, and exclude those unaware of it. Finally, the report indicates that BIM adoption is beyond expectation, and all indications suggest that BIM will become an industry norm in the years to come.

2.3.2 The Benefits of using BIM

Most of the published literature states the benefits of using BIM, and few mention obstacles. A large portion of the literature build their views based on qualitative metrics, where few others build their views based on real case studies from the construction industry. Bryde, Broquetas et al. (2013) measured the projects' benefits of Building Information Modeling (BIM) based on 35 published construction case studies (Bryde, Broquetas et al. 2013). The method of his research is to find out

the positive and negative effects of BIM, and measure the benefits of implementing BIM.

Bryde, Broquetas et al. (2013) developed "success criteria": time, cost, quality objectives, management output and communication, based on the output of the tested projects. The positive and negative outputs derived from the projects managers' reports. The results showed that "cost reduction or control" ranked the highest in positive benefits, with total of 29 positive stances and 3 negative stances in 60% of the projects, whereas "software issues" ranked the highest in negative benefits, with a total of nine negative stance in 20% of the projects.

The authors ranked the "success criteria" from the highest positive benefits to the lowest as following: 1) Cost reduction or control, 2) Time reduction or control, 3) Communication improvement, 4) Coordination improvement, 5) Quality increase or control, 6) Negative risk reduction, 7) Scope clarification, 8) Organization improvement, 9) Software issues (Bryde, Broquetas et al. 2013).

Many AEC professionals do not rely on the qualitative benefits of BIM. Instead, they seek for quantitative evidence, derived from real construction cases. Barlish and Sullivan (2012) listed the top derived benefits based on the review of 21 literatures as seen in Table 1.

Table 1. Top mentioned benefits, adopted from (Barlish and Sullivan 2012)

Benefits	Frequency	Unit
Schedule	11	Days
Sequencing coordination	7	N/A
Rework	5	N/A
Visualization	5	N/A
Productivity	5	N/A
Project cost	5	$ or %
Communication	4	N/A
Design/engineering	4	N/A
Physical conflicts	4	N/A
Labor	3	N/A
RFIs	3	#
Safety	3	N/A
Change Orders	2	$ or %
Maintenance application	2	N/A
Prefabrication	2	N/A
Quality	2	N/A
Simulation	2	N/A
As-built	1	N/A
Pilot cost	1	$ or %

Additionally, Barlish and Sullivan (2012) conducted case study analysis from real construction projects. They derived the benefits by building a comparision model of BIM and non-BIM projects, and measured the effects of BIM on the following metrics: RFIs, Change Orders, Schedule, Design Cost, and Construction cost. They found that BIM projects has benefited from BIM by decreasing the number of RFIs, and the percentage of change orders, and the percentage of "behind standard schedule" (Barlish and Sullivan 2012).

FMI/CMAA Eighth Annual Survey of owners compiled a list of BIM benefits and obstacles based on owners point of view. The advantages of this survey is the exploration of the Non-BIM users' views, and how they perceive the benefits of BIM. In this document, we will represent the ranking for the BIM users, as shown in Table 2.

Table 2. BIM benefit Ranking adopted from (D'Agostino, Mikulis et al. 2007)

Rate benefits that BIM soution provide on capital construction projects	BIM Users	
	Score	Rank
Improve Communication and Collaboration among projects participants	4.42	1
Higher quality Project Excution and Decision Making	4.19	2
Greater Assurance of Project Archival	4.08	4
More Coprehensive Planning and Scheduling	4.09	3
Higher Quality Construction Results	4	6
Easier To Achieve Process Standarization	4.06	5
More Realiable Compliance with specification and Regulations	3.85	7
Greater Productivity from Labor and Assets	3.79	10
More Consistent Performance Against Project Budget	3.84	9
Significantly Reduce Change Order/Claims	3.71	11
Boroader Strategic Prespective and Innovation	3.85	8
Decrease Labor Cost	3.62	12
Measurable Reduced Contingencies	3.52	13
Improved Safety Performance	3.32	14
Competitive Advantage in Recruiting and Staffing	3.27	15

Note: (Scale: 1= Strongly disagree; 5= Strongly agree)

We can see from Table 2 that owners who use BIM gave "significantly reduce change order/claim" a low rank among the other benefits, and put more faith in BIM on the improvement of the collaboration and the decision making. Additionally, productivity was ranked 10, whereas reports suggest that productivity is one of the most "influential factors" in the enhancement of the use of BIM. Owners are always looking for reducing monetary conflicts, which is always a result of disagreement in

claimed change orders. Therefore, most of the researchers are looking for evidence to prove that BIM is a tool capable of reducing the change orders, which, in turn, reduce the cost of the project.

McGraw Hill Smart Market report (2012) compiled a list of long and short-term BIM benefits. The top BIM benefit for long-term is “maintain repeat business” with 49% in 2012, and 36% in 2009, whereas “fewer claims/litigation” is the last in the list, with 28% in 2012 and 20% in 2009 (Construction 2012). The other long-term benefits are: “Reduce project Duration, Increase profit, reduce construction cost”. In the short-term benefits, “reduced documents error and omission” is the highest ranked benefit, with 52% in 2012 and 47% in 2009, whereas “Staff recruitment and retention” got the lowest ranking among the short-term benefits.

The AEC professionals ranked BIM benefits based on their interest. Architects, for example, ranked “Reduce Documents Errors and Omission” as the highest ranked benefit, while the Engineers chose “maintain Repeat business” as the top benefits, and the contractor placed “Reduces Rework” on the top of the benefits list (Construction 2012). In addition, in 2014, McGraw Hill Smart Market report presented the top BIM benefits from the contractors point view; these benefits are: “Reduced Errors, Collaboration with owners/Design Firms and ENHANCE Organizational Image” (Construction 2014).

BIM effect on construction can be measured based on the common metrics such as: cost, schedule, and quality. Suremann and Issa (2009) evaluated the perception of BIM on construction based on six key performance indicators (KPIs).

The study results showed that the participants saw an improvement in two indicators: dollars/unit, and units per man hour (Suermann and Issa 2009). Moreover, in 2008, a study indicated that the use of BIM in early design stage reveled several benefits such as: 1) Rapid Visualization, 2) better decision support, 3) accurate updating, 4) reduction of man-hours, 5) increase communication between project's parties, 6) higher confidence of completing project's scope (Manning and Messner 2008). Kaner et al. (2008) found that BIM use has increased the quality of design by eliminating the drawings errors (Kaner, Sacks et al. 2008).

Olofesson et al. (2007) pointed out that BIM implementation had reduced the time for the construction administration, and substantially reduced the time required for resolving field conflicts (Olofsson, Lee et al. 2007). Khanzode et al. (2007) also stated that BIM has resulted in "positive outcomes in the production process as for example, significantly less rework and zero conflicts in the field installation system" (Khanzode, Fisher et al. 2007, Linderoth 2010).

2.3.3 BIM obstacles in AEC industry

The obstacles and hurdles that faced the users of BIM are understandable in many cases. For example, "Software too expensive" as of the obstacles that affect BIM use (Young, Jones et al. 2009). McGraw Hill report in 2009 classified the most important obstacles to BIM adoption as following: "1) Not enough demand from clients and/or other firms on projects; 2) Haven't had sufficient time to evaluate it; 3) Software too expensive; 4) Functional doesn't apply well enough to what we do; 5)

Required hardware upgrades too expensive" (Young, Jones et al. 2009). In addition, the FMI/CMAA list the BIM hurdles in Table 3.

Table 3. BIM hurdles, adopted from (D'Agostino, Mikulis et al. 2007)

Rate Hurdels that slow or prevent adoption of BIM solution on capital construction projects	BIM Users	
	Score	Rank
Lack of Expertise	3.82	1
Greater System Complexity	3.81	2
Lack of Industry Standards	3.74	3
Poor Integration with Existing Systems	3.67	4
Different Needs Across Stakeholders	3.63	5
Training Burden	3.46	6
Unclear Business Value and ROI	3.38	7
Lack of Executive Buy-in	3.2	8
Vague Cost Estimates	3.2	9
Legal / Contractual Concerns	3.02	10
Security Risks	2.84	11

Note: (Scale: 1= Strongly disagree; 5= Strongly agree)

2.3.4 Legal and contractual Issues

Some researchers raised concerns about the legal implication of BIM (Oluwole Alfred 2011). These concerns relate to the model ownership, risk allocation, project's responsibilities, and other contractual issues that will not be addressed in standard contract form. These concerns have been organized in FMI/CMAA survey Table 3 and ranked 10th among the 11th hurdles that prevent the use of BIM (D'Agostino, Mikulis et al. 2007). The FMI/CMAA survey published in 2007, and in 2008, and the American Institute of Architects (AIA) have built a legal protocol Exhibit that covers BIM legal issues. The AIA Document E202-2008 organizes the model use among the project participant, and describes the responsibilities for each

party. AIA E202-2008 describes the limits of the model use, and which party is managing the model, and who is the model owner.

Additionally, in 2008 Concensus Doc has developed a BIM addendum under the name of: ConcensusDOCS 301 BIM Addendum. This legal document has been written by the Associated General Contractors of America (AGC), and it covers the areas that distinguished BIM from the traditional method (Lowe and Muncey 2009). For instance, the information management section at BIM addendum organizes the project's participant's relation when it comes to the model changes. Moreover, BIM addendum requires the project's parties to select an information manager to be responsible for the technological part. Other sections are included to address BIM execution plan, risk allocation and intellectual property rights (Lowe and Muncey 2009).

2.3.5 BIM Evaluation and Scoring methods

After the National BIM Standard published their BIM soring method, several entities have developed a BIM scoring, or evolution tool, to evaluate the maturity of BIM use on project or organizational level (Giel and Issa 2014). Table 4 compares the different "leading" scoring and evaluation tools, and next we will discuss every method in an individually.

Table 4. Comparison between BIM evaluation tools, adopted from (Giel and Issa 2014)

	NBIMS	BIMe	BIM Quick Scan	VDC Scorecard
Intended user	A, E, C, O	A, E, C, O	A, E, C	A, E, C, O
Group Rating Context	Evaluates information management on building projects	Evaluates organizations projects, teams, or indivisuals BIM maturity & performance	Evaluates BIM performance level of organization providing BIM services	Evaluates project BIM performance and maturity
Evaluation Style	Self-evaluation of the model	Multiple types of evaluation offerd	External certified evauator or a free online self-scan assessment	Multiple type of evaluation offered
Measurement Categories and Weightings	11 areas of interest weighted based on importance	Multiple indices with different categories based on the evaluation context	4 chapters and 10 different aspects based on weighted KPIs	4 areas across 10 different dimensions and several weighted measures
Number of Maturity Levels	10 maturity levels	5 maturity/competency levels across various index	None(evaluation is based on weighted KPIs)	5 percential ranges of increasing innovation

2.3.6 BIM maturity levels

Companies used to adopt new technology or method in different level. The adoption of BIM requires an internal change in the organizations (Porwal 2013, Porwal and Hewage 2013). BIM maturity level, shown in Figure 14, was created by the UK Department of Business Innovation and Skills (BIS). It shows four levels of maturity, from 0 to 3. In the past years, the majority of the AEC market work in level 1 (Porwal and Hewage 2013). Nowadays, BIM is almost dominating the market. For this reason we can see in Figure 14 the companies that reached higher level, such as level 2.

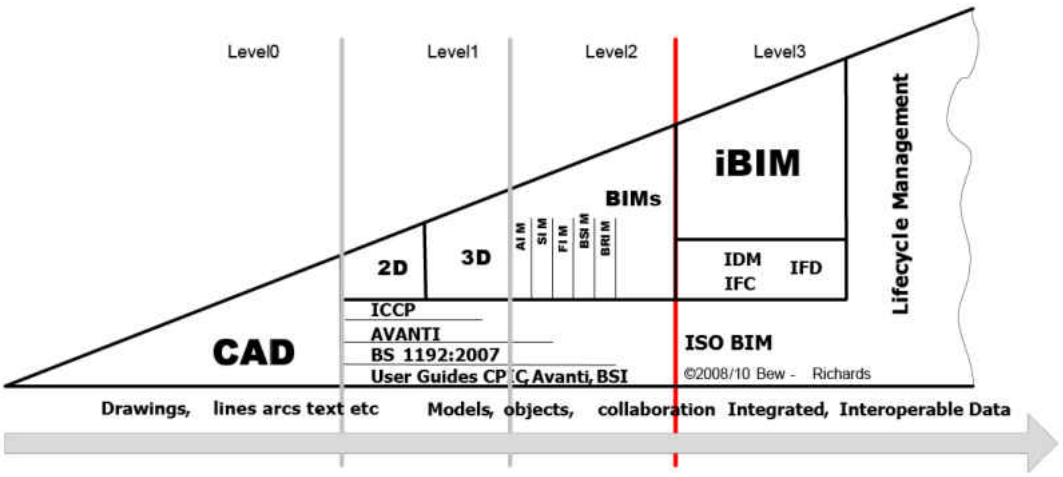


Figure 14. BIM maturity levels U.K. Adopted from BIS (BSI 2012)

2.3.7 BIM Level of Development (LOD)

LOD is one of the most common abbreviations in BIM industry. It is used to refer to the level of detail, but the most reliable sources in this field refer to LOD as level of development. The difference between the two terminologies is described in the BIM Forum Specification report. The report indicates that Level of detail is referring to how much detail does the model have for each element in a project, whereas level of development is "the degree to which the element's geometry and attached information has been thought through- the degree to which project team members may rely on the information when using BIM" (BIMForum 2015).

In October 2015, BIM Forum in collaboration with National Institute of Steel Detailing (NISD) and Building Information Modeling for Masonry (BIM-M) have issued a specification report called "Level of Development Specification" (BIMForum 2015). This report is essential in AEC and its aim is to set up a clear and

unified specification that describes the level of development for the buildings' elements. This specification will help the AEC parties to set a clear and undoubted agreement about the level of development by which the project will be executed. The report specifies five different levels of development, starting from LOD 100 to LOD 500. This specification does not cover LOD 500, and it describe the elements in 5 categories as shown in figure 15.

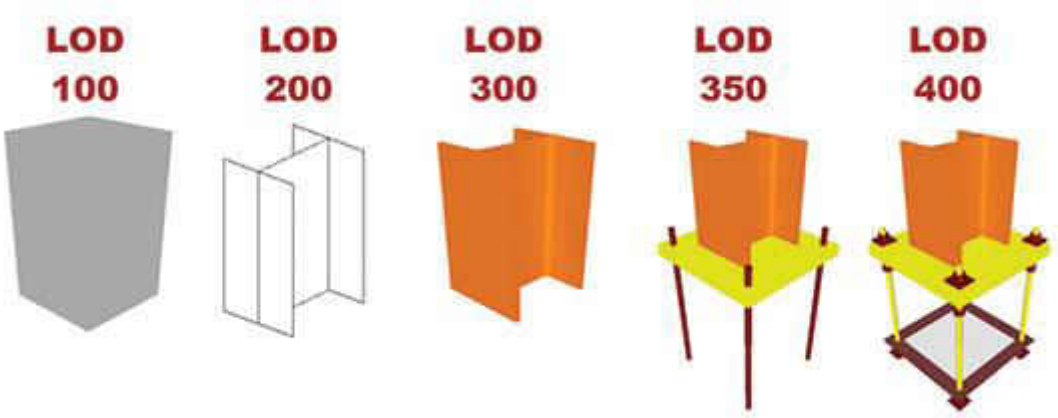


Figure 15. Level of Development Adopted from (BIMForum 2015)

2.3.8 BIM uses

Years ago, the perception of BIM was all about 3D models that could be used for visualization purposes. Massachusetts Port Authority (MPA) has issued two BIM guideline reports called "Guideline for Vertical and Horizontal Construction and Appendix A // MPA BIM Guideline" (Affairs 2015, Massport 2015). The Appendix A report classifies the use of BIM in eight categories, starting from the exit condition to the facility management stage. This report is the first that specify the use of BIM in each construction process with a total of 52 uses. Figure 16 shows OmniClass that is

"a faceted building information classification system made up of interrelated tables that define the built environment" (Affairs 2015, OmniClass 2015).

The OmniClass defines the BIM uses based on the project progress, starting from the criterion that represents the schematic design phase, up to the operation phase. The chart in figure 16, indicates that BIM uses will reach 30%, and may reach 90% at the design and coordination stages.

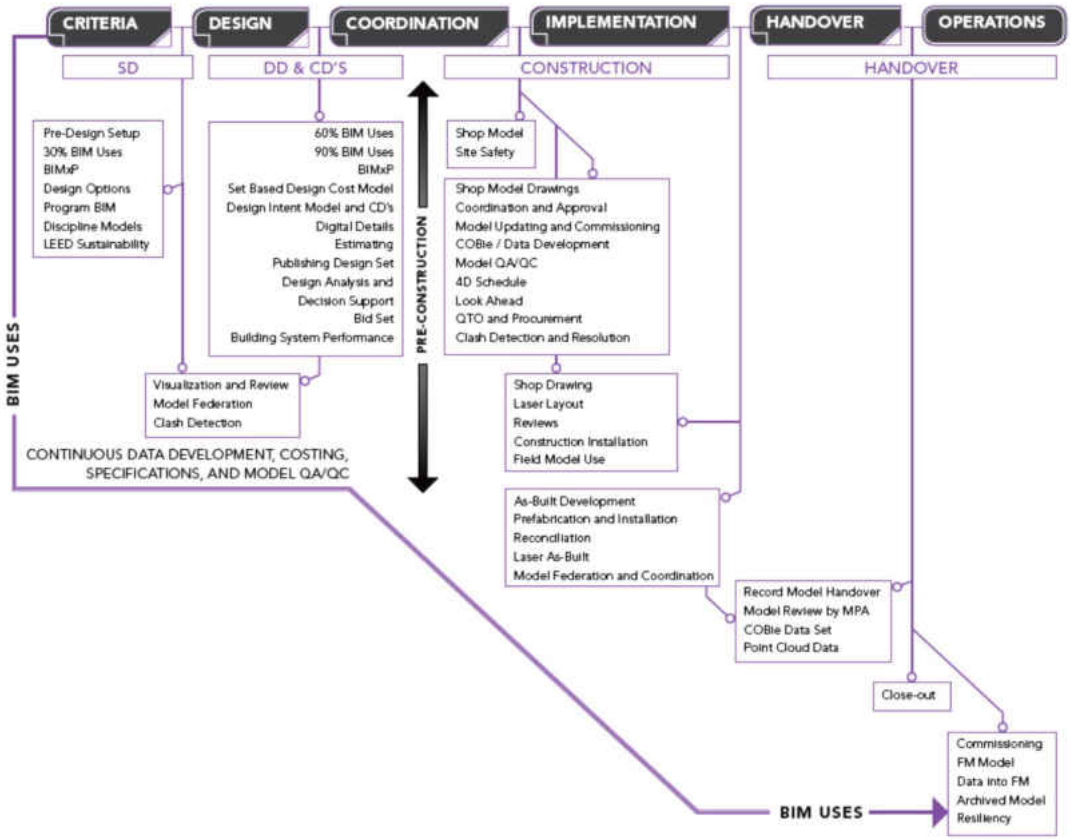


Figure 16. BIM use mapping, Omni phases and traditional phase for project progression, Adopted from (Affairs 2015, OmniClass 2015)

BIM uses based on the Massport (2015) report were specified based on eight major categories. For instance, the report named eight BIM uses for the analysis and reports, and clash avoidance and detection is one of these eight uses. For this use, the report gives a brief description about it, the responsibility, model elements, deliverables, and software.

CHAPTER 3: METHODOLOGY

3.1 Overview

This research conducted in two main steps. The first step was based on an extensive general survey that covered many aspects related to BIM, and the second step consisted of interviews with selected BIM experts in the design and construction industry. The main objective of the first step was discover the effect of BIM in AEC industry, and how BIM is implemented among different sizes of firms.

The general survey questionnaire was designed in 30 questions, starting with general information about the participant's discipline, the company's role and level of experience. Further on, the questions switch to specific and detailed issues about BIM as described in section 3.2. The second step was the professionals' interviews, focusing on how the professional perceived the value of BIM features, and how it effects their project and overall business. The professionals were selected from the design and construction industry. The criteria of selection and the interviews' topics will be discussed in section 3.3.

3.2 Data Collection

This process consisted of two steps as described in section 3.2.1. The first step was a general survey questionnaire, investigating all aspects related to BIM. The second step was the conduction of a sequence of interviews with BIM professionals,

to emphasize on some of the aspects related to BIM collected from the general survey results.

3.2.1 General Survey Questionnaire

3.2.1.1 Overview

A questionnaire survey has been deployed among the BIM professionals in design and construction industry. The purpose of this survey was to determine the perception regards the effects of BIM in design and construction. The reason of concentration on design and construction firms was because they considered themselves partners in each and every project. However, when it comes to BIM, both have different perception and different usage of the technology. Therefore, it is important to understand the current use of BIM, and how BIM features affected the industry. Before building the questionnaire, the author attended several meetings with BIM professionals in AEC industry, the meetings were held in Orlando and Jacksonville. The attendees were BIM managers, engineers, architects, and professionals from other disciplines, all sharing their concerns or issues associated to BIM.

After attending the BIM professional meetings, we started looking researching published BIM surveys, and how these surveys were attached with the current issues of BIM. The following surveys and researches were major sources of our survey.

1. McGraw Hill, Smart Market book, several reports were used as listed below:

- The Business Value of BIM; Getting Building Information modeling to the Bottom Line (Construction 2009).
- The Business Value of BIM in North America; Multi-Years Trend Analysis and User Rating (2007-2012) (Construction 2012).
- Building Information Modeling (BIM); Transforming Design and Construction to Achieve Greater Industry Productivity (Construction 2013).

2. VDC and BIM scorecard, Stanford University, Center of Integrated Facility Engineering (Kam, Senaratna et al. 2013).
3. NBS National BIM Report (2014), by Royal Institute of British Architects (NBS 2014).
4. The Perceived Value of Building Information Modeling in the US Building Industry (Becerik-Gerber and Rice 2010).
5. BIM Guideline for Vertical and Horizontal Construction, BIM Appendix A, MPA BIM Guideline (Massport 2015).

The web based survey was created through a well-known survey engine called Survey-Monkey. The link (https://www.surveymonkey.com/r/YahyaOloufa) was used to direct the participant to the survey web page, and this link was employed and promoted in different ways, as discussed in the next section 3.2.1.2.

3.2.1.2 Survey Distribution – Targeted Participants

For the current research, we targeted the following BIM professionals at AEC industry: all Managers, Engineers and Architects who had experience with, and used

BIM professionally in actual projects. The choice for BIM experts had to do with the idea of a deeper insight and understanding about how BIM features are used. BIM professionals in experienced firms tend to overcome the minor issues related to BIM, therefore their use of BIM will be meaningful.

After careful consideration, we have targeted three groups of BIM professionals who use and implement BIM in most of their projects. The first group is called Orlando Revit Users Group. It is located in Orlando Florida and combines almost 300 members who are working in design firms in Orlando area. The second group is called Central Florida Contractors' Users Group, this group combines 75 members, representing general and sub-contractors who work in different construction areas, and implementing BIM professionally.

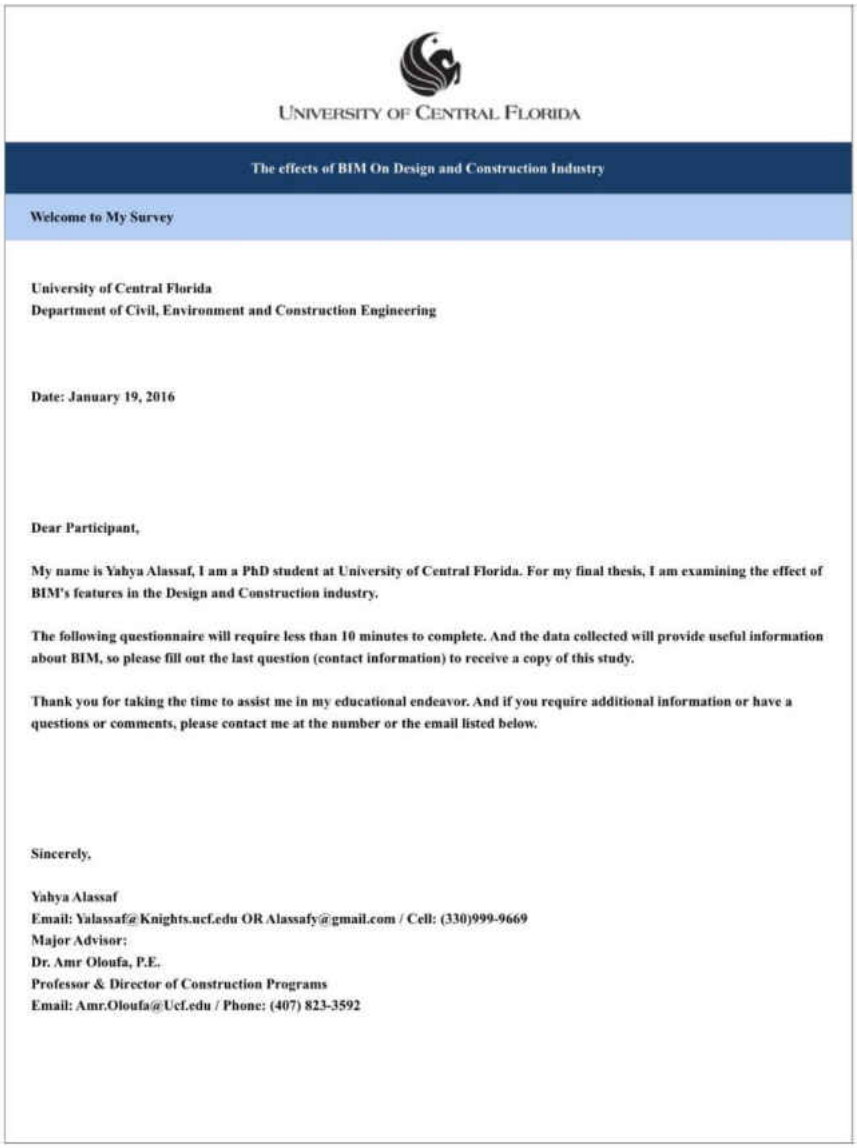
The third group is called BIM managers, and it is located in Jacksonville, Florida. It consists of a monthly gathering for the BIM managers who represent deign, contractors and public entities. We got involved in these groups after establishing personal connections with group founders. After it, we started deploying the questionnaire through their web groups in LinkedIn and Facebook, or sending the questionnaire link to their personal emails.

In addition, the questionnaire was posted in several professional groups at LinkedIn, such as BIM Experts and Revit Users, BIM Architecture, Autodesk University, The American Society of Civil Engineering ASCE, The American Society of Civil Engineering Construction Institution ASCE-CI, and other groups. Apart from

those, the survey was sent to other BIM professionals who were among BIM Forum presenters last October 2015.

3.2.1.3 Survey Specifics

The survey consists of 30 questions, and was designed to cover most of BIM features. The questions were conceived as multiple choices, open ended, ranking scaling, matrix, dichotomous, and contingency questions. The questions were devised to distinguish the participants, based on their positions and their firm's sector, role, experience, firm's size, and BIM level of implementation, and to highlight the participant's views on BIM in general and specific topics.



UNIVERSITY OF CENTRAL FLORIDA

The effects of BIM On Design and Construction Industry

Welcome to My Survey

University of Central Florida
Department of Civil, Environment and Construction Engineering

Date: January 19, 2016

Dear Participant,

My name is Yahya Alassaf, I am a PhD student at University of Central Florida. For my final thesis, I am examining the effect of BIM's features in the Design and Construction industry.

The following questionnaire will require less than 10 minutes to complete. And the data collected will provide useful information about BIM, so please fill out the last question (contact information) to receive a copy of this study.

Thank you for taking the time to assist me in my educational endeavor. And if you require additional information or have a questions or comments, please contact me at the number or the email listed below.

Sincerely,

Yahya Alassaf
Email: Yalassaf@Knights.ucf.edu OR Alassafy@gmail.com / Cell: (330)999-9669
Major Advisor:
Dr. Amr Oloufa, P.E.
Professor & Director of Construction Programs
Email: Amr.Oloufa@Ucf.edu / Phone: (407) 823-3592

Figure 17. The Survey Introduction

Initially, the participants were asked to specify his firm or organization's role, followed by a question about the participant's specialty, and another one to determine the sector to which the organization belongs (Figure 18). The following 4 questions focused on the organization's specifics, such as market level, BIM level of implementation, duration of BIM implementations, and BIM experience, as shown in Figure 19 .

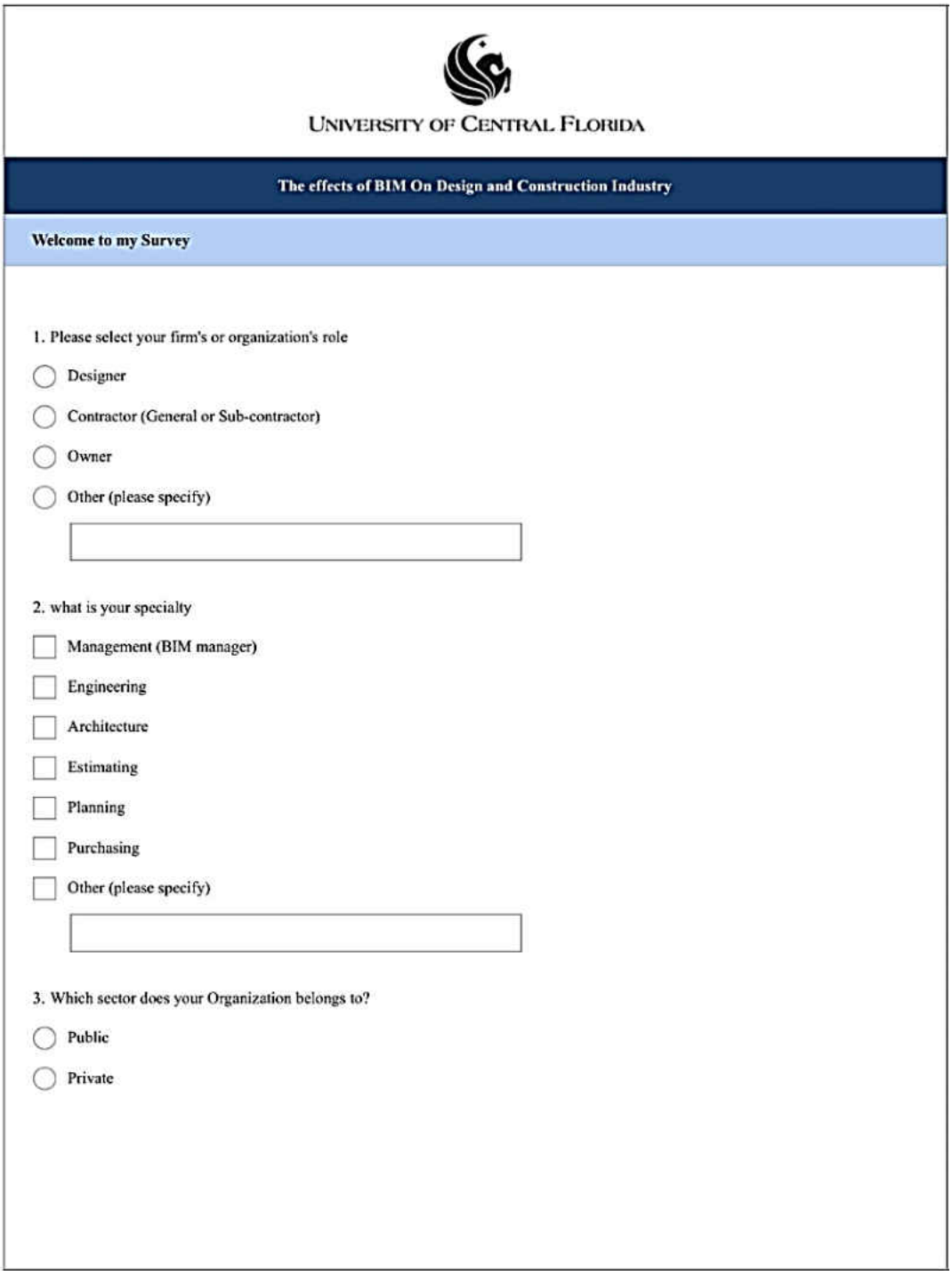


Figure 18. Companies' information (Survey questions from 1 to 3)

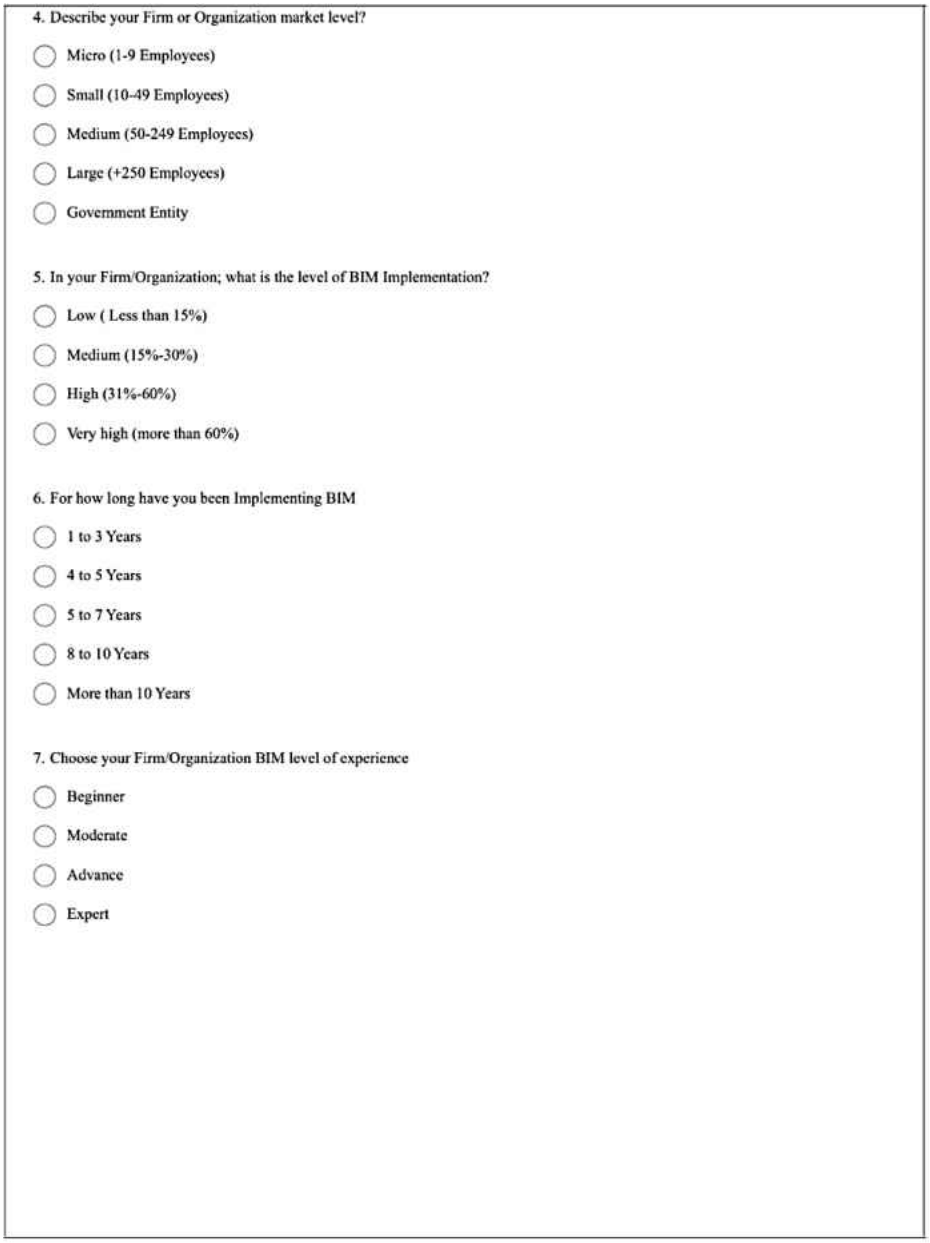
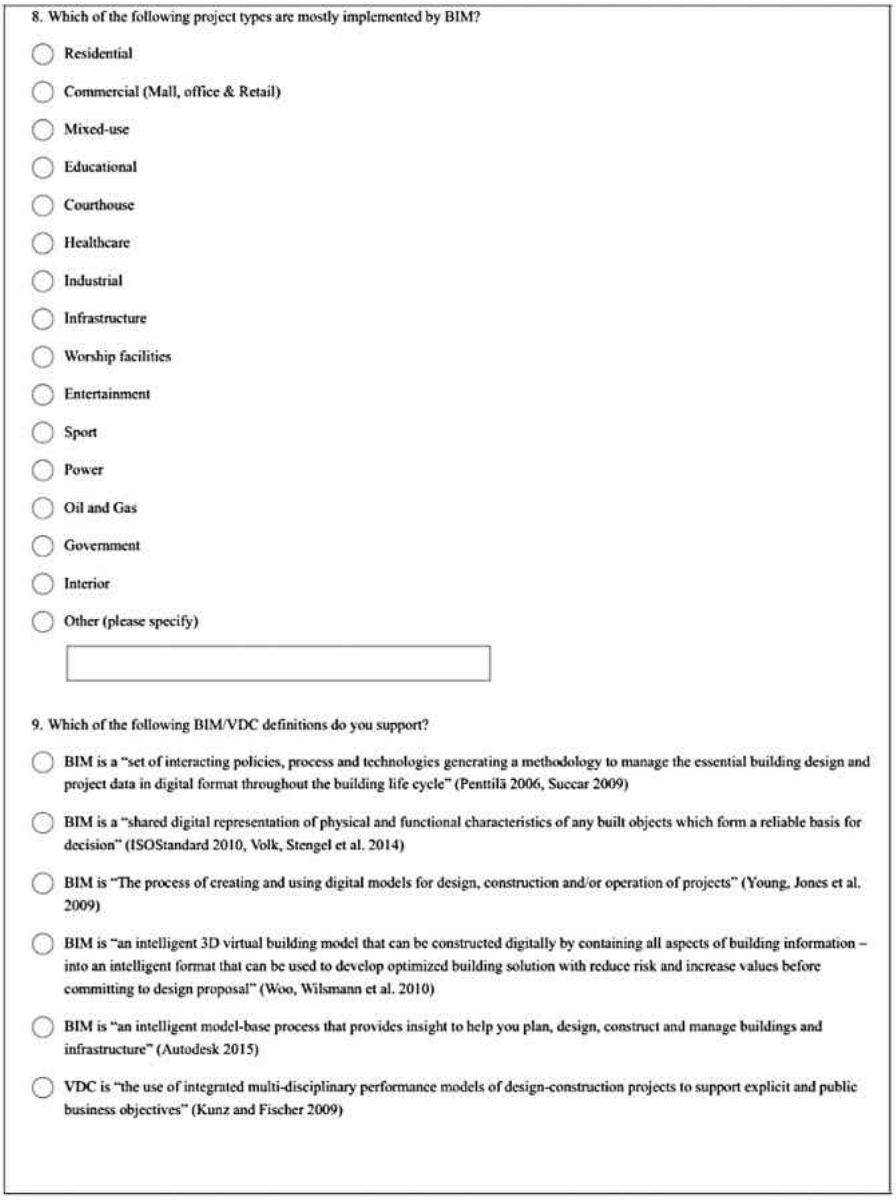


Figure 19. Companies' information (Survey questions from 4 to 7)

From question 8 to 13, we started collecting the primary information. First, we asked about the type of project mostly implemented by BIM. The reason of asking this question was to determine the type of projects that need BIM tools. Then, we

asked the participants to define BIM by picking one of the different stated definitions, to understand their perception about BIM (Figure 20).


8. Which of the following project types are mostly implemented by BIM?

- ◯ Residential
- ◯ Commercial (Mall, office & Retail)
- ◯ Mixed-use
- ◯ Educational
- ◯ Courthouse
- ◯ Healthcare
- ◯ Industrial
- ◯ Infrastructure
- ◯ Worship facilities
- ◯ Entertainment
- ◯ Sport
- ◯ Power
- ◯ Oil and Gas
- ◯ Government
- ◯ Interior
- ◯ Other (please specify)

9. Which of the following BIM/VDC definitions do you support?

- ◯ BIM is a "set of interacting policies, process and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building life cycle" (Penttilä 2006, Succar 2009)
- ◯ BIM is a "shared digital representation of physical and functional characteristics of any built objects which form a reliable basis for decision" (ISOStandard 2010, Volk, Stengel et al. 2014)
- ◯ BIM is "The process of creating and using digital models for design, construction and/or operation of projects" (Young, Jones et al. 2009)
- ◯ BIM is "an intelligent 3D virtual building model that can be constructed digitally by containing all aspects of building information – into an intelligent format that can be used to develop optimized building solution with reduce risk and increase values before committing to design proposal" (Woo, Wilsmann et al. 2010)
- ◯ BIM is "an intelligent model-base process that provides insight to help you plan, design, construct and manage buildings and infrastructure" (Autodesk 2015)
- ◯ VDC is "the use of integrated multi-disciplinary performance models of design-construction projects to support explicit and public business objectives" (Kunz and Fischer 2009)

Figure 20. Projects type and BIM definitions (Survey questions from 8 to 9)

Further on, we followed with three questions that we considered as the main variables of this survey. Question 10 is about BIM motivations and can determine the most important aspects that drive BIM users to adopt such technology. With question 11, we wanted to figure out the main concerns that BIM users have when they decide to use it. Previous researches suggest that AEC companies concern mostly about the cost of BIM and its return, what made us limit the concerns in three major issues, as stated in question 11. The concerns are linked to the required investment when using BIM. Thus, in question 12 we asked the participant about the investment needed when using BIM. Training, software, hardware and communication infrastructure are all associated with the adoption of new technology, and it is essential to understand which one is needed the most when using BIM

Question 13 asks the participants about their BIM objectives as shown in figure 18. The objectives will defined the real reason of using BIM. If the company stated the quality as their objective, it will indicates that BIM is a tool that companies are looking for to achieve quality (Figure 21).

In question 14, as shown in Figure 22, we indicated 7 metrics, and asked the participants to rank them (1 being most important and 7 being least important). Cost, scheduling, safety, quality, communication and BIM management were considered the most common metrics. Also, this question was planned to find out how the designers and contractors are weighting the metrics.

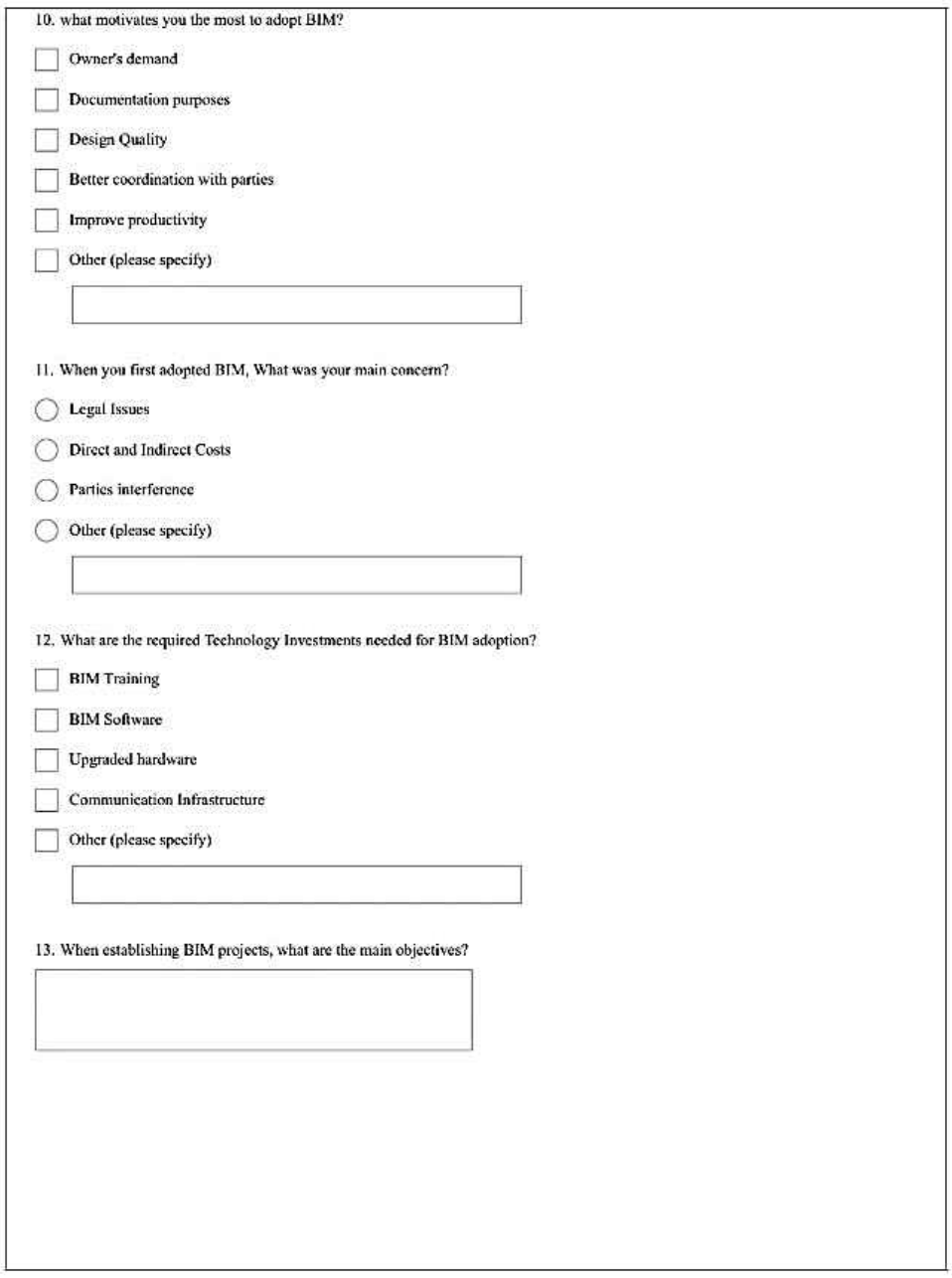


Figure 21. Motivations, concerns, Investment needed and objective (Survey questions from 10 to 13)

In question 15, we asked the participants about the importance of the BIM execution plan. It is a free-answer question, to get more insight on the professional perception about BIM execution plan. Question 16 is about the features included in

the BIM execution plan, to better understand how the project parties organize BIM works (Figure 22).

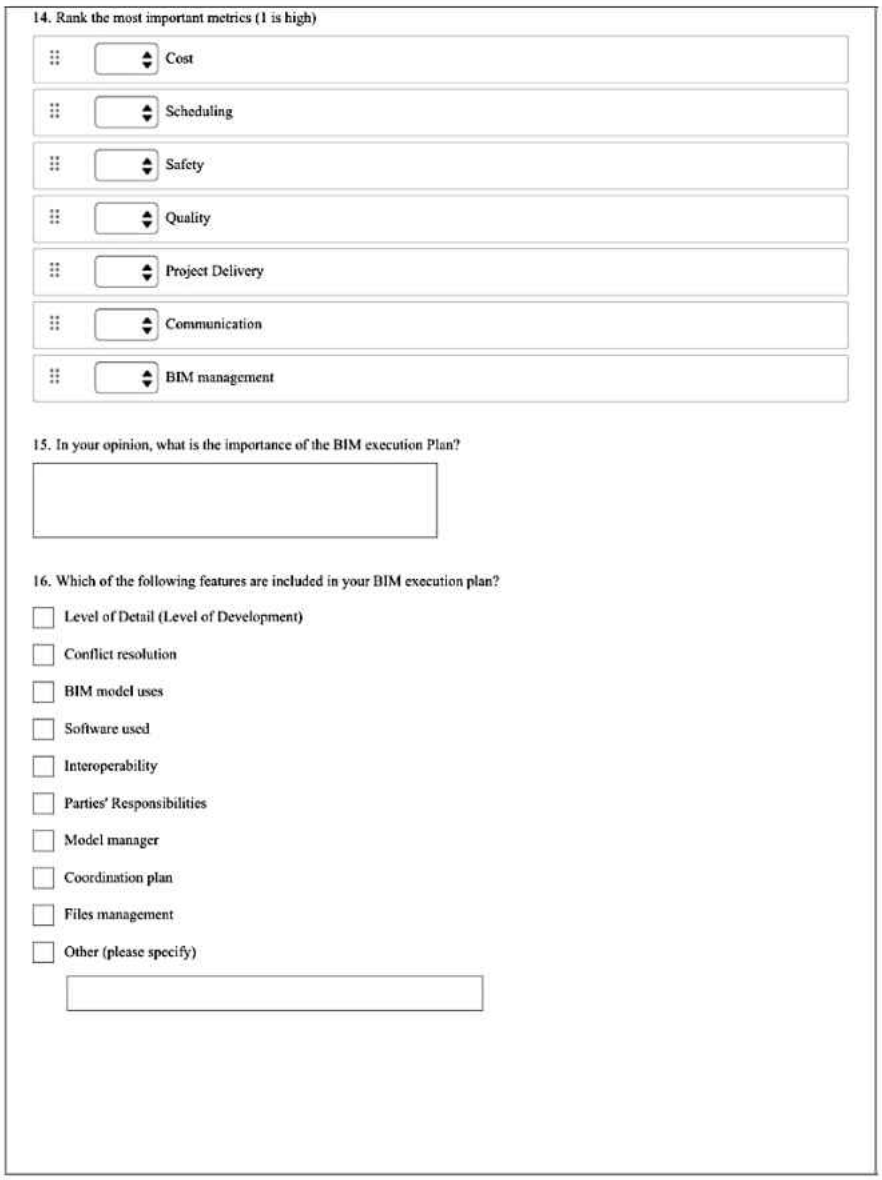


Figure 22. Metrics and BIM execution plan (Survey questions from 14 to 16)

Figure 23 shows questions 17 and 18. Question 17 was about the best delivery method for BIM projects. This question gives the participant the choice between the most known delivery methods that are used in construction project contracts. The reason of asking this question is to determine which delivery method are more suitable for BIM projects. In question 18, we listed the most well-known BIM software that are available in the market. In this question we will know the software that designer and contractor use, which means the software that is dominating the market.

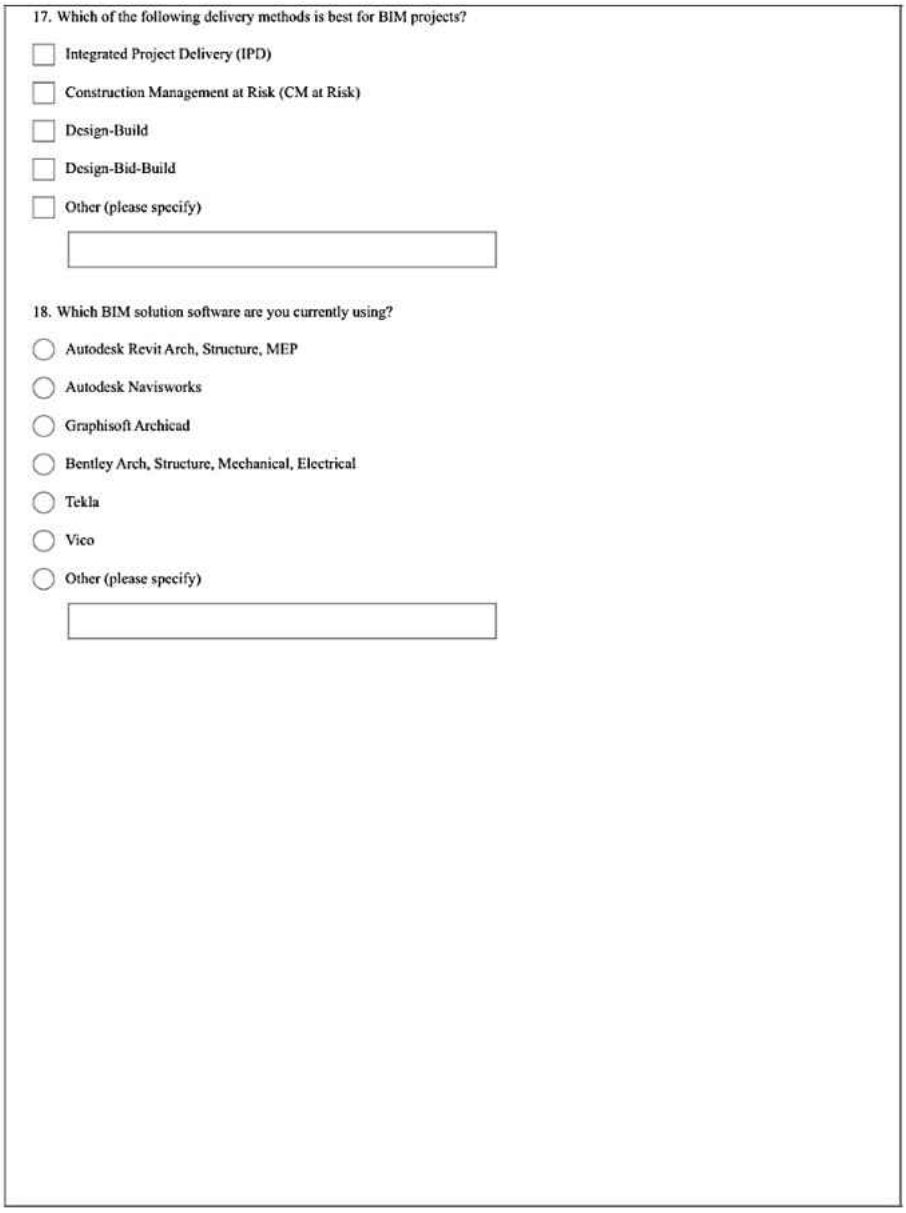
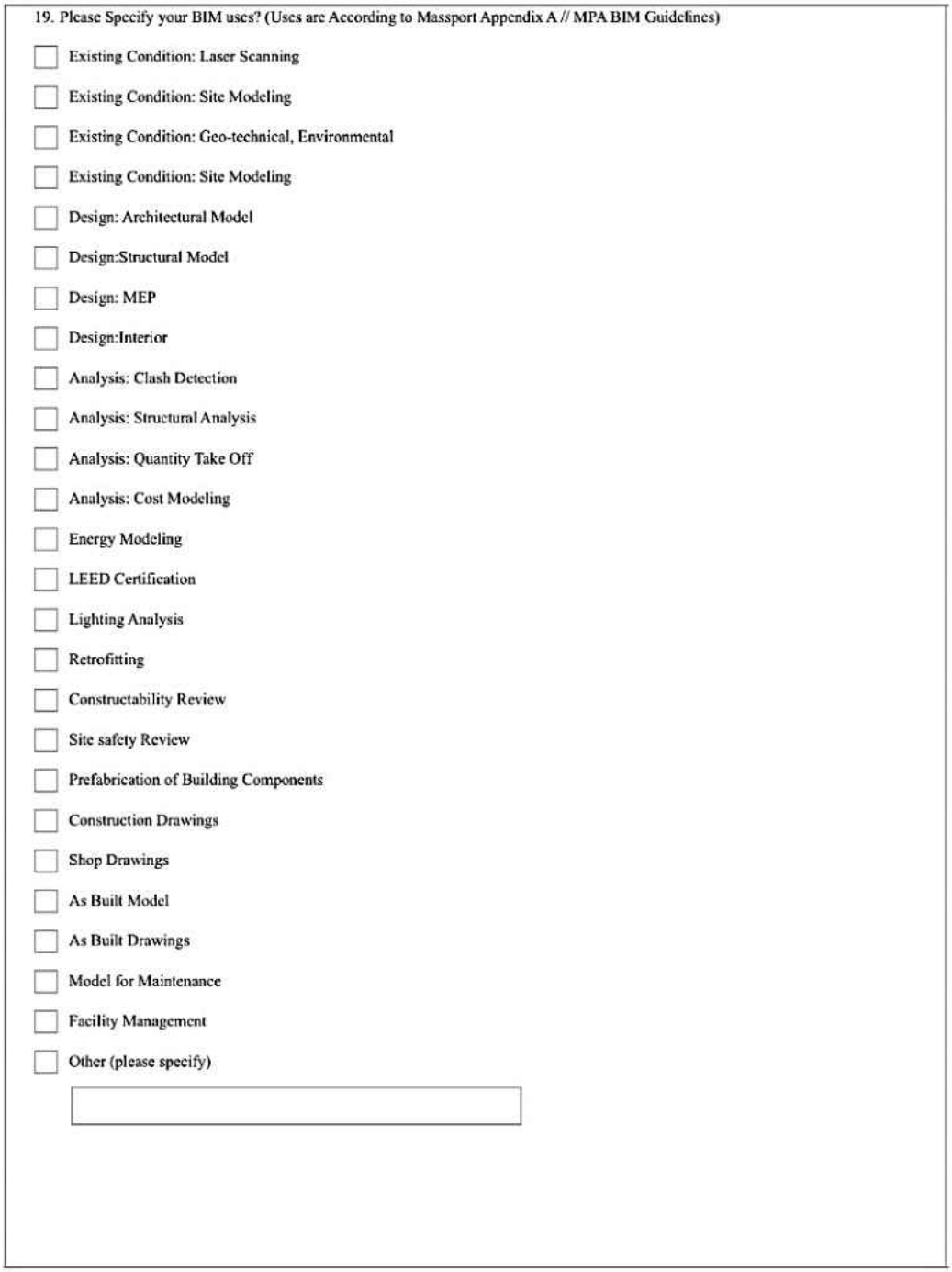


Figure 23. Delivery method and BIM software (Survey questions from 17 to 18)

Question 19 is the most important question of the survey (Figure 24). In this question we asked the participant to select the BIM features used by BIM users. The 26 uses were selected from the Massport BIM Guideline (Affairs 2015). The uses were categorized to cover BIM features that are usable from the existing condition to

facility management. The survey participants were able to select multiple uses, and this enabled us to know the most used features by designers and contractors.


19. Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)

- [ ] Existing Condition: Laser Scanning
- [ ] Existing Condition: Site Modeling
- [ ] Existing Condition: Geo-technical, Environmental
- [ ] Existing Condition: Site Modeling
- [ ] Design: Architectural Model
- [ ] Design:Structural Model
- [ ] Design: MEP
- [ ] Design:Interior
- [ ] Analysis: Clash Detection
- [ ] Analysis: Structural Analysis
- [ ] Analysis: Quantity Take Off
- [ ] Analysis: Cost Modeling
- [ ] Energy Modeling
- [ ] LEED Certification
- [ ] Lighting Analysis
- [ ] Retrofitting
- [ ] Constructability Review
- [ ] Site safety Review
- [ ] Prefabrication of Building Components
- [ ] Construction Drawings
- [ ] Shop Drawings
- [ ] As Built Model
- [ ] As Built Drawings
- [ ] Model for Maintenance
- [ ] Facility Management
- [ ] Other (please specify)

Figure 24. BIM uses (Survey question 19)

Figure 25 displays the questions 20 to 27. Question 20 is free answer question, and concerns the method of data sharing. This issue is important for the project's stockholder, since BIM is a model base technology. Questions 21 and 22 are about how BIM generates business opportunities to the users, and if BIM has a positive return of investment (ROI). This information is important to justify the use of BIM, or to convince future users of its business returns. Questions 23 and 26 are about the benefits derived from BIM. Question 23 is about the valuable benefits, such as change order, whereas question 26 is about the intangible benefits. On questions 24 and 25, we asked the participants whether or not they calculate the ROI regularly. If the answer was yes, we asked them how they calculate it.

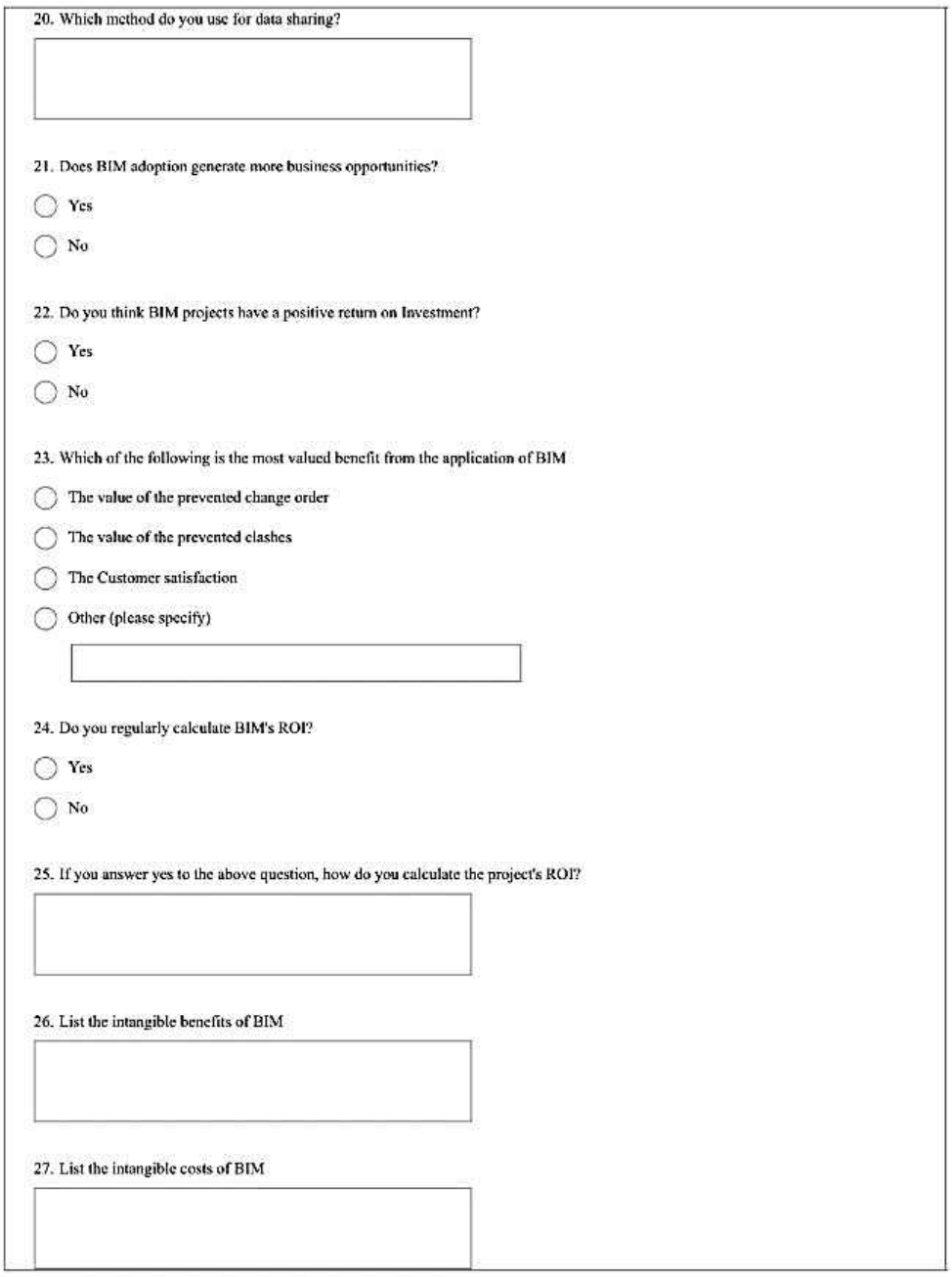
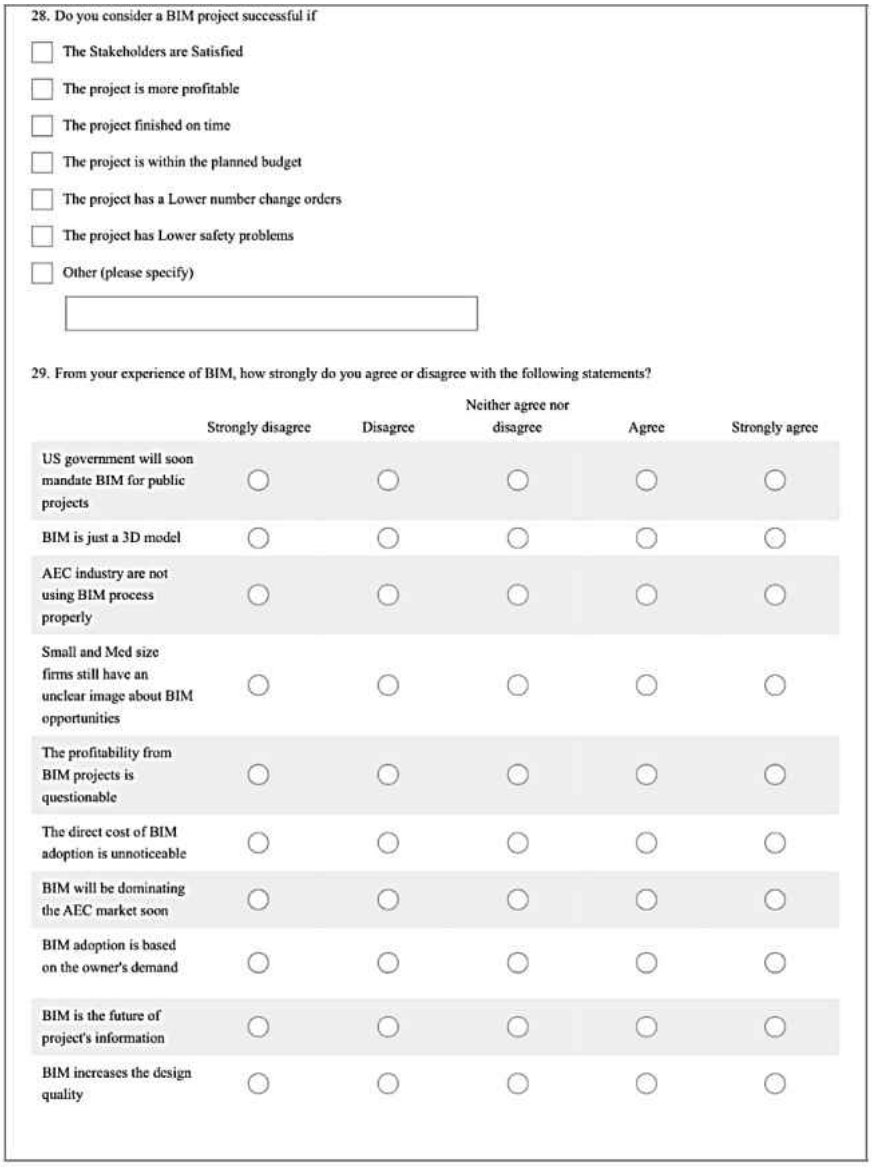


Figure 25. Data sharing, business opportunities, ROI and benefits (Survey questions from 20 to 27)

The last 2 questions, as shown in figure 26, are about the BIM success measures, and participants' opinions about many aspects answered through Likert scale. In question 28, we asked the participants to pinpoint BIM's success measures,

such as customer satisfaction, project profitability, and other measures. Question 29 is the last question, where we ask the participants to give their opinion based on agree/ disagree scale. The aim of this question was to emphasize on different issues, and get the participant perceptions on BIM use.



28. Do you consider a BIM project successful if

- ☐ The Stakeholders are Satisfied
- ☐ The project is more profitable
- ☐ The project finished on time
- ☐ The project is within the planned budget
- ☐ The project has a Lower number change orders
- ☐ The project has Lower safety problems
- ☐ Other (please specify)

29. From your experience of BIM, how strongly do you agree or disagree with the following statements?

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
US government will soon mandate BIM for public projects	○	○	○	○	○
BIM is just a 3D model	○	○	○	○	○
AEC industry are not using BIM process properly	○	○	○	○	○
Small and Med size firms still have an unclear image about BIM opportunities	○	○	○	○	○
The profitability from BIM projects is questionable	○	○	○	○	○
The direct cost of BIM adoption is unnoticeable	○	○	○	○	○
BIM will be dominating the AEC market soon	○	○	○	○	○
BIM adoption is based on the owner's demand	○	○	○	○	○
BIM is the future of project's information	○	○	○	○	○
BIM increases the design quality	○	○	○	○	○

Figure 26. Success measures and Likert scale (Survey question from 28 to 29)

3.2.2 Interviews to Measure the Effect of BIM on AEC Industry

3.2.2.1 Overview

These interviews were the last step in this research. The interviews were conducted with BIM professionals who work in real life projects, implemented with BIM. The rationale behind this step is to prove certain findings found in the general survey. The interview questions focused in two major parts; BIM features, and the intangible benefits of using BIM. The questions were designed to explore how BIM is used in real life projects, and how the intangible benefits of BIM are affecting the project's outcomes. In this step we reached the BIM leaders in the different AEC parties: Contractors, Engineers, Architects, and Owners.

The first part of the interview focused on BIM features that the participant's organization used in general or specific case study. We measured how these features affected the project's outcomes. Moreover, we measured the effect based on real life projects, by testing the case studies on common metrics such as cost, scheduling, quality, safety, and BIM management. These questions were only directed to the General and sub-contractors.

The second part of the interview focused on whether or not the intangible benefits are the benefits generated from the use of BIM. The list of intangibles derived from the general survey. In this part we found out the most essential intangibles to the project's success. Additionally, we specified the measurable intangibles, and the aim of this question was to explore the ways by which the participants use to measure these intangibles.

3.2.2.2 Interviews – Targeted Participants

The targeted interviews aimed contractors and designers. The BIM manager is usually the person who convince his company to adopt and be part of BIM world. Therefore, the interviews were conducted with the BIM managers or directors in the targeted organizations. We followed the following criteria when conducting the interviews:

- BIM manager, director, or leader
- Large or medium companies, experienced in BIM projects
- The BIM case study could not be the first experience for the company
- The project had to be in advanced BIM level of development, such as 300 or more based on the AIA or BIM forum standard.

3.2.2.3 Interviews' Specifics

The interviews consist of 14 questions, in two major parts. The first part is related to BIM features, and there are eight question in this part. The second part is related to intangible benefits and there are six questions covering this issue. The interviews were built as a structured interview, containing multiple choice questions, direct questions, and open ended questions. The interviews have been conducted either face to face, or by phone, the two methods were chosen based on the interviewee desire, and schedule availability. The transcript of each interview along with the analysis will be presented in chapter 4.

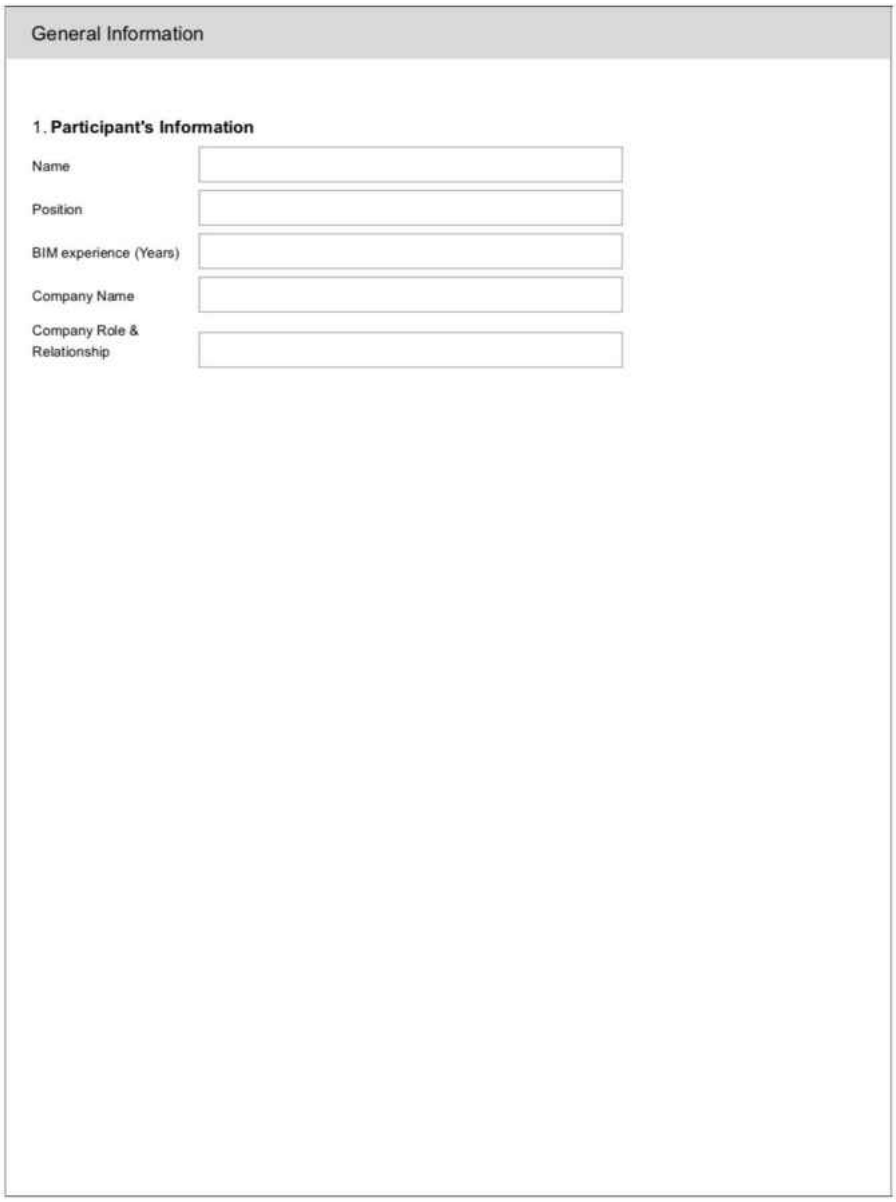


Figure 27. Interview: participant's Information

Figure 27 is about the participant's information. The participants were chosen based on their experience and position. They also answered if they were shareholder or part owner of the firm or company he works for.

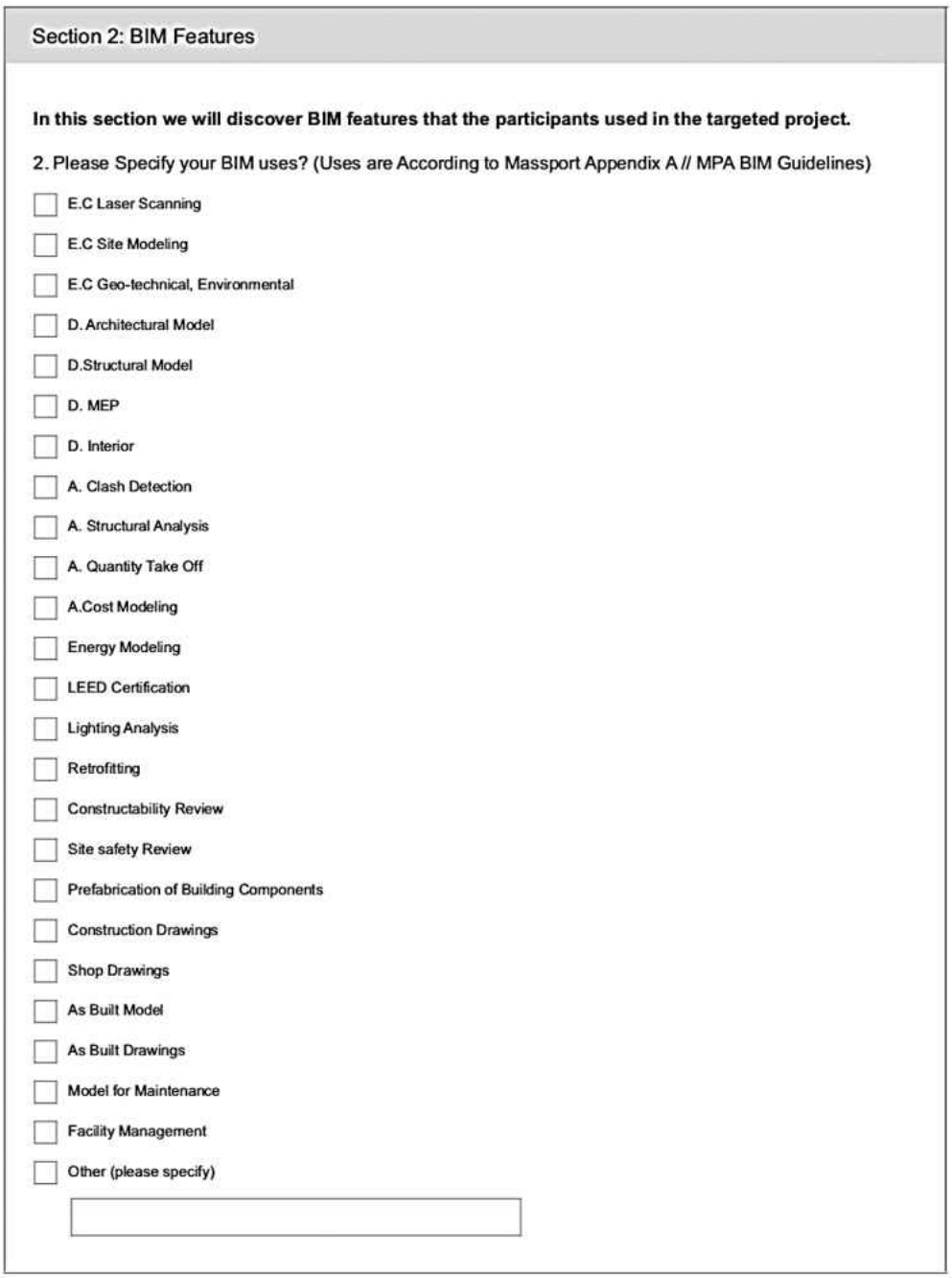


Figure 28. Interview: question 2 about the BIM features

Question 2 is about BIM features that the interviewees used in their projects. The purpose of this question is to explore how deep the firm are in with BIM adoption. In addition, this question showed how the AEC parties use BIM in diverse ways.


3. Do these features contribute in the project's ROI? If yes, How?

4. After choosing successful BIM project as a case study, How the project succeeded in the following criteria? (Question for General and Sub-Contractors)

Project Type	
Location	
Total Budget	
Construction Budget	
Design Budget	
Start Date	
End Date	
Contract Type & Delivery Method	
LOD (Level of Development)	
Cost Conformance (% of Variance)	
Minimize change order rate (% of total contract amount)	
Schedule Conformance (% of all Activities)	
Rework (# of rework)	
# of RFIs	
Design accuracy (# RFI for design errors)	
Safety (# of accidents)	

5. Please specify the challenges that you face when using these features?

6. From your technical perspective, what makes BIM a better method?

Figure 29. Interview: questions from 3 to 6

Question 3 investigates how BIM features contribute in the project's ROI, showing the difference between BIM and the traditional methods. Also, in this question we urged the participants to explain how they calculate or identify the

project's ROI. In question 4, we asked the general and sub-contractors about a successful BIM project case study. The metrics used to evaluate the project success were adopted from the VDC Score Card (Kam, Senaratna et al. 2013, Kam, Senaratna et al. 2013). In question 5, we asked the participants about the challenges they faced as company, when using BIM features. This question aimed exploring the challenges faced by the companies when adopting BIM, and pin pointing the difficulties that companies might face when using BIM. Question 6 is about BIM superiority from the technical perspective. In this question we asked the interviewees to explain from their experience, how BIM is better (Figure 29).

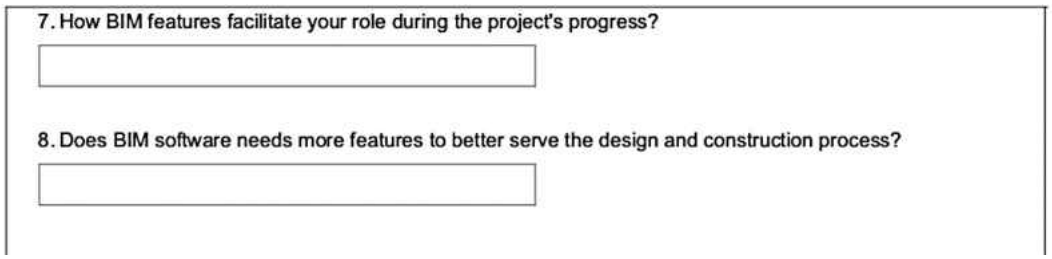
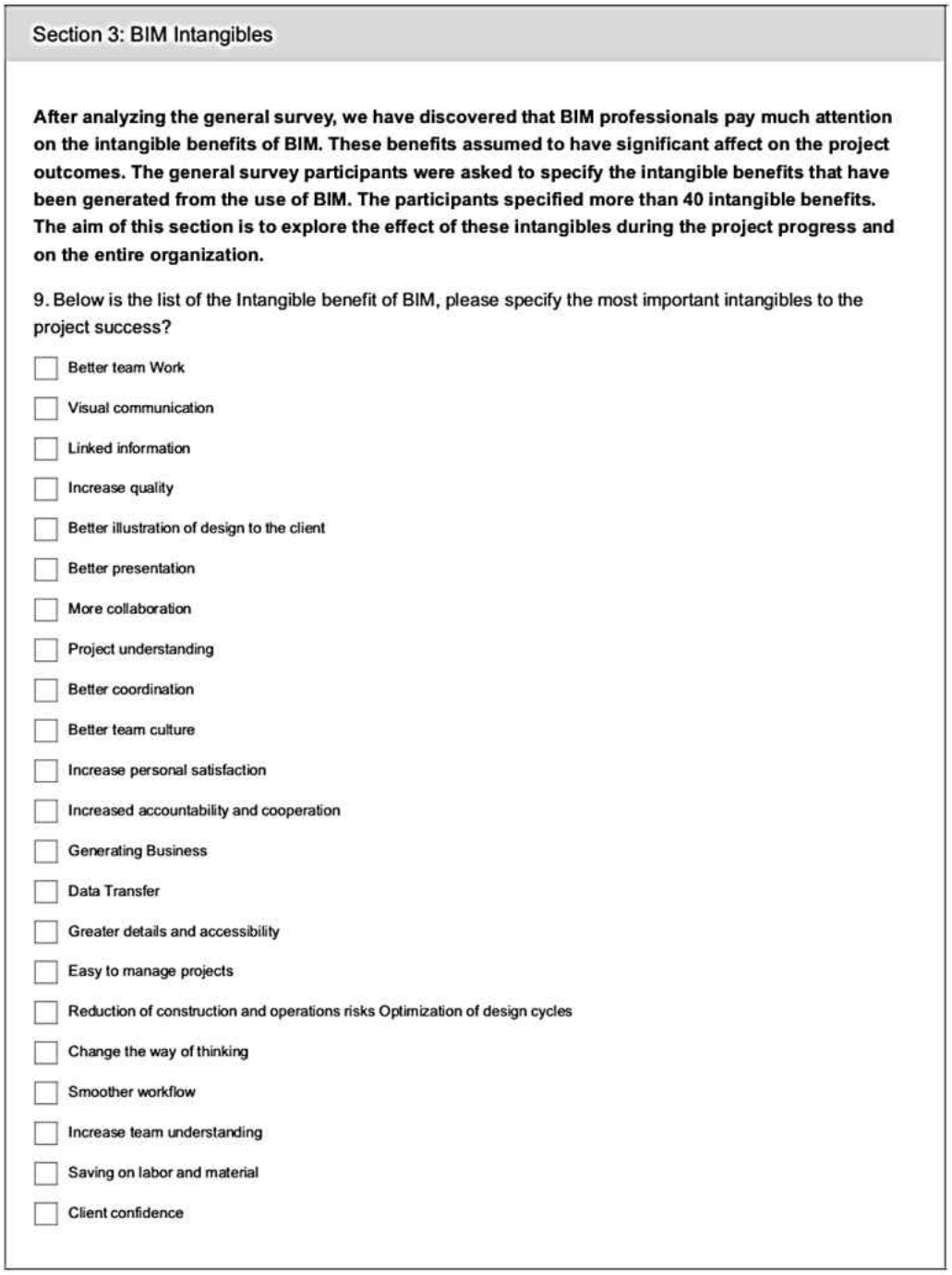


Figure 30. Interview: questions 7 and 8

Question 7 is an open ended question, we asked the participant how BIM facilitate his or her role at the company. The aim of this question was to bring to light the BIM features that facilitate the BIM manager's role during the project's progress. This question was important because it implicitly asked the participant to compare BIM with traditional method, during the project's progress. In question 8, we asked the participants about their experience with BIM, and how it can be implemented as a software to better serve the project's outcomes. This question's objective was to

discover the disadvantages that BIM software might have. Also, the question gave the participants an opportunity to think of other necessary features for different stages of the project (Figure 30).



Section 3: BIM Intangibles

After analyzing the general survey, we have discovered that BIM professionals pay much attention on the intangible benefits of BIM. These benefits assumed to have significant affect on the project outcomes. The general survey participants were asked to specify the intangible benefits that have been generated from the use of BIM. The participants specified more than 40 intangible benefits. The aim of this section is to explore the effect of these intangibles during the project progress and on the entire organization.

9. Below is the list of the Intangible benefit of BIM, please specify the most important intangibles to the project success?

- ☐ Better team Work
- ☐ Visual communication
- ☐ Linked information
- ☐ Increase quality
- ☐ Better illustration of design to the client
- ☐ Better presentation
- ☐ More collaboration
- ☐ Project understanding
- ☐ Better coordination
- ☐ Better team culture
- ☐ Increase personal satisfaction
- ☐ Increased accountability and cooperation
- ☐ Generating Business
- ☐ Data Transfer
- ☐ Greater details and accessibility
- ☐ Easy to manage projects
- ☐ Reduction of construction and operations risks Optimization of design cycles
- ☐ Change the way of thinking
- ☐ Smoother workflow
- ☐ Increase team understanding
- ☐ Saving on labor and material
- ☐ Client confidence

Figure 31. Interview: question 9

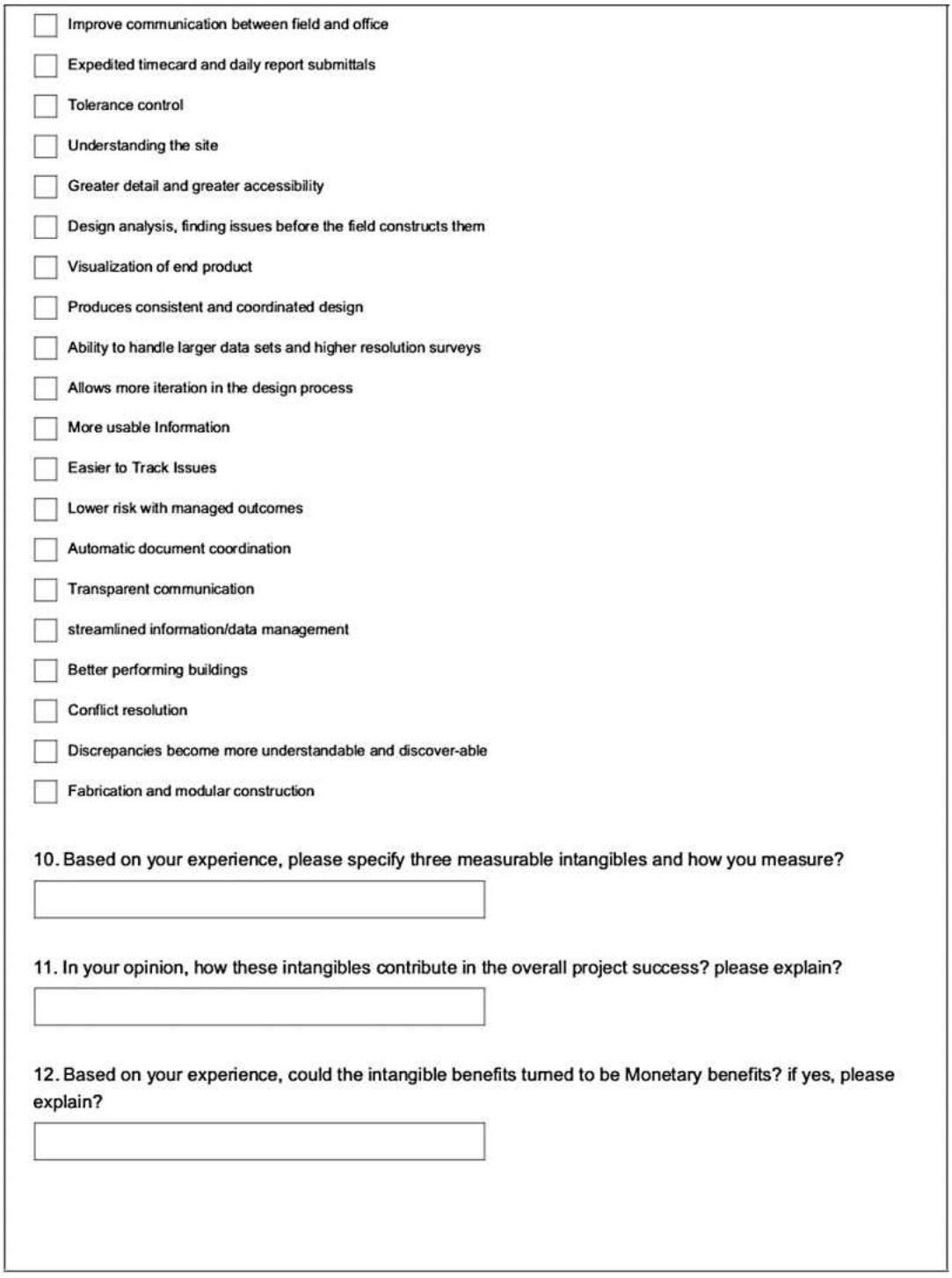


Figure 32. Interview: questions from 9 to 12

Figure 31 displays the beginning of the interview' third part, which is related to the intangible benefits. In question 9, we asked the interviewees to choose the most

important intangibles to a successful project. Finding BIM intangible benefits is a very difficult task. Love et al (2013) indicate that “the determination of the intangible benefits that can be derived from the implementation of BIM is considered to be a nebulous task” (Love, Matthews et al. 2014). Therefore, the list of intangibles in question 9 derived from BIM professional themselves. In the general survey, we have asked 145 participants to state the intangible benefits of BIM. Based on the analysis of the general survey, 55 among 145 participants responded to the intangibles question. After reviewing all answers, we have found that 43 out of 55 intangible benefits represent all listed benefits, as shown in table 6, where the remaining 12 were eliminated due to text redundancy. Some AEC professionals may argue that some of the listed benefits are tangibles, but we decided to list every benefit stated by BIM professionals.

Table 5. Intangible benefits

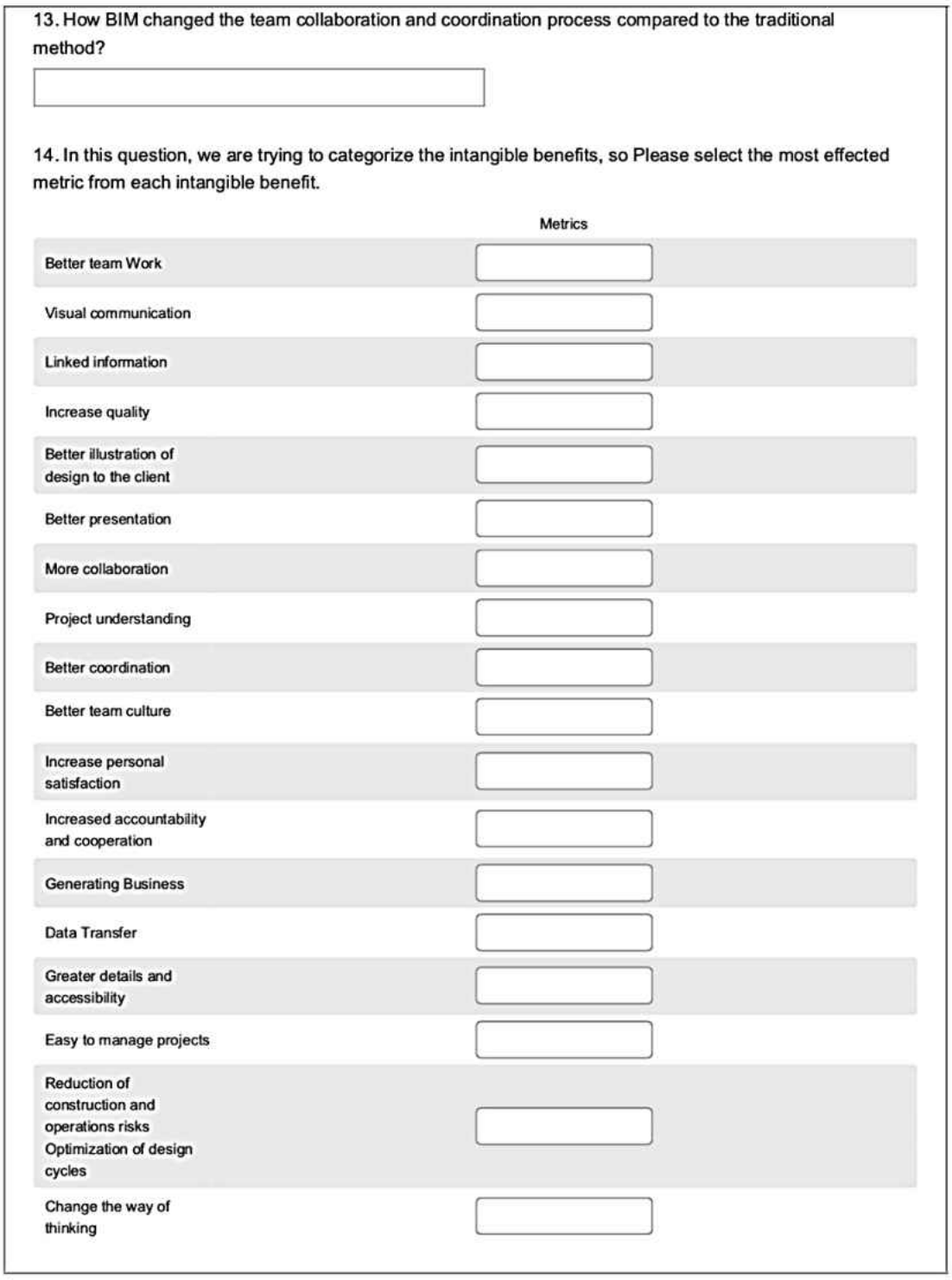
Intangible benefits
Better team Work
Visual communication
Linked information
Increase quality
Better illustration of design to the client
Better presentation
More collaboration
Project understanding
Better coordination
Better team culture
Increase personal satisfaction
Increased accountability and cooperation
Generating Business
Data Transfer
Greater details and accessibility
Easy to manage projects

Intangible benefits
Reduction of construction and operations risks Optimization of design cycles
Change the way of thinking
Smoother workflow
Increase team understanding
Saving on labor and material
Client confidence
Improve communication between field and office
Expedited timecard and daily report submittals
Tolerance control
Understanding the site
Greater detail and greater accessibility
Design analysis, finding issues before the field constructs them
Visualization of end product
Produces consistent and coordinated design
Ability to handle larger data sets and higher resolution surveys
Allows more iteration in the design process
More usable Information
Easier to Track Issues
Lower risk with managed outcomes
Automatic document coordination
Transparent communication
streamlined information/data management
Better performing buildings
Conflict resolution
Discrepancies become more understandable and discover-able
Fabrication and modular construction

Question 10, in Figure 32, is about the measureable intangibles. In this question we asked the participants to choose three intangibles that he or she believed to be measurable. The purpose of this question was to find measurable metrics for the intangibles. The experts had the chance to express their thoughts based on their company's role. Our expectation was to see different measures form each AEC party, each of the measures expressing their way of implementing BIM, and how they

derived the benefits from it. Question 11 is about how these intangibles contribute in overall project's success. We asked this question to figure out how the different AEC parties measure the positive outcomes of the intangibles. When we asked about the overall project success, we asked for all the aspects that contribute on the project's success such as: managerial, operational, procurement and other aspects.

Question 12, is about how the intangibles' benefits could represent monetary benefit. Participants could explain how his or her organization understood the financial benefits of BIM intangibles. The monetary benefits could be represented by saving of labor and time, reducing rework, business gains, minimizing conflicts, and other aspects.


13. How BIM changed the team collaboration and coordination process compared to the traditional method?

14. In this question, we are trying to categorize the intangible benefits, so Please select the most effected metric from each intangible benefit.

	Metrics
Better team Work	
Visual communication	
Linked information	
Increase quality	
Better illustration of design to the client	
Better presentation	
More collaboration	
Project understanding	
Better coordination	
Better team culture	
Increase personal satisfaction	
Increased accountability and cooperation	
Generating Business	
Data Transfer	
Greater details and accessibility	
Easy to manage projects	
Reduction of construction and operations risks Optimization of design cycles	
Change the way of thinking	

Figure 33. Interview: question 13 and 14

In question 13, we asked the participants to compare between BIM and the traditional method in coordination and collaboration processes. The question aimed

testing how the different AEC parties evaluate BIM processes, and how BIM change the project's environment. Question 14, the last question, quests the categorization of the intangibles based on the common metrics. Each intangible benefit was to be categorized to the most effective metric. We have stated nine metrics: 1) BIM management, 2) Business, 3) Cost, 4) Communication, 5) Quality, 6) Safety, 7) Schedule, 8) Project delivery, 9) Procurement. The aimed revealing how the participants perceive the effects of intangible benefits, based on the different metrics.

3.2.2.4 Interview Method

The interviews were conducted as a subject matter expert interviews (SMEs). The selected participants represent the major AEC parties, such as contractors (general and sub), designers (architectures, engineers), and owners. The participants were selected based on the criteria presented in section 3.2.2.2. The number of participants can range between: two or more, three to five, or six to eight (Crouch and McKenzie 2006). Crouch and McKenzie (2006) indicate that there is no fixed number for the count of the interviewees, except the recommended numbers in some articles.

For instance, three to five is the number of interviews that DuBois and Shalin (2000) conducted, where six to eight was recommended by (Shachak, Hadas-Dayagi et al. 2009) as cited in (Crouch and McKenzie 2006). Therefore, the number of interviewees will be determined based on the outcomes of the first interview outcomes.

3.3 Data Analysis

3.3.1 General Survey

The analysis of the general survey was conducted in two ways. First, the totality of results is presented in descriptive analysis fashion, as percentage distribution of the participant in every question. Second, a statistical approach is used to test the significance relationship between the tested variable, as discussed in detail in the following section.

3.3.1.1 Statistical approach – Person Chi-square

Person's chi-square test for the independence was used to analyze the relationship between the independent and the outcome variables. The test is designed to find if the there is a significant relationship between two categorical variables (Science 2016). Chi-square can be calculated by the following steps:

- Calculate the expected value for the observed counts as follows:

$$Expected\ value = \frac{row\ total\ x\ Column\ total}{sample\ size} \quad (1)$$

- Calculate Chi-square

$$X^{2*} = \frac{\Sigma(O_i - E_i)^2}{E} \quad (2)$$

X^2 = Chi-square, O_j = Observed value, E_i = Expected value

- Degree of freedom

$$df = (row - 1)(Column - 1) \quad (3)$$

The significant relationship between the independent and outcome variables can be found by calculating the P value, based on the degree of freedom and the significant level. The significant level usually 0.05. The chi-square analysis was carried out using SPSS software, and will be presented in chapter five.

3.3.2 The Interviews

The results of the interviews will be presented in two ways: first, the direct interpretation from the interviews transcripts; then, using the interpretive structural modeling analysis to analyze the relationship between the intangibles.

3.3.2.1 Interviews' Transcript Interpretation

In this section we will use the interviews transcripts to derive the answers for each one of the questions. The aim of the interviews was to gather BIM professional's vision and thoughts about BIM issues. Therefore, it is an essential part of this research to get their direct thought about issues raised in the interviews. Each one of the interviews, both face to face and by phone, lasted about one hour. Some of the questions asked were discussed as an open ended dialog, and there were in between questions to obtain more answers and thoughts. In this part, we will present the answers for each question, and the answers will be labeled by the participants' role.

3.3.2.2 Interpretive Structural Modeling (ISM)

Interpretive Structural Modeling (ISM) was proposed by (Warfield 1974). The aim of this method is to "develop a map of a complex relationships among elements involved in a complex decision situation" (Rajaprasad and Chalapathi 2015). This

method is based on the judgment of experts, and it helps in classifying and categorizing the variables (Ketkar, Shankar et al. 2012, Rajaprasad and Chalapathi 2015). Four steps constitute the ISM analysis: 1) the determination of variables that related to an issue; 2) finding the contextual relationship between each pair of variables; 3) developing the self-interaction matrix between the variables; 4) build the reachability matrix.

When building the self-interaction matrix, four symbols that represent the interaction between the variables; V, A, X and O. Between two variables (i & j), V means that variable i will help obtain variable j; A means that variable j will help obtain and achieve variable I; X means both led to each other; and O indicates that variable i and j are not related. The symbol of relationship between the variables will be translated to numbers in the reachability matrix. If the relationship between i and j is V, it means in the reachability matrix that i is 1 and j is 0; if the relation is A, then i equal 0 and j equal to 1. For X relations, both i and j variables will have 1; whereas in O relation both i and j will take 0.

CHAPTER 4: RESULTS & ANALYSIS

4.1 Introduction

Building Information Modeling (BIM) "is not widespread in US Architecture, Engineering, Construction, and Operation (AECO)" (Suermann 2009). Moreover, according to Giel and Issa (2014), the use of BIM is still considered low. Also, studies show that the "rate of BIM adoption in the AEC industry still seems to vary greatly among stakeholders and in the different phases of a project's lifecycle" (Giel and Issa 2013). In other hand, researchers insist that BIM adoption is growing significantly, especially in the past few years (Eastman, Teicholz et al. 2011, Bynum, Issa et al. 2013). The two different points of view, and the lack of empirical data indicate that the industry is in need for further research regarding BIM effects. BIM covers many features under its umbrella, thus it is important to conduct a research that connects BIM effects to its advanced technology and features.

The general survey provided valuable data about all aspects that shape the effects of BIM. The survey targeted BIM professionals in the AEC market and it aimed understanding how BIM is implemented, and what are the professionals' perceptions about its effects? This step drew and formulated the second step: the interviews. The objective of conducting interviews was to prove the effects of BIM based on real life case studies. The interviews focused on the effects of BIM based on certain metrics, as discussed in chapter 3.

4.2 General Survey

The survey distribution started in January 19, 2016. Two main methods were used to collect the participants' responses. First, we were able to distribute the survey among BIM users in central Florida and Orlando city. Two main groups were the source of the data collection at the early stage. Orlando Revit users, and Central Florida BIM users were the first targets. The survey was posted in their social media web sites, and direct emails were sent to assure the professionals we were able to contact. Then, we started to wide spread the survey by deploying it via professional social media channels, such as LinkedIn, to reach BIM professionals around the world.

The survey was designed and created through a well-known survey engine called Survey Monkey. The link (https://www.surveymonkey.com/r/YahyaOloufa) was sent to the professionals, and they were able to access the survey and participate digitally. The results and analysis of the general survey will be presented in two main sections: descriptive analysis and cross tabulation analysis, presented below.

4.2.1 General Survey – Descriptive Analysis

The results of this analysis were based on 145 responses, which and the presented figures are the analysis of data that are derived from the survey engine. Figures 34 through 36 show the role, sector and participant's specialty. Regarding the role, the proportion of participants in the general survey is comparable between designers (37.50%) and contractors (38.33 %). Almost 24% of the remaining participants were owners, or had other roles.

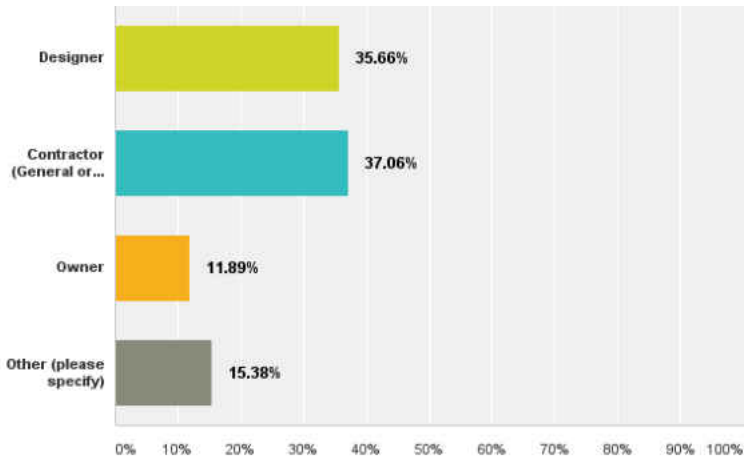


Figure 34. General survey question 1 results

Regarding the specialty, the majority of respondents were BIM managers (61.48 %), Followed by engineers (27.87 %), and architects (22.13%).

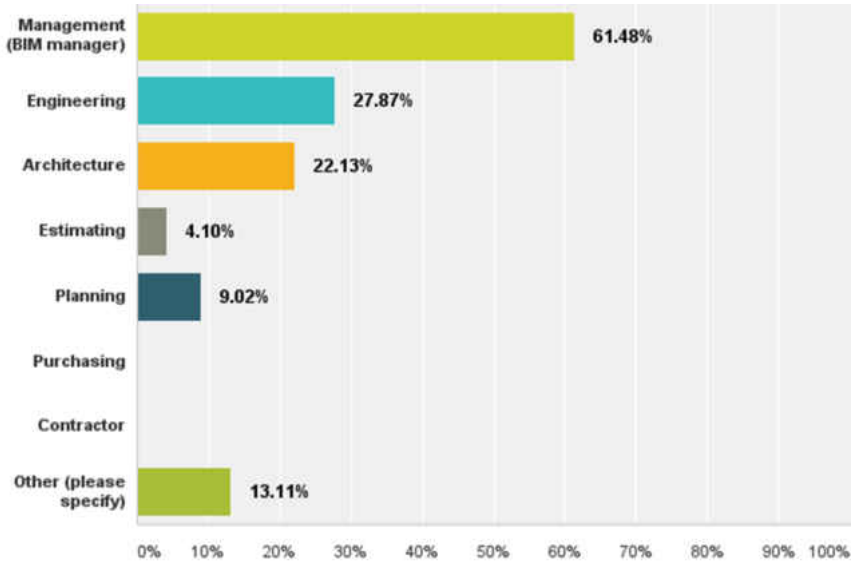


Figure 35. General survey question 2 results

Question 3 results shows that 73.43 % of the respondents work in private firms, while 26.57 % work in public entities.

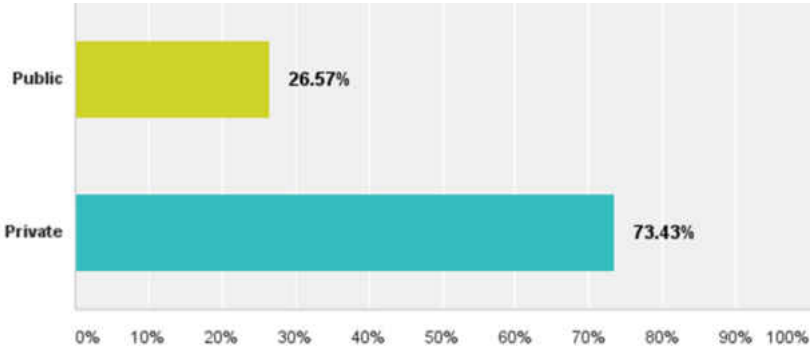


Figure 36. General survey question 3 results

The results for question 4 through 7 show the results of the questions related to the firms' market level, level of implementation, duration of implementation, and level of experience. Regarding the organization market level, the majority of the respondents belong to large size organizations (52.49 %), followed by respondents from medium size organizations (18.49%), then micro and small companies with 14.29 % and 11.76 % respectively.

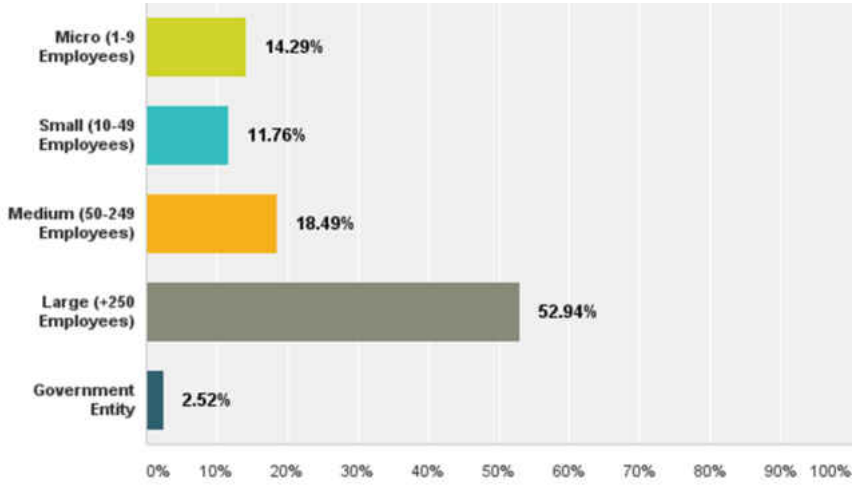


Figure 37. General survey question 4 results

Question 5 and 6 investigated the level of implementation and the duration of implementation. The results show the participants distributed evenly in all levels of implementation. The majority implementing BIM in very high level (30.69 %), followed by respondents who reported high implementation level (25.74 %), then, low and medium levels with 23.76 % and 19.80 % respectively. Regarding the duration of implementation, the majority (33.33 %) reported relatively recent implementation, with duration ranging between 1 and 3 years. The respondents who implemented BIM from 4 to 5 years represent 20.59 % of them, followed by those with more than 10 years of duration (18.63 %). Last, the respondents who implemented BIM for 8 to 10 and 5 to 7 years with 16.67 % and 10.67 % respectively.

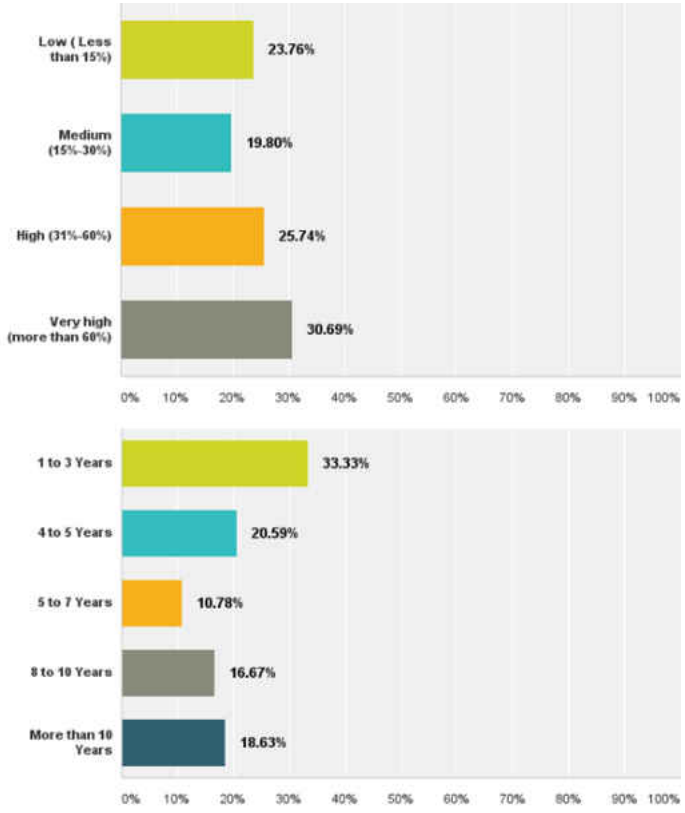


Figure 38. General survey question 5 & 6 results

The results of Question 7 show the distribution of the respondents based on their firms' level of experience. The majority of the respondents informed the moderate and advanced levels firms, with 31.69 % and 27.46 % respectively, while 24.65 % accounted for expert firms, and 13.11 % from beginner firms.

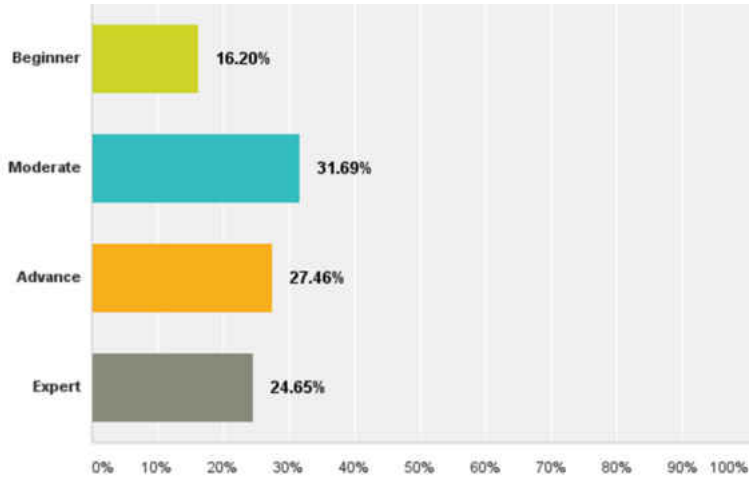


Figure 39. General survey question 7 results

In question 8 we asked the participants about the type of projects that are frequently implemented by BIM. The results show that health care projects were mostly implemented by BIM (17.82%), followed by commercial (16.83%), as shown in Figure 30. The following question intended to perceive the participants' definition of BIM. The results revealed the majority (28.28%) to agree with Autodesk definition "BIM is an intelligent model-base process that provides insight to help you plan, design, construct and manage buildings and infrastructure" (AutoDesk 2015) with.

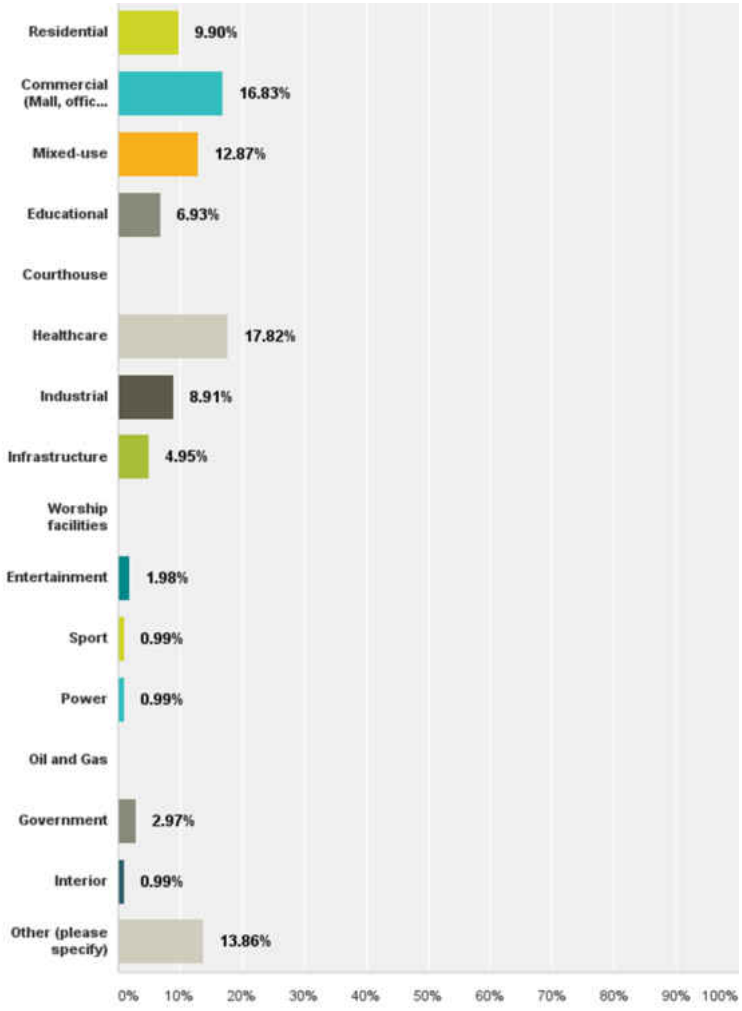


Figure 40. General survey question 8 results

Questions 10 to 13 were about the BIM adoption motivations, concerns, investment needed and objectives. Regarding the motivations, the results show that majority of the respondents adopt BIM because of better coordination; to improve productivity; and design quality. Figure 31 presents the results, which exceeded 100% due to the possibility to choose more than one answer. Question 11 examines the concerns about BIM use, and reveals that most of the participants are alarmed by the direct and indirect costs of BIM (41.41%). Also, 33.33% of the respondents' concerns are about parties' interference when adopting BIM.

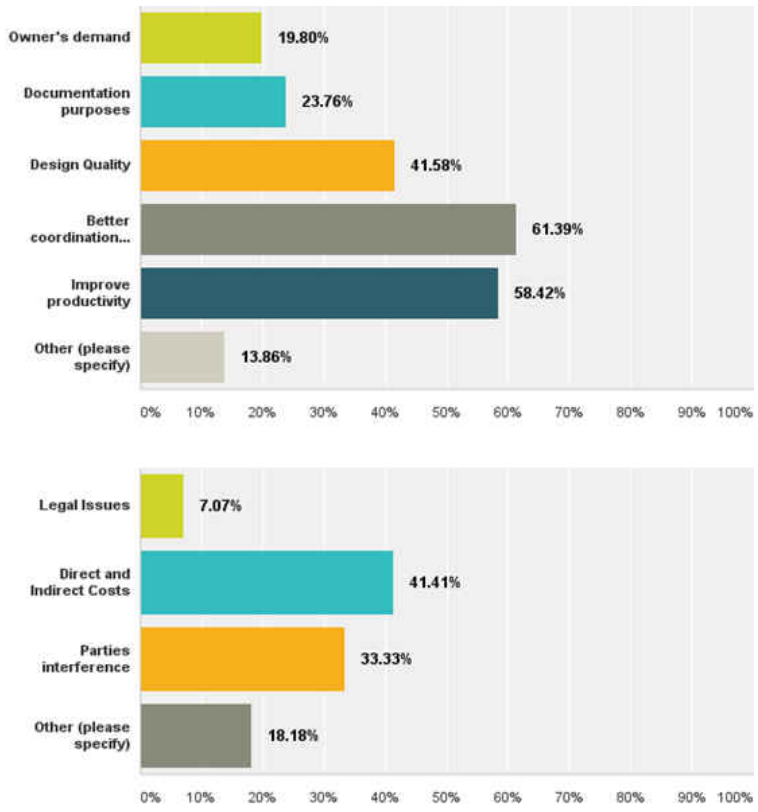


Figure 41. General survey questions 10 & 11 results

Regarding the investment needed, the results of question 12 show that the majority require BIM training (83.00 %), followed by BIM software (76.00). The remaining respondents require upgraded hardware (53.00%) and communication software (37.00%), and the lower percentage (12.00) chose other option. Likewise, due to the possibility of choosing more than one answer, the total percentage exceeded 100%.

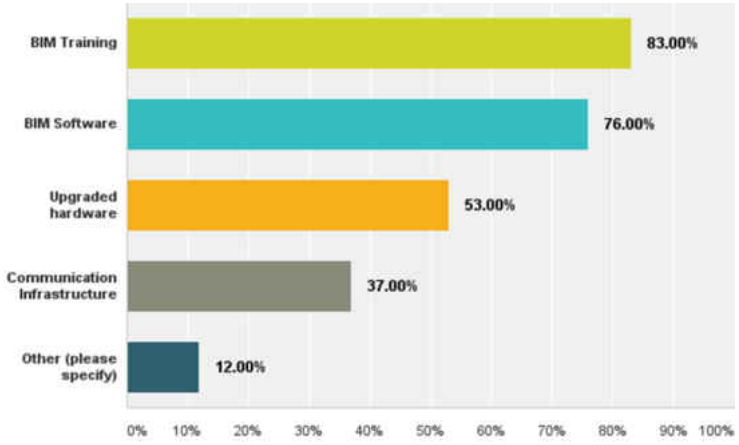


Figure 42. General survey question 12 results

In question 14 we asked the participants to rank the most important metrics. The participants were asked to rank seven metrics: cost, scheduling, safety, quality, communication, project delivery, and BIM management. The results illustrate safety on the top of the rank, followed by scheduling, cost, BIM management, project delivery, communication and quality respectively.

Table 6. General Survey question 14 results

Answer Option	1	2	3	4	5	6	7	Average	Response Count
Cost	13	19	14	11	22	15	14	4.03	108
Scheduling	8	13	13	17	22	24	9	4.32	106
Safety	16	3	8	15	16	21	29	4.77	108
Quality	20	20	19	20	9	14	3	3.30	105
Project Delivery	20	13	20	12	12	9	15	3.69	101
Communication	16	25	22	14	10	14	11	3.56	112
BIM management	17	17	12	18	18	6	22	3.99	110

Question 15 and 16 were about the importance of the BIM execution plan and the features that are included in this plan. The results for question 16 demonstrate that

all listed features are included, and level of development appeared with the highest percentage, followed by BIM model uses, coordination plan, and files management, respectively. Figure 43 displays the results.

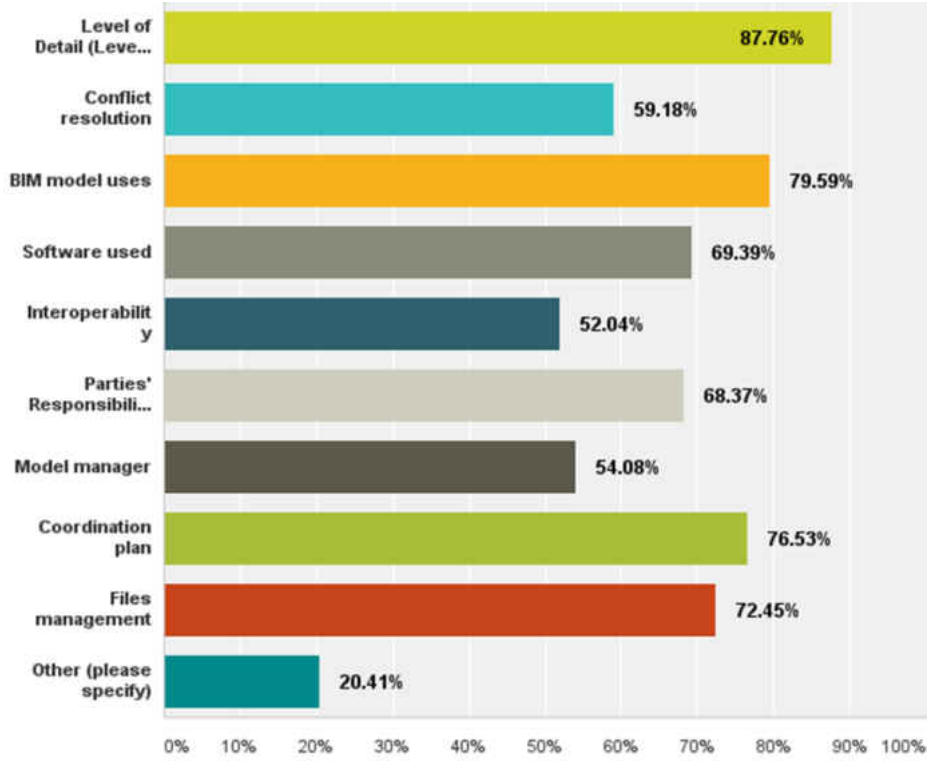


Figure 43. General survey question 16 results

Questions 17 and 18 are about the delivery methods, and BIM software. Regarding delivery methods, the majority of the respondents chose integrated project delivery (IPD) as the best delivery method. Design-build ranked second, followed by design-bid-build, and construction management at risk. The lowest percentage appeared on ‘specify other method’. Regarding BIM software in question 18, Autodesk Revit ranked first (52.53%), followed by Autodesk Navisworks (16.16%), and 29.29% chose other options.

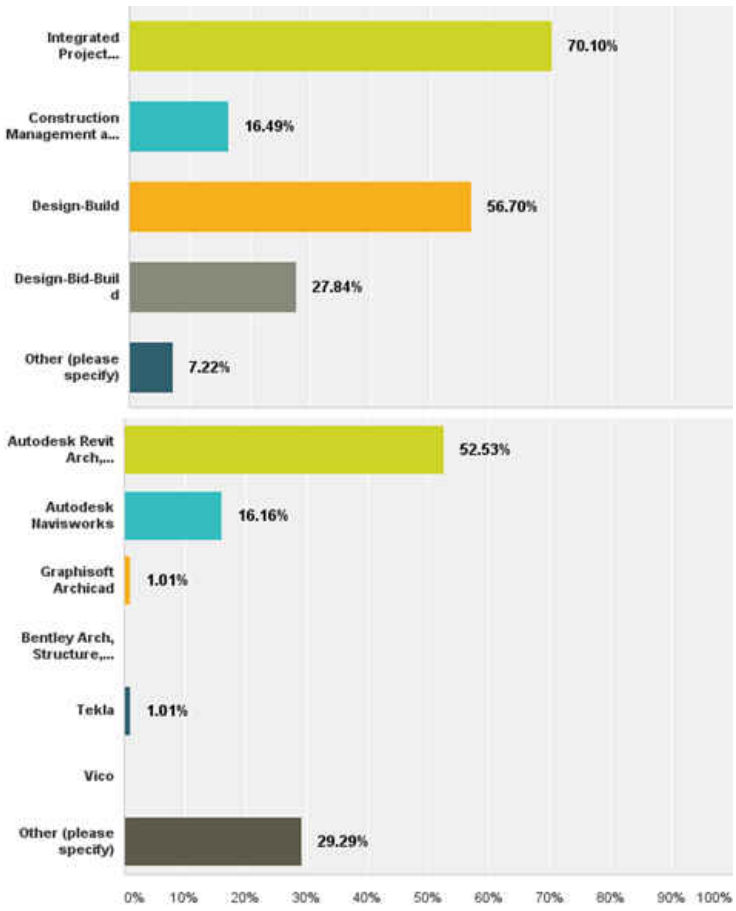


Figure 44. . General survey questions 17 & 18 results

Question 19 was vital, since the participants were asked to specify their BIM uses by choosing from the listed features. Twenty-six features were listed as the most used ones, and the respondents were able to choose more than one feature. The results, presented in Figure 45, reveal that architecture modeling, design MEP, clash detection, construction drawing, and built model are the most selected features.

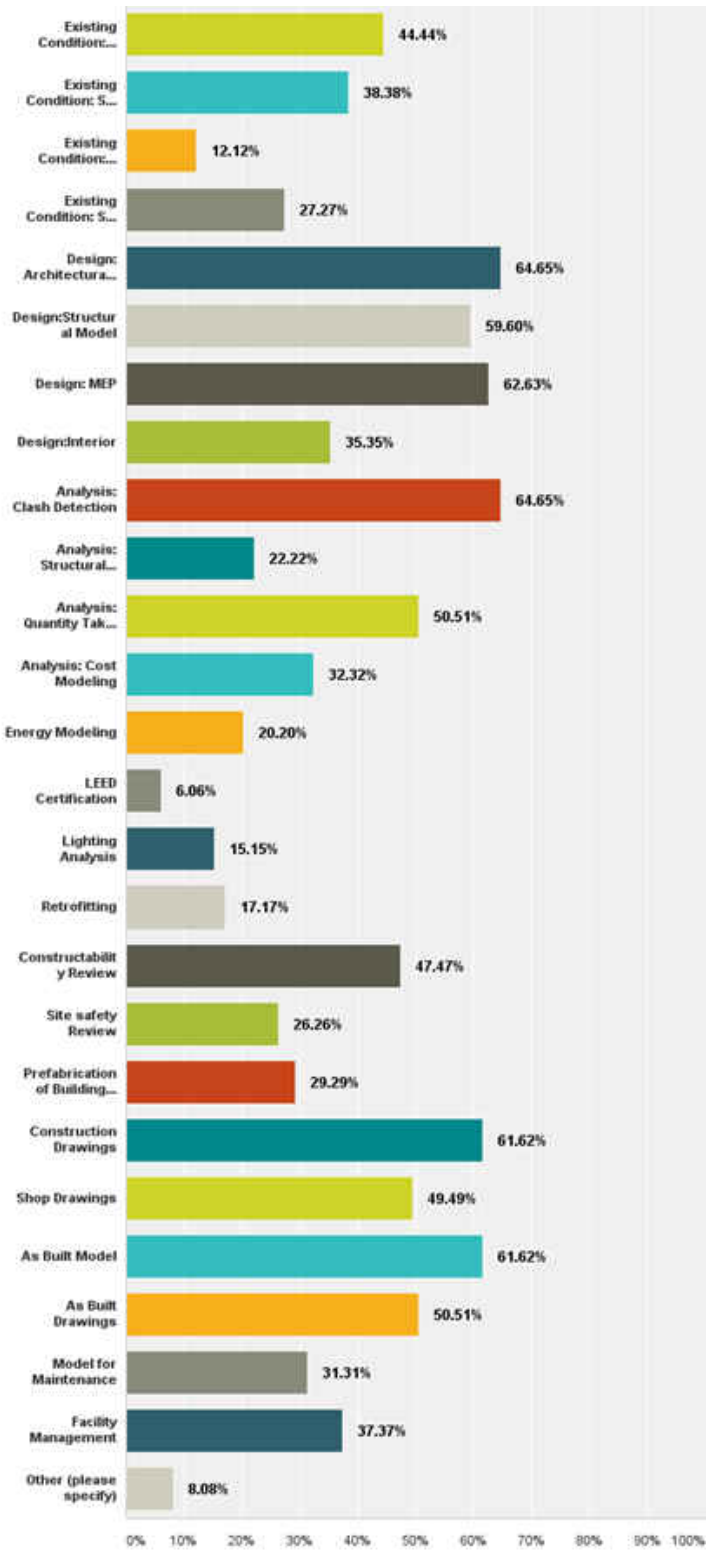


Figure 45. General survey question 19 results

Question 20 explores data sharing, and questions 21, 22, 23 and 24 examine BIM business opportunity, return of investment (ROI), valued benefits, and calculating ROI. Regarding business opportunity, 89.90% of the respondent consider BIM as a generator of business opportunities.

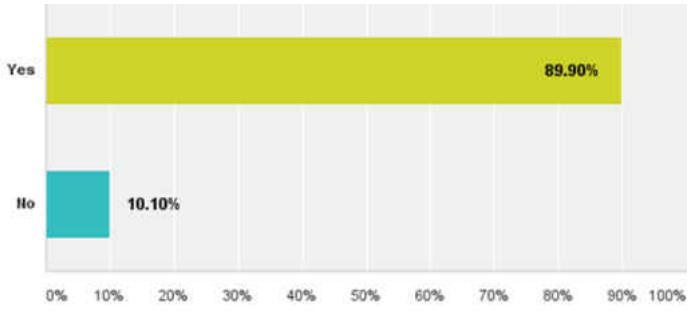


Figure 46. General survey question 21 result

Regarding ROI, 91.92 % of the survey participants believe that BIM relates to positive ROI. Which means that the majority of the respondents think they are making more money and customers by adopting BIM.

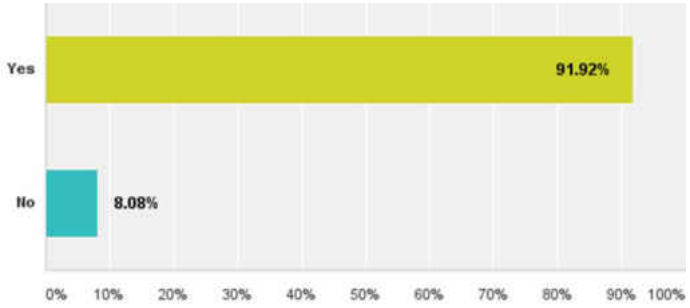


Figure 47. General survey question 22 result

In question 23, the participants were asked to point out the most valuable benefits of using BIM. From the respondents, 42.84% chose the value of prevented

change order as the most valuable benefit. The value of prevented clash ranked second, accumulating 24.49%, and customer satisfaction ranked third with 21.43%.

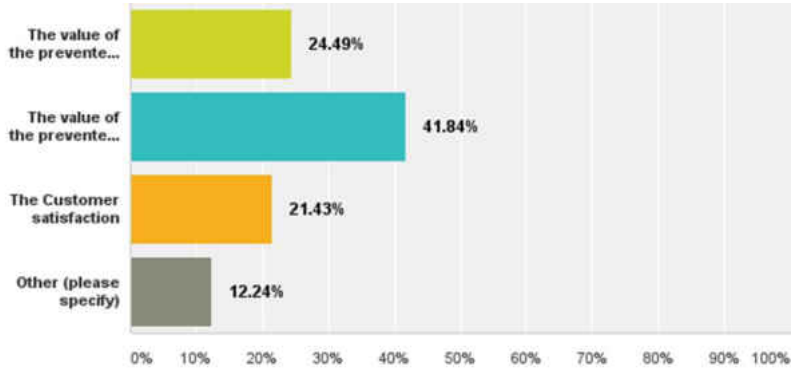


Figure 48. General survey question 23 results

Regarding ROI in question 24, the participants were inquired whether or not they frequently calculate BIM's ROI. The results show that 84.69% do not calculate ROI regularly, meaning that BIM users believe in BIM without determining its return.

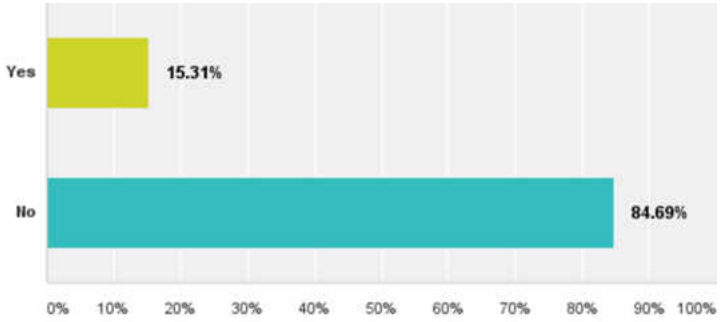


Figure 49. General survey question 24 results

Question 25, 26, and 27 explored the methods used to calculate BIM ROI, intangible benefits, and intangible cost. The answers for these question were open ended, and will be analyzed in a specific section. Regarding the success measures, the majority of the respondents in question 28 chose 'the project finished on time',

followed by the ‘stakeholder satisfaction’, and ‘the profitability of the project’ as shown in figure 50. The participants were allowed to choose more than one answer, which results in percentage sum exceeding 100%.

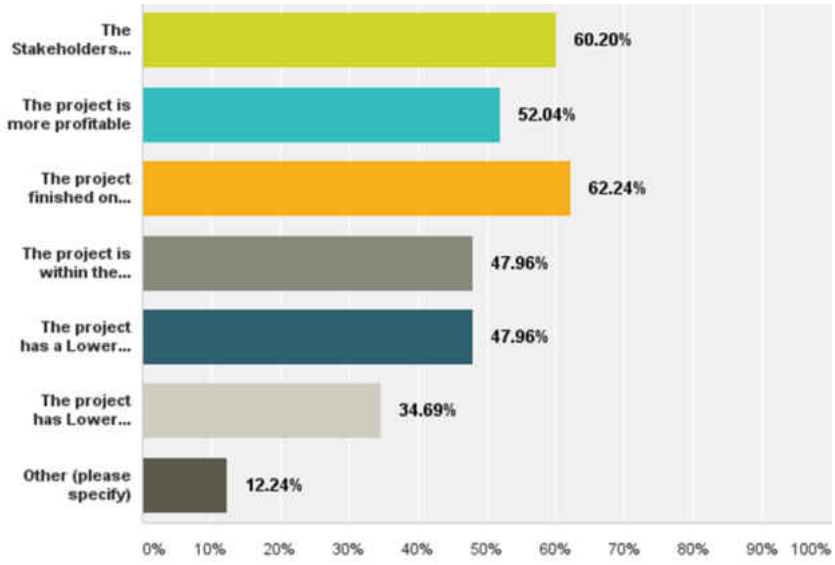


Figure 50. General Survey question 28 results

Question 29 requested the participants to answer through a 5-point Likert whether they agreed or disagreed with the statements provided. Each item emphasized on a specific topic, and aimed procuring an accurate perception from BIM professionals. Figure 51 displays the results.

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	Total	Weighted Average
US government will soon mandate BIM for public projects	1.96% 1	7.84% 4	34.67% 33	41.49% 39	28.72% 27	94	3.83
BIM is just a 3D model	69.07% 67	20.62% 20	7.22% 7	3.09% 3	1.03% 1	97	1.45
AEC industry are not using BIM process properly	2.11% 2	8.42% 8	34.74% 33	42.11% 40	11.58% 11	95	3.52
Small and Med size firms still have an unclear image about BIM opportunities	1.03% 1	9.28% 9	11.34% 11	63.92% 62	15.31% 15	98	3.83
The profitability from BIM projects is questionable	17.35% 17	36.73% 36	24.49% 24	20.41% 20	1.02% 1	98	2.51
The direct cost of BIM adoption is unreasonable	16.49% 16	44.33% 43	21.65% 21	14.43% 14	3.09% 3	97	2.43
BIM will be dominating the AEC market soon	1.04% 1	4.17% 4	16.67% 16	45.83% 44	32.29% 31	96	4.04
BIM adoption is based on the owner's demand	6.19% 6	23.71% 23	31.96% 31	37.11% 36	11.34% 11	97	3.34
BIM is the future of project's information	1.02% 1	1.02% 1	8.16% 8	33.67% 33	56.12% 55	98	4.43
BIM increases the design quality	4.08% 4	3.06% 3	8.16% 8	34.69% 34	50.00% 49	98	4.23
BIM will improve the building energy efficiency	0.00% 0	3.09% 3	16.49% 16	45.36% 44	33.05% 32	97	4.09
BIM will improve the communications between project's parties	2.04% 2	2.04% 2	8.16% 8	34.69% 34	53.06% 52	98	4.35
BIM will improve the cost performance (Minimize change order, cost conference)	1.02% 1	2.04% 2	14.29% 14	42.86% 42	39.59% 39	98	4.18
BIM will improve the schedule performance (Minimize rework, Minimize RFIs, schedule conference)	1.02% 1	1.02% 1	7.14% 7	54.08% 53	36.73% 36	98	4.24
BIM will improve the construction productivity	1.03% 1	1.03% 1	7.22% 7	51.55% 50	39.18% 38	97	4.27
The more detailed model the less error occurred	5.10% 5	10.20% 10	16.33% 16	36.73% 36	31.63% 31	98	3.80

Figure 51. General survey question 29 results

4.2.2 General survey – Cross-Tabulation Analysis

The analysis in this section were conducted to test the relationship between the independent and outcome variables. Chi-square test for independence is used based on the following hypothesis:

- H_o: There is no relationship between the tested variables
- H_a: There is a relationship between the tested variables
- Significance level: 0.05

The table below (Table 7) itemizes the independent and outcome variables. Considering that the cross tabulation analysis were conducted and based on the P value, we detected which variables shown significant relationship.

Table 7. Independent and outcome variables

Independent Variables	Outcome Variables
Role	Motivation
Sector	Concern
Specialty	Investment needed
Market level	Software
Level Of Implementation	Valuable benefits
Years of Implementation	Success measures
Experience	Uses (features)

4.2.2.1 Role (Designer / Contractors) X Motivation

In this section, we will assess the relationship between motivation and organization's role. The results point out to a significant relationship between the motivations, specifically the design quality, and the organization's role, such as designer and contractor. The table below reveals that designers were strongly

motivated by BIM design quality. The designers counted for 46.2 % of those who selected ‘design quality’ as the strongest motivation to adopt BIM.

Table 8. Role X Motivations

			what motivates you the most to adopt BIM?		
			0	Design Quality	Total
Please select your firm's or organization's role	Other (please specify)	Count	9	10	19
		% within Please select your firm's or organization's role	47.4%	52.6%	100.0%
		% within what motivates you the most to adopt BIM?	13.2%	19.2%	15.8%
	Designer	Count	17	24	41
		% within Please select your firm's or organization's role	41.5%	58.5%	100.0%
		% within what motivates you the most to adopt BIM?	25.0%	46.2%	34.2%
	Contractor (General or Sub-contractor)	Count	33	10	43
		% within Please select your firm's or organization's role	76.7%	23.3%	100.0%
		% within what motivates you the most to adopt BIM?	48.5%	19.2%	35.8%
	Owner	Count	9	8	17
		% within Please select your firm's or organization's role	52.9%	47.1%	100.0%
		% within what motivates you the most to adopt BIM?	13.2%	15.4%	14.2%
Total		Count	68	52	120
		% within Please select your firm's or organization's role	56.7%	43.3%	100.0%
		% within what motivates you the most to adopt BIM?	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	11.683[a]	3	.009
Likelihood Ratio	12.141	3	.007
Linear-by-Linear Association	3.304	1	.069
N of Valid Cases	120		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 7.37.

4.2.2.2 Role (Designer / Contractors) X Software

The aim of this section was to assess the relationship between the role and the type of software uses. The results in table 9 reveal a relationship between the software used and the role of the participants with P value 0.005, disclosing the fact that the software (Revit) is mostly used by the designers, flowed by the contractors, then the owners. The second most used software is Autodesk Navisworks, and it's mostly employed by the contractors. The results accurately reflect the reality. However, the data are not adequate for this analysis, which is the only limitation for this section.

Table 9. Role X Software

Please select your firm's or organization's role * Which BIM solution software are you currently using? Crosstabulation

			Which BIM solution software are you currently using?						
			Other (please specify)	Autodesk Revit Arch, Structure, MEP	Autodesk Navisworks	Graphisoft Archicad	Bentley Arch, Structure, Mechanical, Electrical	Tekla	Total
Please select your firm's or organization's role	Other (please specify)	Count	7	10	1	0	0	0	18
		% within Please select your firm's or organization's role	38.9%	55.6%	5.6%	0.0%	0.0%	0.0%	100.0%
		% within Which BIM solution software are you currently using?	20.6%	15.6%	5.9%	0.0%	0.0%	0.0%	15.3%
	Designer	Count	7	31	1	1	0	1	41
		% within Please select your firm's or organization's role	17.1%	75.6%	2.4%	2.4%	0.0%	2.4%	100.0%
		% within Which BIM solution software are you currently using?	20.6%	48.4%	5.9%	100.0%	0.0%	100.0%	34.7%
	Contractor (General or Sub-contractor)	Count	14	13	14	0	1	0	42
		% within Please select your firm's or organization's role	33.3%	31.0%	33.3%	0.0%	2.4%	0.0%	100.0%
		% within Which BIM solution software are you currently using?	41.2%	20.3%	82.4%	0.0%	100.0%	0.0%	35.6%
	Owner	Count	6	10	1	0	0	0	17
		% within Please select your firm's or organization's role	35.3%	58.8%	5.9%	0.0%	0.0%	0.0%	100.0%
		% within Which BIM solution software are you currently using?	17.6%	15.6%	5.9%	0.0%	0.0%	0.0%	14.4%
Total		Count	34	64	17	1	1	1	118
		% within Please select your firm's or organization's role	28.8%	54.2%	14.4%	0.8%	0.8%	0.8%	100.0%
		% within Which BIM solution software are you currently using?	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	32.785[a]	15	.005
Likelihood Ratio	34.036	15	.003
Linear-by-Linear Association	.127	1	.721
N of Valid Cases	118		

a. 15 cells (62.5%) have expected count less than 5. The minimum expected count is .14.

4.2.2.3 Role X BIM Uses

According to the data, there is a significant relationship between the role of participants and BIM uses. The results reveal seven use that indicate significance relationship. The uses are: Laser scanning with P value 0.049, Constructability review with P value 0.000, Site safety with P value of 0.005, Prefabrication of Building components with P value 0.014, Shop drawing with P Value 0.019, As Built Model with P value 0.033, and Facility management with P value 0.030. The results are shown in the following tables:

Table 10. Role X BIM Uses (Laser Scanning)

			Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)		
			0	Existing Condition: Laser Scanning	Total
Please select your firm's or organization's role	Other (please specify)	Count	7	11	18
		% within Please select your firm's or organization's role	38.9%	61.1%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	13.5%	20.8%	17.1%
	Designer	Count	23	10	33
		% within Please select your firm's or organization's role	69.7%	30.3%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	44.2%	18.9%	31.4%
	Contractor (General or Sub-contractor)	Count	16	23	39
		% within Please select your firm's or organization's role	41.0%	59.0%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	30.8%	43.4%	37.1%
	Owner	Count	6	9	15
		% within Please select your firm's or organization's role	40.0%	60.0%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	11.5%	17.0%	14.3%
Total		Count	52	53	105
		% within Please select your firm's or organization's role	49.5%	50.5%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.858[a]	3	.049
Likelihood Ratio	8.017	3	.046
Linear-by-Linear Association	.779	1	.378
N of Valid Cases	105		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 7.43.

Table 11. Role X BIM Uses (Constructability review)

			Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)		
			0	Constructability Review	Total
Please select your firm's or organization's role	Other (please specify)	Count	6	12	18
		% within Please select your firm's or organization's role	33.3%	66.7%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	12.0%	21.8%	17.1%
	Designer	Count	26	7	33
		% within Please select your firm's or organization's role	78.8%	21.2%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	52.0%	12.7%	31.4%
	Contractor (General or Sub-contractor)	Count	10	29	39
		% within Please select your firm's or organization's role	25.6%	74.4%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	20.0%	52.7%	37.1%
	Owner	Count	8	7	15
		% within Please select your firm's or organization's role	53.3%	46.7%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	16.0%	12.7%	14.3%
Total		Count	50	55	105
		% within Please select your firm's or organization's role	47.6%	52.4%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	22.074[a]	3	.000
Likelihood Ratio	23.172	3	.000
Linear-by-Linear Association	.791	1	.374
N of Valid Cases	105		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 7.14.

Table 12. Role X BIM Uses (Site Safety)

			Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)		
			0	Site safety Review	Total
Please select your firm's or organization's role	Other (please specify)	Count	12	6	18
		% within Please select your firm's or organization's role	66.7%	33.3%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	15.8%	20.7%	17.1%
	Designer	Count	31	2	33
		% within Please select your firm's or organization's role	93.9%	6.1%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	40.8%	6.9%	31.4%
	Contractor (General or Sub-contractor)	Count	22	17	39
		% within Please select your firm's or organization's role	56.4%	43.6%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	28.9%	58.6%	37.1%
	Owner	Count	11	4	15
		% within Please select your firm's or organization's role	73.3%	26.7%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	14.5%	13.8%	14.3%
Total		Count	76	29	105
		% within Please select your firm's or organization's role	72.4%	27.6%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	12.949[a]	3	.005
Likelihood Ratio	14.933	3	.002
Linear-by-Linear Association	1.297	1	.255
N of Valid Cases	105		

a. 2 cells (25.0%) have expected count less than 5. The minimum expected count is 4.14.

Table 13. Role X BIM Uses (Prefabrication of Building Components)

Crosstab

			Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)		
			0	Prefabrication of Building Components	Total
Please select your firm's or organization's role	Other (please specify)	Count	11	7	18
		% within Please select your firm's or organization's role	61.1%	38.9%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	15.5%	20.6%	17.1%
	Designer	Count	28	5	33
		% within Please select your firm's or organization's role	84.8%	15.2%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	39.4%	14.7%	31.4%
	Contractor (General or Sub-contractor)	Count	20	19	39
		% within Please select your firm's or organization's role	51.3%	48.7%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	28.2%	55.9%	37.1%
	Owner	Count	12	3	15
		% within Please select your firm's or organization's role	80.0%	20.0%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	16.9%	8.8%	14.3%
Total		Count	71	34	105
		% within Please select your firm's or organization's role	67.6%	32.4%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	10.626[a]	3	.014
Likelihood Ratio	11.058	3	.011
Linear-by-Linear Association	.108	1	.742
N of Valid Cases	105		

a. 1 cells (12.5%) have expected count less than 5. The minimum expected count is 4.86.

Table 14. Role X BIM Uses (Shop Drawing)

Crosstab

			Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)		
			0	Shop Drawings	Total
Please select your firm's or organization's role	Other (please specify)	Count	6	12	18
		% within Please select your firm's or organization's role	33.3%	66.7%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	12.2%	21.4%	17.1%
	Designer	Count	19	14	33
		% within Please select your firm's or organization's role	57.6%	42.4%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	38.8%	25.0%	31.4%
	Contractor (General or Sub-contractor)	Count	13	26	39
		% within Please select your firm's or organization's role	33.3%	66.7%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	26.5%	46.4%	37.1%
	Owner	Count	11	4	15
		% within Please select your firm's or organization's role	73.3%	26.7%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	22.4%	7.1%	14.3%
Total		Count	49	56	105
		% within Please select your firm's or organization's role	46.7%	53.3%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	9.935[a]	3	.019
Likelihood Ratio	10.147	3	.017
Linear-by-Linear Association	1.167	1	.280
N of Valid Cases	105		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 7.00.

Table 15. Role X BIM Uses (As Built Model)

Crosstab

			Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)		
			0	As Built Model	Total
Please select your firm's or organization's role	Other (please specify)	Count	3	15	18
		% within Please select your firm's or organization's role	16.7%	83.3%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	10.7%	19.5%	17.1%
	Designer	Count	15	18	33
		% within Please select your firm's or organization's role	45.5%	54.5%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	53.6%	23.4%	31.4%
	Contractor (General or Sub-contractor)	Count	7	32	39
		% within Please select your firm's or organization's role	17.9%	82.1%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	25.0%	41.6%	37.1%
	Owner	Count	3	12	15
		% within Please select your firm's or organization's role	20.0%	80.0%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	10.7%	15.6%	14.3%
Total		Count	28	77	105
		% within Please select your firm's or organization's role	26.7%	73.3%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.734[a]	3	.033
Likelihood Ratio	8.367	3	.039
Linear-by-Linear Association	.712	1	.399
N of Valid Cases	105		

a. 2 cells (25.0%) have expected count less than 5. The minimum expected count is 4.00.

Table 16. Role X BIM Uses (Facility Management)

Crosstab

			Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)		
			0	Facility Management	Total
Please select your firm's or organization's role	Other (please specify)	Count	7	11	18
		% within Please select your firm's or organization's role	38.9%	61.1%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	11.7%	24.4%	17.1%
	Designer	Count	25	8	33
		% within Please select your firm's or organization's role	75.8%	24.2%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	41.7%	17.8%	31.4%
	Contractor (General or Sub-contractor)	Count	22	17	39
		% within Please select your firm's or organization's role	56.4%	43.6%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	36.7%	37.8%	37.1%
	Owner	Count	6	9	15
		% within Please select your firm's or organization's role	40.0%	60.0%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	10.0%	20.0%	14.3%
Total		Count	60	45	105
		% within Please select your firm's or organization's role	57.1%	42.9%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.927[a]	3	.030
Likelihood Ratio	9.186	3	.027
Linear-by-Linear Association	.201	1	.654
N of Valid Cases	105		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 6.43.

4.2.2.4 Sector X Concerns

There is a significant relationship between the sectors and the concerns. Both public and private sector are mainly concern about the direct and indirect cost of BIM. With P value 0.037, private sector are concern about the indirect and direct cost of BIM and the parties' interference, rather than the legal issues.

Table 17. Sector X Concerns

Which sector does your Organization belongs to? * When you first adopted BIM, What was your main concern? Crosstabulation

			When you first adopted BIM, What was your main concern?				
			Other (please specify)	Legal Issues	Direct and Indirect Costs	Parties interference	Total
Which sector does your Organization belongs to?	Public	Count	4	6	14	8	32
		% within Which sector does your Organization belongs to?	12.5%	18.8%	43.8%	25.0%	100.0%
		% within When you first adopted BIM, What was your main concern?	20.0%	66.7%	28.6%	20.5%	27.4%
	Private	Count	16	3	35	31	85
		% within Which sector does your Organization belongs to?	18.8%	3.5%	41.2%	36.5%	100.0%
		% within When you first adopted BIM, What was your main concern?	80.0%	33.3%	71.4%	79.5%	72.6%
Total		Count	20	9	49	39	117
		% within Which sector does your Organization belongs to?	17.1%	7.7%	41.9%	33.3%	100.0%
		% within When you first adopted BIM, What was your main concern?	100.0%	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.500[a]	3	.037
Likelihood Ratio	7.608	3	.055
Linear-by-Linear Association	.418	1	.518
N of Valid Cases	117		

a. 1 cells (12.5%) have expected count less than 5. The minimum expected count is 2.46.

4.2.2.5 Sector X BIM Uses

In this section, we can reject the null hypothesis, and indicate that there is a significant relationship between the sector and BIM uses. Considering the P value 0.038, we can infer a significant relationship between the sector and BIM uses, and Retrofitting used proportionally more in public sector compared to private sector, as shown in table below.

Table 18. Sector X BIM Uses (Retrofitting)

Crosstab

			Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)		
			0	Retrofitting	Total
Which sector does your Organization belongs to?	Public	Count	19	10	29
		% within Which sector does your Organization belongs to?	65.5%	34.5%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	23.2%	45.5%	27.9%
	Private	Count	63	12	75
		% within Which sector does your Organization belongs to?	84.0%	16.0%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	76.8%	54.5%	72.1%
Total		Count	82	22	104
		% within Which sector does your Organization belongs to?	78.8%	21.2%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	4.283[a]	1	.038		
Continuity Correction[b]	3.247	1	.072		
Likelihood Ratio	4.012	1	.045		
Fisher's Exact Test				.059	.039
Linear-by-Linear Association	4.242	1	.039		
N of Valid Cases	104				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 6.13.

b. Computed only for a 2x2 table

4.2.2.6 Market Level X Motivations

In this section, we can reject the null hypothesis, and indicate a significant relationship between the market level and the motivations. With P value 0.039, 77% of the participants do not select "Owner demand" as a motivation of using BIM. The results reveal that micro companies' motivations relate mostly to the owners' demand, whereas large companies are the least motivated by that.

Table 19. Market Level X Motivations (Owners demand)

Crosstab

			what motivates you the most to adopt BIM?		
			0	Owner's demand	Total
Describe your Firm or Organization market level?	Micro (1-9 Employees)	Count	8	6	14
		% within Describe your Firm or Organization market level?	57.1%	42.9%	100.0%
		% within what motivates you the most to adopt BIM?	8.8%	22.2%	11.9%
	Small (10-49 Employees)	Count	11	3	14
		% within Describe your Firm or Organization market level?	78.6%	21.4%	100.0%
		% within what motivates you the most to adopt BIM?	12.1%	11.1%	11.9%
	Medium (50-249 Employees)	Count	17	5	22
		% within Describe your Firm or Organization market level?	77.3%	22.7%	100.0%
		% within what motivates you the most to adopt BIM?	18.7%	18.5%	18.6%
	Large (+250 Employees)	Count	50	8	58
		% within Describe your Firm or Organization market level?	86.2%	13.8%	100.0%
		% within what motivates you the most to adopt BIM?	54.9%	29.6%	49.2%
	Government Entity	Count	5	5	10
		% within Describe your Firm or Organization market level?	50.0%	50.0%	100.0%
		% within what motivates you the most to adopt BIM?	5.5%	18.5%	8.5%
Total		Count	91	27	118
		% within Describe your Firm or Organization market level?	77.1%	22.9%	100.0%
		% within what motivates you the most to adopt BIM?	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	10.065[a]	4	.039
Likelihood Ratio	9.277	4	.055
Linear-by-Linear Association	.982	1	.322
N of Valid Cases	118		

a. 3 cells (30.0%) have expected count less than 5. The minimum expected count is 2.29.

4.2.2.7 Market Level X Success Measures

For this section, the results indicate that the null hypothesis is rejected, and indicate that there is significant relationship between the market level and the success measures. With P value 0.008, 69% of the small companies determine the success of their project in measures of being "within the planned budget". Likewise, 60% of the large companies consider success in correspondence to planned budget.

Table 20. Market Level X Success Measures (Project within planned budget)

Crosstab

			Do you consider a BIM project successful if		
			0	The project is within the planned budget	Total
Describe your Firm or Organization market level?	Micro (1-9 Employees)	Count	8	7	15
		% within Describe your Firm or Organization market level?	53.3%	46.7%	100.0%
		% within Do you consider a BIM project successful if	15.1%	11.3%	13.0%
	Small (10-49 Employees)	Count	4	9	13
		% within Describe your Firm or Organization market level?	30.8%	69.2%	100.0%
		% within Do you consider a BIM project successful if	7.5%	14.5%	11.3%
	Medium (50-249 Employees)	Count	16	4	20
		% within Describe your Firm or Organization market level?	80.0%	20.0%	100.0%
		% within Do you consider a BIM project successful if	30.2%	6.5%	17.4%
	Large (+250 Employees)	Count	23	35	58
		% within Describe your Firm or Organization market level?	39.7%	60.3%	100.0%
		% within Do you consider a BIM project successful if	43.4%	56.5%	50.4%
	Government Entity	Count	2	7	9
		% within Describe your Firm or Organization market level?	22.2%	77.8%	100.0%
		% within Do you consider a BIM project successful if	3.8%	11.3%	7.8%
Total		Count	53	62	115
		% within Describe your Firm or Organization market level?	46.1%	53.9%	100.0%
		% within Do you consider a BIM project successful if	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	13.831[a]	4	.008
Likelihood Ratio	14.488	4	.006
Linear-by-Linear Association	1.707	1	.191
N of Valid Cases	115		

a. 2 cells (20.0%) have expected count less than 5. The minimum expected count is 4.15.

4.2.2.8 Market Level X BIM Uses

In reference to this category, we found a significant relationship between the companies' market level and BIM uses. With P value 0.006, clash detection is heavily used by the large companies. As shown in the table below, 44 among the 72 companies that use clash detection are large ones. This confirms the idea that larger companies permanently benefit from new technologies. In addition, the results show that 64.3% of the micro companies do not utilize this feature.

Table 21. Market Level X BIM Uses (Clash Detection)

Crosstab

			Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)		
			0	Analysis: Clash Detection	Total
Describe your Firm or Organization market level?	Micro (1-9 Employees)	Count	9	5	14
		% within Describe your Firm or Organization market level?	64.3%	35.7%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	25.7%	6.9%	13.1%
	Small (10-49 Employees)	Count	5	8	13
		% within Describe your Firm or Organization market level?	38.5%	61.5%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	14.3%	11.1%	12.1%
	Medium (50-249 Employees)	Count	8	11	19
		% within Describe your Firm or Organization market level?	42.1%	57.9%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	22.9%	15.3%	17.8%
	Large (+250 Employees)	Count	9	44	53
		% within Describe your Firm or Organization market level?	17.0%	83.0%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	25.7%	61.1%	49.5%
	Government Entity	Count	4	4	8
		% within Describe your Firm or Organization market level?	50.0%	50.0%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	11.4%	5.6%	7.5%
Total		Count	35	72	107
		% within Describe your Firm or Organization market level?	32.7%	67.3%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	14.343[a]	4	.006
Likelihood Ratio	14.452	4	.006
Linear-by-Linear Association	7.051	1	.008
N of Valid Cases	107		

a. 3 cells (30.0%) have expected count less than 5. The minimum expected count is 2.62.

4.2.2.9 Level of Implementation X BIM Uses

The results indicate that we can reject the null hypothesis and that there is significant relationship between the level of implementation and BIM uses. Construction Drawings and Shop Drawings are two features that show significance among the companies with different levels of BIM implementation. Construction Drawings and Shop Drawings with P value 0.023 and 0.050 respectively, are both strongly employed by the companies with high level of implementation. These results demonstrate that companies with long high level of implementation benefit from BIM features.

Table 22. Level of Implementation X BIM uses (Construction Drawings)

Crosstab

			Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)		
			0	Shop Drawings	Total
In your Firm/Organization; what is the level of BIM Implementation?	Low (Less than 15%)	Count	16	7	23
		% within In your Firm/Organization; what is the level of BIM Implementation?	69.6%	30.4%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	33.3%	12.5%	22.1%
	Medium (15%-30%)	Count	10	10	20
		% within In your Firm/Organization; what is the level of BIM Implementation?	50.0%	50.0%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	20.8%	17.9%	19.2%
	High (31%-60%)	Count	10	16	26
		% within In your Firm/Organization; what is the level of BIM Implementation?	38.5%	61.5%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	20.8%	28.6%	25.0%
	Very high (more than 60%)	Count	12	23	35
		% within In your Firm/Organization; what is the level of BIM Implementation?	34.3%	65.7%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	25.0%	41.1%	33.7%
Total		Count	48	56	104
		% within In your Firm/Organization; what is the level of BIM Implementation?	46.2%	53.8%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	9.518[a]	3	.023
Likelihood Ratio	9.041	3	.029
Linear-by-Linear Association	5.241	1	.022
N of Valid Cases	104		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 6.15.

Table 23. Level of Implementation X BIM uses (Shop Drawing)

Crosstab

			Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)		
			0	Shop Drawings	Total
In your Firm/Organization; what is the level of BIM Implementation?	Low (Less than 15%)	Count	16	7	23
		% within In your Firm/Organization; what is the level of BIM Implementation?	69.6%	30.4%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	33.3%	12.5%	22.1%
	Medium (15%-30%)	Count	10	10	20
		% within In your Firm/Organization; what is the level of BIM Implementation?	50.0%	50.0%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	20.8%	17.9%	19.2%
	High (31%-60%)	Count	10	16	26
		% within In your Firm/Organization; what is the level of BIM Implementation?	38.5%	61.5%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	20.8%	28.6%	25.0%
	Very high (more than 60%)	Count	12	23	35
		% within In your Firm/Organization; what is the level of BIM Implementation?	34.3%	65.7%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	25.0%	41.1%	33.7%
Total		Count	48	56	104
		% within In your Firm/Organization; what is the level of BIM Implementation?	46.2%	53.8%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.794[a]	3	.050
Likelihood Ratio	7.915	3	.048
Linear-by-Linear Association	7.123	1	.008
N of Valid Cases	104		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 9.23.

4.2.2.10 Length of Implementation X BIM Uses

In this section, we assessed the relationship between the companies' length of BIM implementation and the BIM uses. The results reveal significant relationship in four different uses. Laser Scanning with P value 0.021, Architectural Model with P value 0.008, Prefabrication of Building Components with P value 0.002, and Facility Management with P value 0.003. Regarding Laser Scanning, we verify that companies with 8 to 10 years of BIM implementation rank first in use, counting 26.4% of the total. Additionally, we can observe that 63.3% of the companies with short period of BIM implementation do not employ the Laser Scanning. This indicates that some features, such as Laser Scanning, require high level of experience to reveal its outcomes.

Regarding the Architectural Model, the results indicate that new users are drawn to this feature, meaning that the Architectural capability of BIM is highly used by new BIM users, with 54.3% among the totality. Conversely, the Prefabrication and Facility Management features are used by the companies' with 8 to 10 years of BIM implementation. Therefore, we can conclude that BIM features and uses vary based on the length of use.

Table 24. Length of Implementation X BIM Uses (Laser Scanning)

Crosstab

			Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)		
			0	Existing Condition: Laser Scanning	Total
For how long have you been Implementing BIM	1 to 3 Years	Count	19	11	30
		% within For how long have you been Implementing BIM	63.3%	36.7%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	37.3%	20.8%	28.8%
	4 to 5 Years	Count	15	9	24
		% within For how long have you been Implementing BIM	62.5%	37.5%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	29.4%	17.0%	23.1%
	5 to 7 Years	Count	6	7	13
		% within For how long have you been Implementing BIM	46.2%	53.8%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	11.8%	13.2%	12.5%
	8 to 10 Years	Count	3	14	17
		% within For how long have you been Implementing BIM	17.6%	82.4%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	5.9%	26.4%	16.3%
	More than 10 Years	Count	8	12	20
		% within For how long have you been Implementing BIM	40.0%	60.0%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	15.7%	22.6%	19.2%
Total		Count	51	53	104
		% within For how long have you been Implementing BIM	49.0%	51.0%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	11.594[a]	4	.021
Likelihood Ratio	12.242	4	.016
Linear-by-Linear Association	7.299	1	.007
N of Valid Cases	104		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 6.38.

Table 25. Length of Implementation X BIM Uses (Arch Model)

Crosstab

			Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)		
			0	Design: Architectural Model	Total
For how long have you been Implementing BIM	1 to 3 Years	Count	16	19	35
		% within For how long have you been Implementing BIM	45.7%	54.3%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	42.1%	25.3%	31.0%
	4 to 5 Years	Count	13	12	25
		% within For how long have you been Implementing BIM	52.0%	48.0%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	34.2%	16.0%	22.1%
	5 to 7 Years	Count	1	13	14
		% within For how long have you been Implementing BIM	7.1%	92.9%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	2.6%	17.3%	12.4%
	8 to 10 Years	Count	3	16	19
		% within For how long have you been Implementing BIM	15.8%	84.2%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	7.9%	21.3%	16.8%
	More than 10 Years	Count	5	15	20
		% within For how long have you been Implementing BIM	25.0%	75.0%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	13.2%	20.0%	17.7%
Total		Count	38	75	113
		% within For how long have you been Implementing BIM	33.6%	66.4%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	13.847[a]	4	.008
Likelihood Ratio	15.157	4	.004
Linear-by-Linear Association	6.959	1	.008
N of Valid Cases	113		

a. 1 cells (10.0%) have expected count less than 5. The minimum expected count is 4.71.

Table 26. Length of Implementation X BIM Uses (Prefabrication)

Crosstab

			Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)		
			0	Prefabrication of Building Components	Total
For how long have you been Implementing BIM	1 to 3 Years	Count	25	5	30
		% within For how long have you been Implementing BIM	83.3%	16.7%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	35.7%	14.7%	28.8%
	4 to 5 Years	Count	19	5	24
		% within For how long have you been Implementing BIM	79.2%	20.8%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	27.1%	14.7%	23.1%
	5 to 7 Years	Count	5	8	13
		% within For how long have you been Implementing BIM	38.5%	61.5%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	7.1%	23.5%	12.5%
	8 to 10 Years	Count	13	4	17
		% within For how long have you been Implementing BIM	76.5%	23.5%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	18.6%	11.8%	16.3%
	More than 10 Years	Count	8	12	20
		% within For how long have you been Implementing BIM	40.0%	60.0%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	11.4%	35.3%	19.2%
Total		Count	70	34	104
		% within For how long have you been Implementing BIM	67.3%	32.7%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	17.378[a]	4	.002
Likelihood Ratio	17.060	4	.002
Linear-by-Linear Association	9.164	1	.002
N of Valid Cases	104		

a. 1 cells (10.0%) have expected count less than 5. The minimum expected count is 4.25.

Table 27. Length of Implementation X BIM Uses (Facility Mange.)

Crosstab

			Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)		
			0	Facility Management	Total
For how long have you been Implementing BIM	1 to 3 Years	Count	25	5	30
		% within For how long have you been Implementing BIM	83.3%	16.7%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	42.4%	11.1%	28.8%
	4 to 5 Years	Count	15	9	24
		% within For how long have you been Implementing BIM	62.5%	37.5%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	25.4%	20.0%	23.1%
	5 to 7 Years	Count	5	8	13
		% within For how long have you been Implementing BIM	38.5%	61.5%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	8.5%	17.8%	12.5%
	8 to 10 Years	Count	7	10	17
		% within For how long have you been Implementing BIM	41.2%	58.8%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	11.9%	22.2%	16.3%
	More than 10 Years	Count	7	13	20
		% within For how long have you been Implementing BIM	35.0%	65.0%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	11.9%	28.9%	19.2%
Total		Count	59	45	104
		% within For how long have you been Implementing BIM	56.7%	43.3%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	16.265[a]	4	.003
Likelihood Ratio	17.240	4	.002
Linear-by-Linear Association	14.186	1	.000
N of Valid Cases	104		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 5.63.

4.2.2.11 Experience X BIM Uses

Based on the companies' experience, the results indicate a significant relationship between companies's experience and BIM uses. These uses are: Prefabrication of Building Components, Construction Drawing, Shop Drawing and Facility Management. Concerning Prefabrication, with P value 0.004, 55.2 % of the users are considered experts, and the resutls indicate that the use of this feature increases based on the experience. Regarding construction Drawing, with P value 0.042, the circumstances are different. This feature is used by all levels of experience, and the percentage varies based on the level. On the subject of Shop Drawing, with P value 0.039, results point to a feature used by all the levels, not requiring high level of experience. Finally, regarding Facility Management, the companies that are categorized as experts are the highest users of the Prefabrication feature. This feature, as dicussed in previous section, requires higher level of experience.

Table 28. Experience X BIM Uses (Prefabrication)

Crosstab

			Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)		
			0	Prefabrication of Building Components	Total
Chose your Firm/Organization BIM level of experience	Beginner	Count	13	1	14
		% within Chose your Firm/Organization BIM level of experience	92.9%	7.1%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	18.6%	2.9%	13.5%
	Moderate	Count	27	7	34
		% within Chose your Firm/Organization BIM level of experience	79.4%	20.6%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	38.6%	20.6%	32.7%
	Advance	Count	17	10	27
		% within Chose your Firm/Organization BIM level of experience	63.0%	37.0%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	24.3%	29.4%	26.0%
	Expert	Count	13	16	29
		% within Chose your Firm/Organization BIM level of experience	44.8%	55.2%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	18.6%	47.1%	27.9%
Total		Count	70	34	104
		% within Chose your Firm/Organization BIM level of experience	67.3%	32.7%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	13.309[a]	3	.004
Likelihood Ratio	14.186	3	.003
Linear-by-Linear Association	13.123	1	.000
N of Valid Cases	104		

a. 1 cells (12.5%) have expected count less than 5. The minimum expected count is 4.58.

Table 29. Experience X BIM Uses (Construction Drawing)

Crosstab

			Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)		
			0	Construction Drawings	Total
Chose your Firm/Organization BIM level of experience	Beginner	Count	7	7	14
		% within Chose your Firm/Organization BIM level of experience	50.0%	50.0%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	21.9%	9.7%	13.5%
	Moderate	Count	13	21	34
		% within Chose your Firm/Organization BIM level of experience	38.2%	61.8%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	40.6%	29.2%	32.7%
	Advance	Count	3	24	27
		% within Chose your Firm/Organization BIM level of experience	11.1%	88.9%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	9.4%	33.3%	26.0%
	Expert	Count	9	20	29
		% within Chose your Firm/Organization BIM level of experience	31.0%	69.0%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	28.1%	27.8%	27.9%
Total		Count	32	72	104
		% within Chose your Firm/Organization BIM level of experience	30.8%	69.2%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.219[a]	3	.042
Likelihood Ratio	8.984	3	.030
Linear-by-Linear Association	2.637	1	.104
N of Valid Cases	104		

a. 1 cells (12.5%) have expected count less than 5. The minimum expected count is 4.31.

Table 30. Experience X BIM Uses (Shop Drawing)

Crosstab

			Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)		
			0	Shop Drawings	Total
Chose your Firm/Organization BIM level of experience	Beginner	Count	9	5	14
		% within Chose your Firm/Organization BIM level of experience	64.3%	35.7%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	18.8%	8.9%	13.5%
	Moderate	Count	20	14	34
		% within Chose your Firm/Organization BIM level of experience	58.8%	41.2%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	41.7%	25.0%	32.7%
	Advance	Count	11	16	27
		% within Chose your Firm/Organization BIM level of experience	40.7%	59.3%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	22.9%	28.6%	26.0%
	Expert	Count	8	21	29
		% within Chose your Firm/Organization BIM level of experience	27.6%	72.4%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	16.7%	37.5%	27.9%
Total		Count	48	56	104
		% within Chose your Firm/Organization BIM level of experience	46.2%	53.8%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.389[a]	3	.039
Likelihood Ratio	8.579	3	.035
Linear-by-Linear Association	8.010	1	.005
N of Valid Cases	104		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 6.46.

Table 31. Experience X BIM Uses (Facility Management)

Crosstab

			Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)		
			0	Facility Management	Total
Chose your Firm/Organization BIM level of experience	Beginner	Count	12	2	14
		% within Chose your Firm/Organization BIM level of experience	85.7%	14.3%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	20.3%	4.4%	13.5%
	Moderate	Count	22	12	34
		% within Chose your Firm/Organization BIM level of experience	64.7%	35.3%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	37.3%	26.7%	32.7%
	Advance	Count	16	11	27
		% within Chose your Firm/Organization BIM level of experience	59.3%	40.7%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	27.1%	24.4%	26.0%
	Expert	Count	9	20	29
		% within Chose your Firm/Organization BIM level of experience	31.0%	69.0%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	15.3%	44.4%	27.9%
Total		Count	59	45	104
		% within Chose your Firm/Organization BIM level of experience	56.7%	43.3%	100.0%
		% within Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)	100.0%	100.0%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	13.543[a]	3	.004
Likelihood Ratio	14.230	3	.003
Linear-by-Linear Association	12.421	1	.000
N of Valid Cases	104		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 6.06.

4.3 Experts Interviews Transcripts

In this section we will present the interviews' transcripts. The interviews were based on hour-long face-to-face meetings or phone calls. The interviewees represent all the AEC parties, general and sub-contractors, Engineer, Architect, and owner. The analysis and findings from the interviews will be discussed in thein section 4.4. Additionally, question 14 from all interviews will be presented in a separate section.

4.3.1 The first Interview

Table 32. First Participant's Information

1. Participant's Information
Name: James Darick Brokaw Position: Process Development Leaders or R&D BIM Experience (Years): 13 Years Company Name: Cuhaci & Peterson Architects Company Role & relationship: Architects& engineering and Land Planning

Question 2: Please specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)?

E.C Laser Scanning, E.C. Site Modeling, E.C Geo-technical, Environmental, D. Architectural Model, D. Structural Model, D. MEP, A. Structural Analysis, A. Quality Take off, Retrofitting, Constructability Review, As Built Model, As Built Drawing.

Question 5: Please specify the challenges that you face when using these features?

The biggest problem is adoption in adoption in the sense that we have a culture that tries to meet the minimum requirements only and that compliance is 2D drafted documentation for the sole purpose of meeting the requirements for the city or state jurisdiction plan review requirements what we are trying to accomplish is a BIM model where the objective is to have a built building with less errors constructed faster with less problems and the documentation is a byproduct of the service

Question 6: From your technical perspective, what makes BIM a better method?

Multi user environment, team based, signal file.

Question 7: How BIM features facilitate your role during the project's progress?

Visualization, the ability the extract data schedule, auto updating.

Question 8: Does BIM software needs more features to better serve the design and construction process?

Content management, they have no system to manage the content

Question 9: Below is the list of the Intangible benefit of BIM, please specify the most important intangibles to the project success?

Data Transfer, Change the way of thinking, Increase team understanding, Improve communication between field and office, Tolerance control, Understanding the site, Design analysis, finding issues before the field constructs them, Visualization of end product, Allows more iteration in the design process, More usable Information, Easier to Track Issues, Lower risk with managed outcomes, Automatic document coordination, Transparent communication, Conflict resolution, Discrepancies become more understandable and discover-able, Increased accountability and cooperation, Increase personal satisfaction, Better coordination, Project understanding, More collaboration, Better illustration of design to the client, Linked information, Visual communication, Better team Work.

Question 10: Based on your experience, please specify three measurable intangibles and how you measure?

So satisfaction goes up because the drafters and milers can see the result of their work in a way that is real. When you model something, you can see what they modeled, versus a bunch of lines.

(Visualization) (You can measure it from the clients, in can be reflected through the clients' satisfaction?)

-I don’t know how to measure it. I tried for years to understand this, and I can’t, outside from saying that that’s feeling. Time and time again, but to measure it? No. For some reasons if you would ask the client that very question, they might have had a bad experience because the color wasn’t right. Because it wasn’t at the last door. So you could have actually turn, I don’t know. They’re happy that they solved the problem, but we have a whole new set of problem. Or a whole new set of considerations, not problems.

Right now our objective, primarily in our industry, is to get those construction documents to the plan reviewer. There is no budget to track metrics. There’s no way to track those metrics if most of the time our project manager, project executives and owners of businesses, they only care about the bottom line. Therefore, if it’s not directly in their line of sight, those items aren’t attractive. They’re just left to be handled by people who have their roots on the ground that are doing the work. And they’re under pressure for time constraints, so there’s no extra time to actually measure all those things. It would take a heck of a company to find the time to implement the measurement of those items.

And I think it’s too general to say that the number of hours of our projects in total, or per person for that project, it can’t speak to them. It would have to be combined with several other pieces of data, and then you’ll have some data science, to pull apart the data to understand it… I don’t know currently how to do it. I haven’t done. I can’t speak to a measurable way.

- (even with the other items)

-I have no measurement for any of those. And I don't know if anybody that does measure, outside of saying that sheer experience, tells them so. And here's the thing: the answer to that question of what change, depends on the individual you ask. If their experience is, you know one or two years, they may not have experienced that. They might be on a bad culture of bad team, where their team doesn't experienced those things for other reasons. Other teams have working environments that are extremely beneficious and promote others, So, you're going to be all over the map with that. I would say that those people who are far experienced with tools, would advocate that all of those intangibles do exist and are worth it.

Question 11: In your opinion, how these intangibles contribute in the overall project success? Please explain?

Here's how they do that: all of those intangibles increase employee engagement, and when you increase employee engagement, they are happier about their job, they are more invested in the job, and therefore they do a better job. And those are results of a project that is far more coordinated, that people care to get it done right, to get it done right the first time, and the projects wins because of that. Because of people invested in the project's outcome, when these things exist. When they don't exist, they are not invested. You'll see in one project if you have people coming in for the last week of a job, to help it get over the… to cross off the deadline, they aren't invested, they haven't got experience with doing these things in that job. It's obvious that without their investment, they don't care. Even if they are good people. They're just not invested in that project. And it makes a big difference when they are part of it.

Question 12: Based on your experience, could the intangible benefits turned to be monetary benefits? If yes, please explain?

Yes, they do because and employee engagement results in a better project. I can name projects, specific projects that have failed and succeeded. I can't directly show you numbers that correlate to these factors, but I can tell you that the ones that failed had none of those, and the ones who did had all of those, and it's not even close. 3 to 4 times the cost. Not a little bit. Three to four times the cost, a ridiculous amount. So you can fail at BIM, you can fail miserably, and it's all about investment in employee engagement. Those intangibles are employee engagement.

Question 13. How BIM changed the team collaboration and coordination process compared to the traditional method?

Collaboration does go up. Even if it's not a one on one collaboration, it's a virtual collaboration in the sense that I can see your walls, so I know where I have to place my water fountain, or my light switch. Which is far more than looking at a plan that's uncoordinated with everything else. And that goes back to the single file environment. Having a single file where everything is at, you can see all aspects from one view, not opening three drawings and looking at them separately. So yes.

(And what about the cooperation?).

Primarily the cooperation is a factor of the existing culture, not the product. The product does enable the idea of better collaboration and cooperation between teams, but if that doesn't exist in the existing culture, it's not going to show through.

For instance we're an A&E firm, architects and engineers, and typically, the engineers and architects can have bad blood, so conflicting issues. So if that existed before him, it's going to exist after him. There is a potential to overcome it more so within, because you're working in the same file. Now, there is the issue of multiple files, when it comes to BIM. There's an architectural model, structural model, M model, E model, B model, and in bringing them together, that does not help. In fact that situation is pulling people apart.

(So it means that in full operation there is a negative and positive side)

It depends on how you execute them. And you can execute them in a number of ways. And largely the way you execute them has to do with the culture of how you work. I don't want the architects dealing with my stuff because they'll mess it up. And likewise in the other side it's the same thing. Then you're going to work in separate files, and you've lost all the benefits of BIM. But if you can come together, you can gain. But there are people who have separate files for their sheer reasons that they have, and they are for it. You've got to work in separate files and bring them together. But it's complicated. I don't know it's just so complicated. Because I can literally xxx many ways that you can execute a project that would both foster it and hander the idea of collaboration. Just based on how you execute them. They will come back to the tool.

4.3.2 The second Interview

Table 33. Second Participant Information

1. Participant's Information
Name: Alfredo Medina
Position: BIM manager
BIM Experience (Years): +/- 10 years
Company Name: Universal Creative
Company Role & relationship: Owner / Employee

Question 2: Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)

E.C Laser Scanning, E.C Site Modeling, D. Architectural Model, D. Structural Model, D. MEP, A. Clash detection, A. Structural Analysis, Energy Modeling, Constructability Review, Prefabrication of Building Components, Construction Drawings, Shop Drawings, As Built Drawings, As Built Model, and Others.

Others, Model as a source of information in 2D format for all the other people who are working on the project. This is important because BIM is not only 3D model. In this case there are other uses, other team members who need 2D models, because that is what they are used to do. And the model is used to export all those section elevations, for providing import of design. Exporting 2D views. Using the model as a source for exporting 2D views to be distributed to designers.

Question 3: Do these features contribute in the project's ROI? If yes, How?

From my point of view, as a manager, I see that the use of this features contribute in a good way for the success of the project, but in a large organization, it is difficult to say that everybody say 'yes'.

(As success, you mean money? Moneywise?)

Not to make money but to avoid spending money on problems that could be detected in a digital environment, before they get to the construction site. In that aspect, following the process of the design and finding all these potential problems, is where I see the huge benefit in regards to money. Money that is saved.

But I can tell you of previous experiences, from my previous BIM projects that there were many occasions where the accuracy of the BIM model was very useful in avoiding change orders, finding alternatives for problems that we couldn't solve by just making drawing. Just by manipulating the model in online meetings with all the engineers we were able to find solutions for things we couldn't solve, like "where do we put this installation?", "how do we do this?" And then, by looking at the models together somebody has an idea "hey, why don't we use this space for doing this? What do you guys think?" And then the other engineer says "ah, I think that's a good idea, yeah, we can use this!" So sometimes there are some kinds of unexpected solutions that we couldn't see before.

(So it's like avoiding change orders)

Finding creative solutions to construction challenges. So, and something I can say is that there were little occurrences of rework, or problems due to lack of

coordination of the drawings. If we had some rework to do, it was because of errors during the construction. But errors due to the GCs and not into the SUBS. Not because the drawings were showing incorrect information. (So from your perspective, from the owner's side, you think it's worth using it, as a tool for the projects?) Yes. And also, in my answers I am kind of combining a little (that's why we're doing interviews, to get your experience, doesn't mean that you exclude the previous experiences).

Question 5: Please, specify the challenges that you face when using these features?

Let's keep the technical things and after that, which is the next question, now the challenges. Is it related to the trainings, is it related to the willing to adapt. Adaption of the BIM?

I would say some of the challenges, the non-technical challenges, is sometimes to have the trust of all the powers, that BIM is necessary, that BIM is good (with its adoption!) Yes, adoption. Sometimes there is resistance in understanding what the BIM process is and how it can benefit the success of the project. So it is a process of educating the team towards something that is the new way of doing projects. It is like a new trend. It is like using the calculator instead of counting, by writing down the numbers on a sheet of paper.

- (It is a little bit hard to convince people to adapt to it)

- Yeah, especially the managers.

- (and do you think of any technical problems related to people, train?)

- Technical problems, let's see. When there is a large project and many people involved it's kind of difficult to deal with, sometimes IT related issues in transmission of files. That's not very easy because some consultants use one method and other consultants use other method. (With the data sharing) So, getting all of those models up and down in a way that is fast, is a challenge, but it's more like an IT challenge. Things as simple as better internet connection, better speed, can play a big role in getting all the information quickly, or not, not quick enough

- (So, data sharing is the main challenge?)

- I would say technical challenge is solving the transmission of files in a way that is fast enough for keeping up with the changes of the project, cause if you are going to spend two days downloading the sets of models and then another day organizing all that, and if you have to do that for several projects, by the time you're done with that, your models have changed, already. So, I would say that having a good exchange information site and a good speed of transmission in upload and download is very important.

- (The file I gave you, Alfredo, it has a question that comes from my survey: what kind of data sharing method you use…)

Question 6: : From your technical perspective, what makes BIM a better method?

- It is a better method because… Again I am going to make some clarifications about BIM. In my opinion, BIM is not about models in general, is more about changing the idea that the drawing is the final product and the drawing is something that the architect who is, or used to be like the God, like making a design. So now all these ideas have changed, and now it's more like everybody has the right to participate and give opinions, contribute with solutions and share information. BIM is more about collaboration between architects and owners and designers> and why is it a better method, is because (the collaboration point of view?) Yes, the collaboration point of view is what really makes a difference in the BIM process, because it used to be like the architect had a design, and he would do all this process almost by himself, and then he would hand over this design to the engineers, and you do the structure part of this and you do the MEP. And then at the end the GC who didn't know of all of these packages of drawings, and now it is like, from the beginning, you know, let's do this together and let's put everything in 3D in one single model together, and then together we will see if there are better ideas to do this, you know, how to make it buildable. So that is, I think is like the main change, is to get into the minds of everybody in the industry, that now we collaborate (so the model represents everybody's efforts) Yeah.

And that of course with coordination, reduction of change borders.

Question 7: How BIM features facilitate your role during the project's progress?

Yes, of course. In my case, representing the owner, if I didn't have the ability to integrate all the models from the consultants I could not help my company to detect potential problems in the buildings. And also, I could not keep a set of drawings to distribute to my team members, drawings that a really coordinated and exported from the models, not drawings that were made individually, one by one, but simply models that are exported from a model (model coordination).

Question 8: Does BIM software needs more features to better serve the design and construction process?

Yes. I think that it would be very good to have the ability to make quick models such as those models that we do in sketch-up, but that didn't have to be modeled again to do construction models, like the construction drawings. At the moment, these two things, quick concept design is kind of separated from the software that we use to do the construction drawings. And I wish that we didn't have to redo one thing again over the other. That something that I wish the industry could integrate those two things, the concept design and the final, final drawings. (I love the point, it's a very important point. which is like a quick concept). Yeah, because this is being done in two separate tools that don't speak together very good.

Question 9: Below is the list of the Intangible benefit of BIM, please specify the most important intangibles to the project success?

Visual Communication, Better Illustration of design to the client, Better Presentation, Better Coordination, Increase team understanding, Client confidence, Improve communication between field and office, Produce consistent and coordinated

design, Automatic document coordination, Discrepancies become more understandable and discover-able.

BIM better coordination many of these refer to coordination

I think this is important too because even if the client doesn't deal with the daily modeling process, at the end the client can see the result in a way that is easy for them to understand. Instead of looking at some drawings that are difficult to understand we can show in the screen all the dots and pipes, and we can show them "hey, there is a problem here" or somebody can say "oh, what is this? Oh it's a tank. And how come I cannot open the top of the tank?" "What do you mean?" You see that pipe over there? Yes. But are you forgetting that this top has to be lifted and this thing has to be removed?" So all these things help to get the input of other people involved in different roles, in maintenance, even cleaning, even operations of the facility.

Question 10: Based on your experience, please specify three measurable intangibles and how you measure?

- Let's just pick an example like, as you always mentioned as collaboration, or coordination.

- Yes, this one can be measured because when we make class detection exercises we can generate every port of all the issues that we find and we can keep track of all these issues in meetings and.

- (Could you think of any other two intangibles that can be measured? I'll go with the one you pick like, uh, team understanding. Do you think that team understanding, will for instance expedite the project duration or lower errors).

- I think it does, because as I said, when the model is exposed to a team and this team, and by this team I mean not only the engineers and architects, but also the people who are going to use the project, people in charge of operations, maintenance, other tasks, not really dedicated to design. Sometimes they can provide the team with input that nobody thought about. Nobody thought that this particular thing needed to be replaced every month and for doing that, some space was required. So only this person, based on his or her experience can tell the designer "oh, be careful with this".

- (So, team understanding reduces errors, for instance?)

- Yes, because if we didn't know about this particular operation clearance, of course, that would be an issue later on, when this person is going to use the (.) in a particular room or space, right? So, we have to include all these people and make them understand the design budget, and get their input, their opinions, that's important.

- (So, well, what about the, let's say for improve communication between field and office, do you think this help can be measured? This one you picked, which is client confidence, any think of it?)

As I said, this confidence will roll as long as the BIM manager and coordinators, so client confidence can be measured by proving that there is a problem

and it has been solved. By proving that with the uses of BIM it was possible to detect, let's say, three or four major problems that nobody had detected before, because everybody is busy doing their own portion of the project. Sometimes, if we combine all these models together, with one person dedicated to finding issues; if we can prove to the owner that we "hey, we found this, this, this, and that", then the confidence from the owners on the process of BIM will roll. I don't know how to measure that, but I am very sure that they will be very happy to see that we saved thousands of dollars by finding these problems.

Question 11: In your opinion, how these intangibles contribute in the overall project success? Please explain?

I think it can contribute to the project's success basically to have a better visualization of the end results of a project. Be help to detect potential problems and have a better coordination between all the drawings, and reduce change orders.

- (So these intangibles turn to be product success?)

-Yes.

Question 12: Based on your experience, could the intangible benefits turned to be monetary benefits? If yes, please explain?

- I would say yes, because it can be money in regards to… Reaching to the end of the design process, I think you can get to that point with much, much better drawings, much better construction drawings that if you don't use BIM process. (is that related to that, the time you worked, with team understanding).Yeah, and the end

product is better coordinated. I would create fewer problems during construction, of course, because we have done a virtual construction during months and months in the computer before we get to the actual construction. So, if something cannot be modeled and coordinated with the computer probably it cannot be built, right? So that means money in the sense that, it's money that is saved, which is not actually money made, but money saved. (I mean this is the coordination and collaboration)

Question 13: How BIM changed the team collaboration and coordination process compared to the traditional method?

- I guess that the big change, the revolution of all this is to use the expertise and knowledge of all the team members, not as before, in which the architect was kind of isolated from the engineers and from the builders. And the builders used to get a thick package of drawings that they had never seen in their lives, and they were expected to build this without any errors.

- (So the coordination/collaboration, there is a lot of changes, compared with the old methods? When it comes to the drawings and).

- Yeah, and understanding that nobody knows everything, nobody can solve everything, that a successful project is a combination of lots of talents and experiences, from all different sources.

4.3.3 The Third Interview

Table 34. Third Participant's Information

1. Participant's Information
Name: Francisco Nunez Position: Project / BIM Coordinator / Business Development BIM Experience (Years): 10 years Company Name: HHCP Architecture Company Role & relationship: Employer

Question 2: Please specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)

D. Architectural Model, D. Structural Model, D. Interior, A. Clash Detection, A. Cost Modeling, LEED Certification, Lighting Analysis, Retrofitting, Construction Drawing, As Built Drawing.

Question 3: Do these features contribute in the project's ROI? If yes, How?

Yes, it definitely does, it reduces the amount of the staff that we need. It is actually alleviate the staff to do more projects. We are much more efficient when we use Revit. The amount of production that a single person can produce I think it equates to five people in the CAD, and the amount this may produces its more, but it's also better because it's actual data and information. When the person in categories is drawing in 2D they were just doing one thing that is unintelligent, and now in Rivet it's a door and they knows it's a door and a door has properties information all feed

to data base. So at the end of the day they only ended faster and it's a better overall product so it's a huge returning ROI.

Question 4: After choosing successful BIM project as a case study, how the project succeeded in the following criteria?

Table 35. Second Interview Case Study

4. Success case study
Project type: bar grill restaurant
Location: Orlando, Florida
Total budget: $ 3.000.000
Design budget : $ 140.000
Start date: august 2015
End date: January 2017
Contract type: design bid build
Level of development (LOD): A2
Cost Conformance (% of variance) : about 4%
Minimize change order rate (% of total contract amount) : extremely minimum
Schedule conformance (% of all activities) : up to date
Rework (# of rework) : very minimum
of RFIs: more than 50%
Design accuracy (#RFI for design error): no errors
Safety (# of accidents): GS

Question 5: Please specify the challenges that you face when using these features?

I think it's more of a human element; there is more of an issue with the amount of time that's available. I think they went down to the economy that a lot of people went to do other jobs, and not architecture, because architecture is one of that one's hardest hit in the recession, just like any recession around the world, the constriction is in the first ones to go. It is easier to stop, and it's a lot of investment.

There isn't a lot of people in the field doing architecture, so they are still a big, big challenge for us to get people to do a job, and finding talented people and find someone who is trained.

(At the first phase, of using Revit, the first challenges were)

Adaptation. Even if there is someone doing something in the wrong way, it's the way they know. So, people would stick to the wrong way, because it's much, you know, there is a learning problem...

Question 6: From your technical perspective, what makes BIM a better method?

The data. The fact that it's a data base constructed software. The fact that we are no longer drawing the buildings; it's no longer a flat representation from what we want to build graphically, but it is actually a virtual version of what we want to build. So people ask me how big of a change is it from CAD to Revit, and from the 2 days of 2D and from the jumping from the pencil to CAD was a foot. The jumping from CAD to Revit is a mile, and it is a mile because there's so much information that has been built in the background of the Revit, beyond what the draft or the person is putting the plans together is doing. There is a free work, if you will. A door schedule, for example, we have to pay 2 people. One guy who is doing the plans and the other guy to populate the schedule and just manually type it there. That 2 steps no longer exist, it combines into one and you have eliminated the human error, which is the most common issue that happen in the site a law suit delegation its always because somebody forget something in the wrong place and Revit eliminate the human error

that is way it's called Revit. The big picture of BIM is having information available. We live in a technological world and having access to information, and having an owner coming to you and say "Oh man, we bought the chairs and have these changes out, and we need to change". And this huge hotel room, as computer room we need to change the legs on the chair; and being to do that for a software, being able to carry the data base. Ask a question like Google and like everything that we are doing, is a bench mark, being able to do pull that information from the bench mark that is a magic of BIM in any software.

Question 7: How BIM features facilitate your role during the project's progress?

Yes definitely, it makes it easier to find things, and produce things, to illustrate things to play the music, if you will, to the client, is what we're doing for every single day. No musician ever tells to the audience, he shows in the music sheet and say "what do you think?" They play it for them, and in the old days, the architects and designers have always shown the music sheet, and told the owner "what do you think?" And the owner just see the plans and lines. He says "I see nothing, don't you have another way of showing it to me?" but now he has virtual building can be shown to them, and the owner can be walked in through and "see the building, see your palace" or whatever it is. So, it changes the whole experience for them and it vague at it that's who actually we are producing it for, and that alleviates my job one hundred percent, because not only I am explaining less, but by office is there and there, and there is no element of surprise, that is why you see a lot of project and people

unhappy with them. A huge hotel, they never visualize it but they were trusting on the architect.

- (Doesn't it make the client a little bit more picky?)

-Yes, you are opening up the door to more and that's why a lot of people come up with the phrase "less is best, less is more" because the more you show, the more options you're giving them. Most successful restaurants have their menu down to 2 to 3 items. Chipotle, any one of these… you have no options, you go in there and you go to in there. And it goes that the more people have, the more we have to think about. Malcom Glad wrote a book about the Campbell effect, the Campbell soup, and the options. Campbell hired him to do a big study like yours, and to test what level of chunkiness in the soup was the best. And the more options you gave people, the more the more confused they were. And nobody had a clue of what they really wanted. Yes, it makes the client be more picky.

- (Which is good to the end product).

-To the end product it is much better. It would seem at first, compared to a client who looks to a floor plan versus a client that looks into virtual model. The client will be more picky, yes, more things to choose from, but you're also having a more rich conversation, because there are things that you would never discuss.

(But when they say yes its yes. It's law. He's involved, yeah?)

Question 8: Does BIM software needs more features to better serve the design and construction process?

With the recent guys that you interviewed lately, I don't know if I would call myself an expert, I think I'm an enthusiast, I'm a very, very high rated enthusiast.

(This is amazing. You amazed me at how you described it, and it makes it easier for me, but. One thing that Steven (at P&C) told me that they have like similar to the ketchup.

So back to your question about the features. I think that that Revit is a great production at modeling. I think that Autodesk is really trying to focus on how to implement a schematic design. It has to be something where you can be more forgiving. There has to be something where Revit can be more loose or free handed, like sketch-up. Sketch-up is a good example, but it's not BIM because it doesn't rely in the database information. So, they have done fluid and in a number of things that the Autodesk is implementing. So forget the Autodesk as a company, and let's talk about the whole big picture. Given what BIM is, information rich, people feel that there is a step between their creative process and loose lines and craziness... So in the office, for example, we still have hand drawing designers we still have people… I would love to give you a tour of our office at some point, before you head back, let's do that soon. So there's people who still do the hand sketches and do layout a hotel I think cause there's still a xx organic portion of our process, and people need to get their ideas out and that's why they do this by hand

(Not yet finished/ revised)

So, it's a big challenge. I think there will always be the bridges. There will be a gap and there will ever be bridges, of the design process and the organic-ness of

discovering a design to the actual xxx and structure it and building a model that has all the information and everything that you need to construct. I know that there are people who wish that they will bridge that gap, and I think that they are doing a lot of efforts, coming up with fluid and a lot of applications that BIM providers have xxx they can do these crazy messes by hand even 3D and a tablet and somebody can grab it and convert it, but the converter bosses xxx will always happen, either by hand or by BIM (16:03). So I'm glad that you brought up that feature. Yes, that's a feature that I would want but I am saying it out loud and I am thinking about it, it's never going to be missing though, I think that BIM companies out there xxx architects really, really have to learn from the Apples of the world, from Apple, from Linux, from the companies out there even Google, companies out there that graphic and user interface and implement more of an accessibility method. I think they've done very well, but I think it for the new users, the older architects that are the real masters in design, there is a barrier for them, of the appearance of taking a step into it, so I think that any feature that would improve would be just the feature of accessibility.

There was BIM involved in producing the documents? But the GC still using introducing the method of reading pages. And that's where our advice, because there is a model. (Expedite time, they doesn't change much in our end. You see, tolerance control that does, it is impacting. Understanding the site, it is impacted, of course. Greater detail in accessibility, that one is repeated; design analysis, finding issues before constructed.

Question 9: Below is the list of the Intangible benefit of BIM, please specify the most important intangibles to the project success?

Better team Work, Visual communication, Linked information, Increase quality, Better illustration of design to the client, Better presentation, More collaboration, Project understanding, Better coordination, Better team culture, Increase personal satisfaction, Increased accountability and cooperation, Generating Business, Data Transfer, Greater details and accessibility, Easy to manage projects, Reduction of construction and operations risks Optimization of design cycles, Change the way of thinking, Smoother workflow, Increase team understanding, Saving on labor and material, Client confidence.

Question 10: Based on your experience, please specify three measurable intangibles and how you measure?

Better team work can be measured by the fact that you can collaborate in one model, everyone working in one place. And the communication tools that exist in BIN, they differ by software, but those communication tools allow you to keep track of what others are doing; and at the same time, keep others accountable for what they're expecting, their expectations. So if I'm working with you in one model and you've asked me to do all the doors, because we are going to come back and do, fix the schedule, and put the hardware on the doors… I can't wait, so the way to measure, is it a text wise that you want me to measure it or just a bench's mark that you want to. Well the brand that I would measure a benchmark a better collaboration is taking two products of a very similar kind. offices like Roger Peterson they do the same kind of products at the healthcare facility, finding and finding the same type of product and the same owner came back four years later and said, "Now I want this product but the whole firm is and looking at the numbers from. It would be so easy to

say yes, you ‘look at the staff and 15 people there was one guy, and all he did was doors and door schedules installation that job was reduced to teams of 15 were reduced to teams of 5. And teams of 5 were reduced to teams of one. So that’s how the collaboration that you measure or can be measured, and a simple giving someone a building to replicate, a paper to BIM and no BIM platform, by hand or cad and then seeing what the product is at the end of 30 minutes, at the end of an hour, You’ll have a very measurable way of seeing. Yeah there’s a lot of more visual stuff in there than there is in the cad power

How do we measure generating business, you can take like for example, and measure its accessibility to a lot of these highly products with a high coordination requirement, like a roller coaster, a roller coaster where you have graphics and you have many details, you see the returns rate and the acceptance rate of this company, so in the past years you would say “how many of these products you’ve got, compared to before them”. And that would be a great benchmark demonstration, to demonstrate what the success of your own business generation

Question 11: In your opinion, how these intangibles contribute in the overall project success? Please explain?

Yes. Every single one of them that we touched, it contributes with the project success, more visibility, more collaboration, so yes, they contribute

Question 12: Based on your experience, could the intangible benefits turned to be monetary benefits? If yes, please explain?

So, the intangibles are actually, most of the ones listed here, are actually all translated into monetary benefits. When you get more products, that's a monetary benefit, and all of these items contribute to getting more products

- (So the success in BIM so when you feel that must turn to the better business)

Question 13: How BIM changed the team collaboration and coordination process compared to the traditional method?

The old method was that people were working separately, in silence. It's just like this table with all plates. Everybody was working on individual plates, building things that were all part of one product, and you had issues with duplication, issues with mis-coordination… I keep referring to doors; because it's such a task part of a building. But if I'm the person in charge of doing the finishes, the interior design for your hospital, and I am quantifying the amount of carpet that I have in your exam room and this lobby area, but I'm working in cad or any other non BIM platform, I am stuck with the information you provided to me in X date, it's non live data. Everything you write down right now in pen, stops being live. It's stuck there and that's it forever. Until the next time somebody prints it. When you're doing in Cad the last XXX in that xxx somebody is saved. When you're working in BIM, everyone is working in a model. And even though there is a bit of a synchronization period you have to get the information at its latest, it's still a lot closer to be live than the other. So, to answer your question, that's how the collaboration process is increased because

we are all eating of from the same plate, so I don't grab the same fry that you're going to grab, cause it's checked up by you in the software or process were modified

(The team became more invested in the project that they can see and they can work together, and discover the problems together). They discover together and even if you are unaware of the problem that I discovered. I can notify you and there is more communication going on, because we are all looking at the same thing. Instead of two studies going on differently, they're all studying the same animal.

4.3.4 Fourth Interview

Table 36. Fourth Participant's Information

1. Participant's Information
Name: Steven Blevin Position: Principle BIM Experience (Years): 11 years Company Name: Cuhaci & Peterson Architects Company Role & relationship: Architects part Owner

Question 2: Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)

E.C Site Modeling, D. Architectural Model, D. Structural Model, D. MEP, Retrofitting, Construction Drawing, As Built Model.

Question 3: Do these features contribute in the project's ROI? If yes, How?

Yes, Shop Drawing Review times, what we use to do we get the shop drawings and we review those with our drawing to make sure they are consistent with ours. But with BIM we just turn to the model and check which save a lot of time. BIM help facilitate kind of searching multiple sheet for answers , where in the model you can find what is correct what it is not, that's was the ROI the time saving.

Question 5: Please specify the challenges that you face when using these features?

Yeah, challenges has mostly been getting the mind set changed from old to new way, and still we have some challenges in MEPs.

Question 6: From your technical perspective, what makes BIM a better method?

Raises the level of team discussion that focus on the process of putting the building together. Mostly in team work and kind of elevated focus.

Question 7: How BIM features facilitate your role during the project's progress?

Helps to communicate the understanding and communication of overall project goals.

Question 8: Does BIM software needs more features to better serve the design and construction process?

No, needs better contextual controls and lighter mobile interfaces.

Question 9: Below is the list of the Intangible benefit of BIM, please specify the most important intangibles to the project success?

Better team Work, Linked information, More collaboration, Project understanding, Better coordination, Better team culture, Reduction of construction and operations risks Optimization of design cycles, Change the way of thinking, Increase team understanding, Visualization of end product, More usable Information, Lower risk with managed outcomes, Automatic document coordination, Transparent communication, Conflict resolution, Discrepancies become more understandable and discover-able.

Question 10: Based on your experience, please specify three measurable intangibles and how you measure?

Data usage of components, measured though model manager 2. Quality of work, measured though reduced change orders, 3.Reduction of duplicated data working with design and construction teams, measured by reduced number of redesigns and eliminated value engineering after design complete.

Question 11: In your opinion, how these intangibles contribute in the overall project success? Please explain?

Enables the participants to become more engaged and therefore more efficient.

Question 12: Based on your experience, could the intangible benefits turned to be monetary benefits? If yes, please explain?

Yes, though efficiencies and leverage the information for downstream uses, reducing duplicated data entries. For example, we have certain information that is common in our industry, so if we can consolidate these data so we don't have to enter the same data.

Question 13: How BIM changed the team collaboration and coordination process compared to the traditional method?

Model review coordination sessions. Like we have fairly early on.

4.3.5 The Fifth Interview

Table 37. Fifth Participant's Information

1. Participant's Information
Name: Leonard Musselle, II Position: VDC Manager BIM Experience (Years): 12 Years Company Name: Comprehensive Energy Services, Inc. Company Role & relationship: Sub-contractor / Employee

Question 2: Please Specify your BIM uses? (Uses are According to Massport Appendix A // MPA BIM Guidelines)

D. Architectural Model, D. Structural Model, D. MEP, D. Interior, A. Clash Detection, Retrofitting, Facility Management, Model for Maintenance, As Built Drawings, As Built Model, Shop Drawings, Construction Drawings, Prefabrication of Building Components, Constructability Review.

Question 3: Do these features contribute in the project's ROI? If yes, How?

We believe so. My company expects a 5 to 7 percent savings on each BIM project.

Question 4: After choosing successful BIM project as a case study, how the project succeeded in the following criteria?

Table 38. Fifth Interview Case Study

4. Success case study
Project type: Theme Park Attraction
Location: Orlando, Florida
Total budget: $ 2.000.000
Design budget : $ 140.000
Start date: august 11/14
End date: January 9/15
Contract type: Plan & Spec
Level of development (LOD): 400-500
of RFIs: 28
Design accuracy (#RFI for design error): 26
Safety (# of accidents): 1

Question 5: Please specify the challenges that you face when using these features?

One of our biggest challenges is getting unfettered access to the design models. The Architect and Engineer didn’t want to share their models when they made design changes.

Question 6: From your technical perspective, what makes BIM a better method?

Coordinating MEP trades with structure and architectural features is much more accurate and quicker with BIM.

Question 7: How BIM features facilitate your role during the project's progress?

It allows me to clash detect against all of the other obstacles above the ceilings.

Question 8: Does BIM software needs more features to better serve the design and construction process?

Yes, “clash avoidance” and suggested solutions for clashes, will be very helpful.

Question 9: Below is the list of the Intangible benefit of BIM, please specify the most important intangibles to the project success?

Better team Work, Visual communication, Linked information, Increase quality, Better illustration of design to the client, Better presentation, More collaboration, Project understanding, Better coordination, Better team culture, Increase personal satisfaction, Increased accountability and cooperation, Generating Business, Data Transfer, Greater details and accessibility, Easy to manage projects, Reduction of construction and operations risks Optimization of design cycles, Change the way of thinking, Smoother workflow, Increase team understanding, Saving on labor and material, Client confidence, Improve communication between field and office, Expedited timecard and daily report submittals, Tolerance control,

Understanding the site, Greater detail and greater accessibility, Design analysis, finding issues before the field constructs them, Visualization of end product, Produces consistent and coordinated design, Ability to handle larger data sets and higher resolution surveys, Allows more iteration in the design process, More usable Information, Easier to Track Issues, Lower risk with managed outcomes, Automatic document coordination, Transparent communication, streamlined information/data management, Better performing buildings, Conflict resolution, Discrepancies become more understandable and discover-able, Fabrication and modular construction.

Question 10: Based on your experience, please specify three measurable intangibles and how you measure?

Better coordination due to clash detection resolutions. More accurate shop drawings due to clash detection resolutions. Savings on labor and material due to clash detection resolutions.

Question 11: In your opinion, how these intangibles contribute in the overall project success? Please explain?

All of these intangibles contribute to the overall smooth installation of a project and better, faster building construction.

Question 12: Based on your experience, could the intangible benefits turned to be monetary benefits? If yes, please explain?

Maybe, but in most cases it would be difficult or impossible to accurately quantify.

Question 13: How BIM changed the team collaboration and coordination process compared to the traditional method?

Compared to old 2D style coordination BIM coordination can be 100% accurate and many times faster. Also, using BIM, the entire MEP team can participate in coordination collaboration.

4.4 Interviews Derived results:

After looking into the experts views about the major aspects: BIM uses and Intangible benefits. We can derive the main points for each question,

Question 3: Do these features contribute in the project's ROI? If yes, How?

- BIM features can contribute in the project ROI by avoiding spending (money saving) detecting problems in a digital environment.
- It’s alleviate the staff to do more, so one Revit person can do equal to five Cad people. So the amount produces is money.
- All feature add to saving time, money and resources, Having the ability to research and resolve issues before construction start is always more productive and beneficial.
- Expect a 5 to 7 percent savings on each BIM project.

Question 5: Please specify the challenges that you face when using these features?

- One of our biggest challenges is getting unfettered access to the design models. The Architect and Engineer didn't want to share their models when they made design changes.
- Industry BIM experience is the main challenge for me because from job to job you don't know how knowledge of the process of BIM your team maybe. Another challenge is the older more experienced people resist changing from 2D to 3D.
- Adoption, sometimes there is resistance in understanding what the BIM process is and how it can benefit the success of the project.
- Finding talented people to do the job. Also, adoption, people would stick to the wrong way, because it's much, you know, there is a learning problem.
- The biggest problem is adoption in adoption in the sense that we have a culture that tries to meet the minimum requirements only and that compliance is 2D.

Question 6: From your technical perspective, what makes BIM a better method?

- Multi user environment, team based, signal file.
- With BIM it's more like everybody has the right to participate and give opinions, contribute with solutions and share information. BIM is more about collaboration between architects and owners and designers

- The data. The fact that it’s a data base constructed software. The fact that we are no longer drawing the buildings; it’s no longer a flat representation from what we want to build graphically, but it is actually a virtual version of what we want to build.
- It decreases rework, improves productivity and reduces cost.
- Coordinating MEP trades with structure and architectural features is much more accurate and quicker with BIM.

Question 7: How BIM features facilitate your role during the project's progress?

- Sub-contractor: It allows me to clash detect against all of the other obstacles above the ceilings.
- General Contractor: It helps me to improve the coordination process with design and construction.
- Owner: In my case, representing the owner, if I didn’t have the ability to integrate all the models from the consultants I could not help my company to detect potential problems in the buildings.
- Architect: it makes it easier to find things, and produce things, to illustrate things.

Question 8: Does BIM software needs more features to better serve the design and construction process?

- Sub-contractor: lash avoidance” and suggested solutions for clashes, will be very helpful.
- GC: I think the features are in line with the progression of construction currently. It may not have been there is the past but it's caught up to the industry now.
- Owner: Yes. I think that it would be very good to have the ability to make quick models such as those models that we do in sketch-up.
- Architect: I think that Autodesk is really trying to focus on how to implement a schematic design.
- Engineer: Content management, they have no system to manage the content.

Question 10: Based on your experience, please specify three measurable intangibles and how you measure?

- Architect: 1. Data usage of components, measured though model manager 2. Quality of work, measured though reduced change orders, 3.Reduction of duplicated data working with design and construction teams, measured by reduced number of redesigns and eliminated value engineering after design complete.
- GC: better Coordination is evident by the reduction of issues in the field. Increased understanding of the project is shown by reduction in the number of RFI's. Using robotic layout give us the ability to control the tolerance of installed equipment.

- Sub-contractor: Savings on labor and material due to clash detection resolutions.
- Architecture: better teamwork can be measured by the fact that you can collaborate in one model. Generating business can be measured in our situation by the accessibility to the high coordination project such as themed roller coaster.
- Owner: team understanding will expedite the project because all the parties are exposed to the model, which in turn will reduce the errors. Client confidence can be measured by proving that there is a problem and it has been solved.

Question 11: In your opinion, how these intangibles contribute in the overall project success? Please explain?

- Owner: better visualization of the end results of a project will contribute in the project success.
- Architect: Every single one of the intangibles that we touched, it contributes with the project success.
- Engineer: those intangibles increase employee engagement, and when you increase employee engagement, they are happier about their job, they are more invested in the job, and therefore they do a better job.
- Sub-contractor: All of these intangibles contribute to the overall smooth installation of a project and better, faster building construction.

- GC: All these intangibles equal up to better understanding of the overall project from design to construction. It's really about sharing information in a visual format that helps everyone understand a black-and-white 2D construction process.

Question 12: Based on your experience, could the intangible benefits turned to be monetary benefits? If yes, please explain?

- GC: all the intangible should translate into some form of monetary benefit, time saved, reduction of issues, and increase in productive and overall knowledge.
- Owner: if something cannot be modeled and coordinated with the computer probably it cannot be built, right? So that means money in the sense that, it's money that is saved, which is not actually money made, but money saved.
- Architect: When you get more products, that's a monetary benefit, and all of these items contribute to getting more products.
- Engineer: employee engagement results in a better project, project failed in those intangible could cost 3 to 4 times the project that succeeded with the intangibles.

Question 13: How BIM changed the team collaboration and coordination process compared to the traditional method?

- Engineer: Collaboration does go up. Even if it's not a one on one collaboration, it's a virtual collaboration in the sense that I can see your walls.
- Architect: team work all together, discover together and even if you are unaware of the problem that I discovered, I can notify you and there is more communication going on, because we are all looking at the same thing. Instead of two studies going on differently.
- Owner: the revolution of all this is to use the expertise and knowledge of all the team members, not as before, in which the architect was kind of isolated from the engineers and from the builders.
- Sub-contractor: Compared to old 2D style coordination BIM coordination can be 100% accurate and many times faster. Also, using BIM, the entire MEP team can participate in coordination collaboration.
- GC: The BIM breaks down the owner, architect, engineer, and contractor silos, which seem to be sharing-avoidant and stifling to the BIM process.

Question 14:

Table 39. Interviews Question 14 Answers

	Intangible benefits	Designers			G and Sub Contractors		Owner
		Darick	Steven	Franc	Leonard	Curtis	Alfredo
1	Better team Work	Communication	Quality	Communication	Communication	Quality	Communication
2	Visual communication	Communication	Cost	Communication	Project Delivery	Communication	Communication
3	Linked information	Communication	Budget	BIM Management	Communication	BIM management	BIM management
4	Increase quality	Quality	Schedule	BIM Management	Quality	Project Delivery	Quality
5	Better illustration of design to the client	Communication	Business	Communication	Project Delivery	Quality	Communication
6	Better presentation	Communication	Quality	Communication	Procurement	Business	Project Delivery
7	More collaboration	Communication	Communication	Quality	Communication	Communication	BIM management
8	Project understanding	Communication	Procurement	Quality	Quality	Communication	Communication
9	Better coordination	Communication	BIM Management	Quality	Schedule	Quality	BIM management
10	Better team culture	Communication	Quality	Business	Communication	BIM management	Business
11	Increase personal satisfaction	Cost	BIM Management	Business	BIM management	BIM management	Quality
12	Increased accountability and cooperation	Cost	Quality	Quality	Communication	Project Delivery	BIM management
13	Generating Business	Business	Communication	Business	Business	Business	Business
14	Data Transfer	Communication	BIM Management	BIM Management	Communication	BIM management	Communication
15	Greater details and accessibility	BIM management	Procurement	Communication	Procurement	Quality	Quality
16	Easy to manage projects	BIM management	Quality	BIM Management	BIM management	BIM management	Project Delivery
17	Reduction of construction and operat	Quality	Safety	Project Delivery	Cost	Cost	BIM management
18	Change the way of thinking	Project Delivery	BIM Management	Communication	Communication	Communication	Communication
19	Smoother workflow	BIM management	Budget	Communication	BIM management	Schedule	BIM management
20	Increase team understanding	Communication	Cost	Communication	Communication	Communication	Communication
21	Saving on labor and material	Procurement	Budget	Project Delivery	Cost	Cost	Cost

	Intangible benefits	Designers			G and Sub Contractors		Owner
		Darick	Steven	Franc	Leonard	Curtis	Alfredo
22	Client confidence	Communication	Quality	Business	Business	Business	BIM management
23	Improve communication between	Communication	Schedule	Quality	Communication	Communication	Communication
24	Expedited timecard and daily report	Cost	Cost	Schedule	Safety	Schedule	Business
25	Tolerance control	Quality	Safety	Quality	Project Delivery	Quality	Quality
26	Understanding the site	Communication	Quality	Quality	Communication	Safety	
27	Greater detail and greater accessibility	BIM management	Communication	Quality	Procurement	Quality	Quality
28	Design analysis, finding issues before	Schedule	Quality	Quality	Quality	Quality	BIM management
29	Visualization of end product	Communication	BIM Management	Communication	Project Delivery	Project Delivery	Communication
30	Produces consistent and coordinated design	Quality	Schedules	Project Delivery	Quality	Quality	Quality
31	Ability to handle larger data sets and higher	Business	Communication	BIM Management	Communication	BIM management	BIM management
32	Allows more iteration in the design process	Quality	Quality	Quality	BIM management	Quality	
33	More usable Information	Business	Procurement	Quality	BIM management	Communication	Communication
34	Easier to Track Issues	Schedule	Cost	Project Delivery	BIM management	Schedule	BIM management
35	Lower risk with managed outcomes	Schedule	Budget	Safety	Business	Quality	Quality
36	Automatic document coordination	Schedule	Quality	Quality	Project Delivery	Schedule	BIM management
37	Transparent communication	Communication	BIM Management	Quality	Communication	Communication	Communication
38	streamlined information/data management	Business	Schedules	BIM Management	BIM management	BIM management	BIM management
39	Better performing buildings	Business	Business	Project Delivery	Project Delivery	Quality	Quality
40	Conflict resolution	Schedule	Cost	BIM Management	Schedule	Quality	
41	Discrepancies become more understandable	Quality	Communication	Quality	Project Delivery	Communication	BIM management
42	Fabrication and modular construction	Project Delivery	Procurement	Project Delivery	Project Delivery	Schedules	Quality

4.5 The relationship between the Intangible Benefits

4.5.1 Relationship between Intangibles: Structural Self-interaction Matrix

Table 40. Self-interaction Matrix

	Intangible benefits	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	Better team Work	O	V	V	O	O	V	O	V	V	O	O	O	V	O	A	O	O	O	V	V	O	V	V	A	V	V	A	O	O	V	O	V	V	O	V	O	V	V	X	X	
2	Visual communication	V	O	V	O	O	V	O	V	O	A	A	O	O	V	O	O	O	O	V	V	O	V	V	V	O	V	O	O	V	V	V	V	V	V	A	A	V	O	X		
3	Linked information	V	A	V	O	X	X	X	V	V	V	V	O	V	O	A	V	V	V	V	V	A	V	V	O	V	V	V	V	O	V	O	O	V	V	V	O	O	V			
4	Increase quality	O	A	O	V	A	A	O	O	A	O	A	A	A	O	A	A	O	O	A	A	O	X	O	O	V	O	A	O	O	O	O	A	A	A	A	A	A				
5	Better illustration of design to the client	O	A	V	O	A	A	O	A	O	A	A	O	O	A	O	O	O	O	A	V	O	V	V	V	O	O	A	O	V	V	V	A	A	A	A	A					
6	Better presentation	O	V	V	O	A	X	O	V	O	O	X	O	O	V	O	A	O	O	O	V	O	V	O	V	O	O	A	O	V	O	V	O	O	V	O						
7	More collaboration	V	X	V	O	A	X	O	V	O	O	A	O	V	O	V	O	A	O	V	V	O	V	V	V	O	V	O	A	V	V	O	V	V	V							
8	Project understanding	O	A	V	O	A	A	A	O	A	A	O	O	A	A	A	X	V	O	A	V	O	X	O	O	A	X	X	X	O	O	V	A	A								
9	Better coordination	V	V	V	O	A	X	A	V	A	O	A	O	V	O	V	O	V	O	V	V	O	V	V	X	V	V	A	A	V	V	V	X									
10	Better team culture	O	V	V	O	O	X	O	O	O	O	A	O	V	O	O	O	O	V	A	V	O	V	V	O	O	V	O	O	O	A	V										
11	Increase personal satisfaction	O	O	O	O	O	A	O	O	A	O	O	O	A	A	O	O	O	O	A	O	O	X	X	O	O	O	O	O	O	A	O										
12	Increased accountability and cooperation	O	O	V	O	A	A	O	A	O	O	A	O	A	O	A	O	O	O	O	V	O	X	O	O	V	V	O	A	O												
13	Generating Business	O	O	X	O	O	A	O	A	A	A	A	O	A	A	A	O	O	O	A	A	A	A	O	O	O	A	A	O													
14	Data Transfer	V	O	O	O	X	X	O	O	O	O	V	O	O	O	V	O	O	V	V	O	O	V	V	O	O	V	A														
15	Greater details and accessibility	V	V	V	V	X	A	O	V	X	V	A	A	O	V	V	O	O	O	V	V	V	V	O	O	V	V															
16	Easy to manage projects	A	A	O	O	A	A	A	A	A	A	A	A	A	A	A	A	O	O	X	O	O	X	X	O	A																
17	Reduction of construction and operations risks	A	A	O	V	O	O	O	X	X	O	A	O	X	O	X	X	O	O	X	O	O	A	O	O																	
18	Change the way of thinking	O	O	O	V	O	A	O	O	O	A	X	O	O	A	O	O	O	O	O	O	O	X	O																		
19	Smoother workflow	O	O	O	O	A	A	X	O	A	A	O	O	A	O	A	A	O	O	A	O	O	A																			
20	Increase team understanding	O	A	O	O	A	A	O	O	A	A	A	A	A	A	A	A	O	O	X	V	O																				
21	Saving on labor and material	A	O	O	O	O	O	O	O	O	O	O	O	O	O	A	O	A	O	A	O																					
22	Client confidence	O	O	V	O	O	A	O	A	A	A	A	O	O	A	A	O	A	O	A																					
23	Improve communication between field and office	O	A	V	V	A	A	A	V	A	A	A	O	O	A	A	V	O	V																					
24	Expedited timecard and daily report submittals	O	O	O	O	A	A	A	O	A	O	O	O	O	O	O	O	O																							
25	Tolerance control	A	A	O	V	A	A	O	O	A	A	A	O	A	A	A	O																									
26	Understanding the site	O	O	V	V	A	A	O	O	O	O	O	O	O	O	O																									
27	Design analysis, finding issues before the field c	V	X	V	V	X	A	X	X	A	A	A	O	A	O																									
28	Visualization of end product	V	O	V	V	A	O	O	V	V	A	O	O	O																									
29	Produces consistent and coordinated design	V	X	V	V	A	A	V	V	V	O	A	A																									
30	Ability to handle larger data sets and higher	V	O	O	O	O	O	O	O	V	V	O																										
31	Allows more iteration in the design process	V	X	V	V	A	X	O	V	X	V																											
32	More usable Information	V	O	V	O	A	O	O	V	V																												
33	Easier to Track Issues	V	V	V	V	A	X	A	V																													
34	Lower risk with managed outcomes	V	A	V	V	A	A	A																														
35	Automatic document coordination	V	V	V	V	X	V																															
36	Transparent communication	V	A	V	V	A																																
37	streamlined information/data management	V	X	V	V																																	
38	Better performing buildings	O	O	O																																		
39	Conflict resolution	V	A																																			
40	Discrepancies become more understandable	V																																				
41	Fabrication and modular construction																																					

4.5.2 Reachability Matrix

Table 41. Reachability Matrix

IB	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	DP
1	0	1	1	0	0	1	0	1	1	0	0	0	1	0	0	0	0	0	1	1	0	1	1	0	1	1	0	0	0	1	0	0	0	0	1	0	1	1	1	1	1	19
2	0	0	1	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	1	1	0	1	1	1	0	1	0	0	0	1	1	1	1	1	0	0	1	0	0	1	1	18
3	1	0	1	0	1	1	1	1	1	1	1	0	1	0	0	1	1	1	1	1	0	1	1	0	1	1	1	1	0	1	0	0	1	1	1	0	0	1	1	0	1	28
4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4
5	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	1	1	1	0	0	0	0	0	1	1	0	0	0	10
6	0	1	1	0	0	1	0	1	0	0	1	0	0	1	0	0	0	0	0	1	0	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	1	0	1	0	16
7	1	1	1	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0	1	1	0	1	1	1	0	1	0	0	1	1	0	1	1	1	1	0	1	1	0	1	0	22
8	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	1	0	0	0	1	1	1	0	0	1	0	0	1	0	0	1	1	0	0	1	13
9	1	1	1	0	0	1	0	1	0	0	0	0	1	0	1	0	1	0	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1	0	0	1	1	0	0	0	23
10	0	1	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	1	1	0	0	1	0	0	0	0	1	1	1	1	0	0	1	1	0	0	0	15
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3
12	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	7
13	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	3
14	1	0	0	0	1	1	0	0	0	0	1	0	0	0	1	0	0	1	1	0	0	1	1	0	0	1	0	1	0	1	0	0	1	1	1	0	0	0	0	0	0	15
15	1	1	1	1	1	0	0	1	1	1	0	0	0	1	1	0	0	0	1	1	1	1	0	0	1	1	1	1	1	0	0	0	1	1	0	1	1	1	0	0	1	25
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	6
17	0	0	0	1	0	0	0	1	1	0	0	0	1	0	1	1	1	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	11
18	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	5
19	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	4
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	1	0	0	1	1	1	0	0	1	0	0	0	1	0	0	0	12
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	3
22	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	4

IB	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	DP
23	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1	0	1	1	0	0	1	0	1	1	0	1	0	0	1	1	0	0	0	18
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
25	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	5
26	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	10
27	1	1	1	1	1	0	1	1	0	0	0	0	0	0	1	0	1	0	1	1	1	1	1	0	1	1	0	0	1	1	0	0	0	1	0	0	0	1	1	0	1	22
28	1	0	1	1	0	0	0	1	1	0	0	0	0	1	0	0	1	0	1	1	0	1	0	1	0	1	0	0	1	0	1	0	0	1	0	0	1	0	0	0	0	16
29	1	1	1	1	0	0	1	1	1	0	0	0	1	0	1	0	1	0	0	0	0	1	1	0	1	1	0	0	1	1	1	0	0	1	0	0	0	1	0	0	0	19
30	1	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	10
31	1	1	1	1	0	1	0	1	1	1	1	0	1	0	1	0	1	0	1	1	0	1	0	0	1	1	1	0	1	1	0	1	1	0	1	1	1	1	0	1	0	27
32	1	0	1	0	0	0	0	1	1	1	0	0	0	1	1	0	1	0	1	1	0	1	1	1	0	1	0	0	1	0	0	0	0	1	0	0	1	0	0	1	0	18
33	1	1	1	1	0	1	0	1	1	0	1	0	0	0	1	0	1	1	1	1	0	1	1	0	1	1	1	0	1	0	1	0	1	1	0	0	0	1	0	0	0	23
34	1	0	1	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	1	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	11
35	1	1	1	1	1	1	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	1	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	17
36	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	1	1	1	1	1	1	0	1	1	1	0	1	1	0	0	31
37	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	0	1	1	0	0	1	1	1	0	1	0	0	1	1	1	1	1	1	1	0	0	31
38	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
39	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3
40	1	1	1	0	1	1	0	1	0	0	1	0	1	0	1	0	1	0	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0	1	1	0	1	1	1	0	0	19
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
DeP	18	13	27	17	7	14	7	20	13	7	8	2	12	7	15	7	15	9	20	22	7	29	21	10	17	28	8	6	20	15	15	8	12	23	9	6	17	22	8	6	7	

Table 42. Iteration 1

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.2.3.4.5.7.12.16.17.19.20.22.23.29.33.34.36.36.39.40	1.2.3.8.15.18.27	1.2.3	
2	1.2.5.8.9.10.11.12.16.18.19.20.22.23.28.34.36.39	1.2.6.7.31.32	1.2	
3	1.3.4.7.8.9.12.14.15.16.17.19.20.22.23.24.25.26.29.31.32.33.34.35.36.37.39.41	1.3.21.27.35.36.37.40	3.35.36.37	
4	4.17.20.38	1.3.4.5.6.7.8.9.10.15.20.22.23.26.27.29.30.31.33.36.37.40	4.2	
5	4.5.11.12.13.18.19.20.22.39	1.2.5.6.7.8.9.10.15.23.28.30.31.32.34.37.40	5	
6	2.4.5.6.8.11.13.18.20.22.28.31.34.36.39.40	6.15.26.31.36.37	6.31.36	
7	2.4.5.7.8.9.10.12.13.16.18.19.20.22.23.27.29.34.36.39.40.41	1.3.7.14.25.31.36.37.40	7.36.40	
8	1.4.5.8.11.14.15.16.20.22.25.26.39	2.3.6.7.8.9.10.14.15.16.17.20.23.26.27.28.29.32.33.35.36.37.40	8.14.15.16.20.26	
9	4.5.8.9.10.11.12.13.16.17.18.19.20.22.23.25.27.29.34.36.39.40.41	2.3.7.9.10.14.15.18.31.33.35.37	9.10.18	
10	4.5.8.9.10.11.16.19.20.21.22.24.29.36.39.40	2.7.9.10.12.23.31.36	9.10.36	
11	11.19.20	2.5.6.8.9.10.11.13.19.20.23.28.29.33.36	11.19.20	1
12	10.12.16.17.20.22.39	1.2.3.5.7.12.14.20.27.29.31.34.36.37	12.2	
13	11.13.39	5.6.7.9.13.15.16.20.21.22.23.27.28.29.31.32.33.34.36.39	13.39	
14	7.8.9.12.14.16.19.20.23.24.27.31.36.37.41	3.8.14.15.36.37	8.14.36.37	
15	1.4.5.6.8.9.13.14.15.16.17.20.21.22.23.27.28.32.33.34.37.38.39.40.41	3.8.15.30.31.33.36.37	8.9.15.37	
16	8.13.16.19.20.23	1.2.3.7.8.9.10.12.14.15.16.17.19.20.23.26.27.28.29.30.31.32.33.34.35.37.40.41	8.16.19.20.23	
17	8.16.17.23.25.26.27.29.33.34.38	1.3.4.9.12.15.17.20.23.26.27.29.31.33.34.40.41	17.23.26.27.29.33.34	
18	1.9.18.20.38	2.5.6.7.9.18.20.28.31.35	9.18.20	
19	11.16.19.35.	1.2.3.5.7.9.10.11.14.16.19.20.23.26.27.29.32.33.35.36.37	11.16.19.35	1
20	4.8.11.12.13.16.17.18.19.20.22.23	1.2.3.4.5.6.7.8.9.10.11.12.14.15.16.18.20.20.23.26.27.28.29.30.31.32.33.37.38.40	4.8.11.12.16.18.20.23	
21	3.13.21	15.21.23.25.27.38.41	21	
22	4.13.22.39	1.2.3.5.6.7.8.9.10.12.15.20.22.23.25.27.28.31.32.33.34.36	22	
23	4.5.8.10.11.13.16.17.19.20.21.22.23.24.26.34.38.39	1.2.3.7.9.14.15.16.17.20.23.27.28.31.32.33.35.36.37.40	16.17.20.23	
24	24	3.10.14.23.24.33.35.36.37	24	1
25	7.21.22.25.38	3.8.9.17.25.27.28.29.31.32.33.36.37.40.41	25	
26	4.6.8.16.17.19.20.25.26.38.39	3.8.17.23.26.36.37	8.17.26	
27	1.3.4.8.12.13.16.17.19.20.21.22.23.25.27.34.35.37.38.39.40.41	7.15.27.28.32.36.37	27.37	
28	5.8.11.13.16.18.20.22.23.25.28.33.34.38.39.41	2.6.15.28.32.36.37	28	
29	4.8.11.12.13.15.16.17.19.20.25.27.29.33.34.35.38.39.40.41	1.3.7.9.10.16.17.29.30.31.36.37.40	16.17.29.40	
30	4.5.15.16.20.29.30.32.33.41	30.36	30	
31	2.4.5.6.7.9.10.12.13.15.16.17.20.22.23.25.27.29.31.32.33.34.36.38.39.40.41	3.6.14.31.33.36.37.40	6.31.33.36.40	
32	2.5.8.13.16.18.19.20.22.23.25.27.28.32.33.34.39.41	3.15.30.31.32.36.37	32	
33	4.8.9.11.13.15.16.17.19.20.22.23.24.25.27.31.33.34.36.38.39.40.41	1.3.15.17.28.29.30.31.32.33.35.36.37	15.17.31.33.36	
34	5.12.13.16.17.22.27.34.38.39.41	1.2.3.6.7.9.15.17.23.27.28.29.31.32.33.34.35.36.37.40	17.27.34	
35	3.8.9.16.19.23.24.27.33.34.35.36.37.38.39.40.41	3.19.27.29.35.36.37	3.19.27.35.36	
36	3.4.6.7.8.10.11.12.13.14.15.18.19.22.23.24.25.26.27.28.29.30.31.32.33.34.35.36.38.39.41	1.2.3.6.7.9.10.14.31.33.35.36.37.40	3.6.7.10.14.31.33.35.36	
37	3.4.5.7.8.9.12.14.15.16.19.20.23.24.25.26.27.28.29.31.32.33.34.35.36.37.38.39.40.41	3.14.15.27.35.37.40	3.14.15.27.35.37.40	
38	20.21.38	4.15.17.18.23.25.26.27.28.29.31.33.34.35.36.37.38	38	
39	13.39.41	1.2.3.5.6.7.9.10.12.13.15.22.23.26.27.28.29.31.32.33.34.35.36.37.39.40	13.39	
40	3.4.5.7.8.16.17.20.23.25.27.29.31.34.36.37.39.40.41	1.6.7.9.10.15.27.29.31.33.35.37.40	7.27.29.31.37.40	
41	16.17.21.25.41	3.7.9.14.15.27.28.29.30.31.32.33.34.35.36.37.39.40.41	41	

Table 43. Iteration 2

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.2.3.4.5.7.12.16.17.20.22.23.29.33.34.36.36.39.40	1.2.3.8.15.18.27	1.2.3	
2	1.2.5.8.9.10.12.16.18.20.22.23.28.34.36.39	1.2.6.7.31.32	1.2	
3	1.3.4.7.8.9.12.14.15.16.17.20.22.23.25.26.29.31.32.33.34.35.36.37.39.41	1.3.21.27.35.36.37.40	3.35.36.37	
4	4.17.20.38	1.3.4.5.6.7.8.9.10.15.20.22.23.26.27.29.30.31.33.36.37.40	4.2	
5	4.5.12.13.18.20.22.39	1.2.5.6.7.8.9.10.15.23.28.30.31.32.34.37.40	5	
6	2.4.5.6.8.13.18.20.22.28.31.34.36.39.40	6.15.26.31.36.37	6.31.36	
7	2.4.5.7.8.9.10.12.13.16.18.20.22.23.27.29.34.36.39.40.41	1.3.7.14.25.31.36.37.40	7.36.40	
8	1.4.5.8.14.15.16.20.22.25.26.39	2.3.6.7.8.9.10.14.15.16.17.20.23.26.27.28.29.32.33.35.36.37.40	8.14.15.16.20.26	
9	4.5.8.9.10.12.13.16.17.18.20.22.23.25.27.29.34.36.39.40.41	2.3.7.9.10.14.15.18.31.33.35.37	9.10.18	
10	4.5.8.9.10.16.20.21.22.29.36.39.40	2.7.9.10.12.23.31.36	9.10.36	
12	10.12.16.17.20.22.39	1.2.3.5.7.12.14.20.27.29.31.34.36.37	12.2	
13	13.39	5.6.7.9.13.15.16.20.21.22.23.27.28.29.31.32.33.34.36.39	13.39	2
14	7.8.9.12.14.16.20.23.27.31.36.37.41	3.8.14.15.36.37	8.14.36.37	
15	1.4.5.6.8.9.13.14.15.16.17.20.21.22.23.27.28.32.33.34.37.38.39.40.41	3.8.15.30.31.33.36.37	8.9.15.37	
16	8.13.16.20.23	1.2.3.7.8.9.10.12.14.15.16.17.20.23.26.27.28.29.30.31.32.33.34.35.37.40.41	8.16.20.23	
17	8.16.17.23.25.26.27.29.33.34.38	1.3.4.9.12.15.17.20.23.26.27.29.31.33.34.40.41	17.23.26.27.29.33.34	
18	1.9.18.20.38	2.5.6.7.9.18.20.28.31.35	9.18.20	
20	4.8.12.13.16.17.18.20.22.23	1.2.3.4.5.6.7.8.9.10.12.14.15.16.18.20.20.23.26.27.28.29.30.31.32.33.37.38.40	4.8.12.16.18.20.23	
21	3.13.21	15.21.23.25.27.38.41	21	
22	4.13.22.39	1.2.3.5.6.7.8.9.10.12.15.20.22.23.25.27.28.31.32.33.34.36	22	
23	4.5.8.10.13.16.17.20.21.22.23.26.34.38.39	1.2.3.7.9.14.15.16.17.20.23.27.28.31.32.33.35.36.37.40	16.17.20.23	
25	7.21.22.25.38	3.8.9.17.25.27.28.29.31.32.33.36.37.40.41	25	
26	4.6.8.16.17.20.25.26.38.39	3.8.17.23.26.36.37	8.17.26	
27	1.3.4.8.12.13.16.17.20.21.22.23.25.27.34.35.37.38.39.40.41	7.15.27.28.32.36.37	27.37	
28	5.8.13.16.18.20.22.23.25.28.33.34.38.39.41	2.6.15.28.32.36.37	28	
29	4.8.12.13.15.16.17.20.25.27.29.33.34.35.38.39.40.41	1.3.7.9.10.16.17.29.30.31.36.37.40	16.17.29.40	
30	4.5.15.16.20.29.30.32.33.41	30.36	30	
31	2.4.5.6.7.9.10.12.13.15.16.17.20.22.23.25.27.29.31.32.33.34.36.38.39.40.41	3.6.14.31.33.36.37.40	6.31.33.36.40	
32	2.5.8.13.16.18.20.22.23.25.27.28.32.33.34.39.41	3.15.30.31.32.36.37	32	
33	4.8.9.13.15.16.17.20.22.23.25.27.31.33.34.36.38.39.40.41	1.3.15.17.28.29.30.31.32.33.35.36.37	15.17.31.33.36	
34	5.12.13.16.17.22.27.34.38.39.41	1.2.3.6.7.9.15.17.23.27.28.29.31.32.33.34.35.36.37.40	17.27.34	
35	3.8.9.16.23.27.33.34.35.36.37.38.39.40.41	3.19.27.29.35.36.37	3.27.35.36	
36	3.4.6.7.8.10.12.13.14.15.18.22.23.25.26.27.28.29.30.31.32.33.34.35.36.38.39.41	1.2.3.6.7.9.10.14.31.33.35.36.37.40	3.6.7.10.14.31.33.35.36	
37	3.4.5.7.8.9.12.14.15.16.20.23.25.26.27.28.29.31.32.33.34.35.36.37.38.39.40.41	3.14.15.27.35.37.40	3.14.15.27.35.37.40	
38	20.21.38	4.15.17.18.23.25.26.27.28.29.31.33.34.35.36.37.38	38	
39	13.39.41	1.2.3.5.6.7.9.10.12.13.15.22.23.26.27.28.29.31.32.33.34.35.36.37.39.40	13.39	
40	3.4.5.7.8.16.17.20.23.25.27.29.31.34.36.37.39.40.41	1.6.7.9.10.15.27.29.31.33.35.37.40	7.27.29.31.37.40	
41	16.17.21.25.41	3.7.9.14.15.27.28.29.30.31.32.33.34.35.36.37.39.40.41	41	

Table 44. Iteration 3

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.2.3.4.5.7.12.16.17.20.22.23.29.33.34.36.36.39.40	1.2.3.8.15.18.27	1.2.3	
2	1.2.5.8.9.10.12.16.18.20.22.23.28.34.36.39	1.2.6.7.31.32	1.2	
3	1.3.4.7.8.9.12.14.15.16.17.20.22.23.25.26.29.31.32.33.34.35.36.37.39.41	1.3.21.27.35.36.37.40	3.35.36.37	
4	4.17.20.38	1.3.4.5.6.7.8.9.10.15.20.22.23.26.27.29.30.31.33.36.37.40	4.2	
5	4.5.12.18.20.22.39	1.2.5.6.7.8.9.10.15.23.28.30.31.32.34.37.40	5	
6	2.4.5.6.8.18.20.22.28.31.34.36.39.40	6.15.26.31.36.37	6.31.36	
7	2.4.5.7.8.9.10.12.16.18.20.22.23.27.29.34.36.39.40.41	1.3.7.14.25.31.36.37.40	7.36.40	
8	1.4.5.8.14.15.16.20.22.25.26.39	2.3.6.7.8.9.10.14.15.16.17.20.23.26.27.28.29.32.33.35.36.37.40	8.14.15.16.20.26	
9	4.5.8.9.10.12.16.17.18.20.22.23.25.27.29.34.36.39.40.41	2.3.7.9.10.14.15.18.31.33.35.37	9.10.18	
10	4.5.8.9.10.16.20.21.22.29.36.39.40	2.7.9.10.12.23.31.36	9.10.36	
12	10.12.16.17.20.22.39	1.2.3.5.7.12.14.20.27.29.31.34.36.37	12.2	
14	7.8.9.12.14.16.20.23.27.31.36.37.41	3.8.14.15.36.37	8.14.36.37	
15	1.4.5.6.8.9.14.15.16.17.20.21.22.23.27.28.32.33.34.37.38.39.40.41	3.8.15.30.31.33.36.37	8.9.15.37	
16	8.16.20.23	1.2.3.7.8.9.10.12.14.15.16.17.20.23.26.27.28.29.30.31.32.33.34.35.37.40.41	8.16.20.23	3
17	8.16.17.23.25.26.27.29.33.34.38	1.3.4.9.12.15.17.20.23.26.27.29.31.33.34.40.41	17.23.26.27.29.33.34	
18	1.9.18.20.38	2.5.6.7.9.18.20.28.31.35	9.18.20	
20	4.8.12.16.17.18.20.22.23	1.2.3.4.5.6.7.8.9.10.12.14.15.16.18.20.20.23.26.27.28.29.30.31.32.33.37.38.40	4.8.12.16.18.20.23	
21	3.21	15.21.23.25.27.38.41	21	
22	4.22.39	1.2.3.5.6.7.8.9.10.12.15.20.22.23.25.27.28.31.32.33.34.36	22	
23	4.5.8.10.16.17.20.21.22.23.26.34.38.39	1.2.3.7.9.14.15.16.17.20.23.27.28.31.32.33.35.36.37.40	16.17.20.23	
25	7.21.22.25.38	3.8.9.17.25.27.28.29.31.32.33.36.37.40.41	25	
26	4.6.8.16.17.20.25.26.38.39	3.8.17.23.26.36.37	8.17.26	
27	1.3.4.8.12.16.17.20.21.22.23.25.27.34.35.37.38.39.40.41	7.15.27.28.32.36.37	27.37	
28	5.8.16.18.20.22.23.25.28.33.34.38.39.41	2.6.15.28.32.36.37	28	
29	4.8.12.15.16.17.20.25.27.29.33.34.35.38.39.40.41	1.3.7.9.10.16.17.29.30.31.36.37.40	16.17.29.40	
30	4.5.15.16.20.29.30.32.33.41	30.36	30	
31	2.4.5.6.7.9.10.12.15.16.17.20.22.23.25.27.29.31.32.33.34.36.38.39.40.41	3.6.14.31.33.36.37.40	6.31.33.36.40	
32	2.5.8.16.18.20.22.23.25.27.28.32.33.34.39.41	3.15.30.31.32.36.37	32	
33	4.8.9.15.16.17.20.22.23.25.27.31.33.34.36.38.39.40.41	1.3.15.17.28.29.30.31.32.33.35.36.37	15.17.31.33.36	
34	5.12.16.17.22.27.34.38.39.41	1.2.3.6.7.9.15.17.23.27.28.29.31.32.33.34.35.36.37.40	17.27.34	
35	3.8.9.16.23.27.33.34.35.36.37.38.39.40.41	3.19.27.29.35.36.37	3.27.35.36	
36	3.4.6.7.8.10.12.14.15.18.22.23.25.26.27.28.29.30.31.32.33.34.35.36.38.39.41	1.2.3.6.7.9.10.14.31.33.35.36.37.40	3.6.7.10.14.31.33.35.36	
37	3.4.5.7.8.9.12.14.15.16.20.23.25.26.27.28.29.31.32.33.34.35.36.37.38.39.40.41	3.14.15.27.35.37.40	3.14.15.27.35.37.40	
38	20.21.38	4.15.17.18.23.25.26.27.28.29.31.33.34.35.36.37.38	38	
39	39.41	1.2.3.5.6.7.9.10.12.15.22.23.26.27.28.29.31.32.33.34.35.36.37.39.40	39	
40	3.4.5.7.8.16.17.20.23.25.27.29.31.34.36.37.39.40.41	1.6.7.9.10.15.27.29.31.33.35.37.40	7.27.29.31.37.40	
41	16.17.21.25.41	3.7.9.14.15.27.28.29.30.31.32.33.34.35.36.37.39.40.41	41	

Table 45. Iteration 4

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.2.3.4.5.7.12.17.20.22.23.29.33.34.36.36.39.40	1.2.3.8.15.18.27	1.2.3	
2	1.2.5.8.9.10.12.18.20.22.23.28.34.36.39	1.2.6.7.31.32	1.2	
3	1.3.4.7.8.9.12.14.15.17.20.22.23.25.26.29.31.32.33.34.35.36.37.39.41	1.3.21.27.35.36.37.40	3.35.36.37	
4	4.17.20.38	1.3.4.5.6.7.8.9.10.15.20.22.23.26.27.29.30.31.33.36.37.40	4.2	
5	4.5.12.18.20.22.39	1.2.5.6.7.8.9.10.15.23.28.30.31.32.34.37.40	5	
6	2.4.5.6.8.18.20.22.28.31.34.36.39.40	6.15.26.31.36.37	6.31.36	
7	2.4.5.7.8.9.10.12.18.20.22.23.27.29.34.36.39.40.41	1.3.7.14.25.31.36.37.40	7.36.40	
8	1.4.5.8.14.15.20.22.25.26.39	2.3.6.7.8.9.10.14.15.17.20.23.26.27.28.29.32.33.35.36.37.40	8.14.15.20.26	
9	4.5.8.9.10.12.17.18.20.22.23.25.27.29.34.36.39.40.41	2.3.7.9.10.14.15.18.31.33.35.37	9.10.18	
10	4.5.8.9.10.20.21.22.29.36.39.40	2.7.9.10.12.23.31.36	9.10.36	
12	10.12.17.20.22.39	1.2.3.5.7.12.14.20.27.29.31.34.36.37	12.2	
14	7.8.9.12.14.20.23.27.31.36.37.41	3.8.14.15.36.37	8.14.36.37	
15	1.4.5.6.8.9.14.15.17.20.21.22.23.27.28.32.33.34.37.38.39.40.41	3.8.15.30.31.33.36.37	8.9.15.37	
17	8.17.23.25.26.27.29.33.34.38	1.3.4.9.12.15.17.20.23.26.27.29.31.33.34.40.41	17.23.26.27.29.33.34	
18	1.9.18.20.38	2.5.6.7.9.18.20.28.31.35	9.18.20	
20	4.8.12.17.18.20.22.23	1.2.3.4.5.6.7.8.9.10.12.14.15.18.20.20.23.26.27.28.29.30.31.32.33.37.38.40	4.8.12.18.20.23	
21	3.21	15.21.23.25.27.38.41	21	4
22	4.22.39	1.2.3.5.6.7.8.9.10.12.15.20.22.23.25.27.28.31.32.33.34.36	22	
23	4.5.8.10.17.20.21.22.23.26.34.38.39	1.2.3.7.9.14.15.17.20.23.27.28.31.32.33.35.36.37.40	17.20.23	
25	7.21.22.25.38	3.8.9.17.25.27.28.29.31.32.33.36.37.40.41	25	
26	4.6.8.17.20.25.26.38.39	3.8.17.23.26.36.37	8.17.26	
27	1.3.4.8.12.17.20.21.22.23.25.27.34.35.37.38.39.40.41	7.15.27.28.32.36.37	27.37	
28	5.8.18.20.22.23.25.28.33.34.38.39.41	2.6.15.28.32.36.37	28	
29	4.8.12.15.17.20.25.27.29.33.34.35.38.39.40.41	1.3.7.9.10.17.29.30.31.36.37.40	17.29.40	
30	4.5.15.20.29.30.32.33.41	30.36	30	
31	2.4.5.6.7.9.10.12.15.17.20.22.23.25.27.29.31.32.33.34.36.38.39.40.41	3.6.14.31.33.36.37.40	6.31.33.36.40	
32	2.5.8.18.20.22.23.25.27.28.32.33.34.39.41	3.15.30.31.32.36.37	32	
33	4.8.9.15.17.20.22.23.25.27.31.33.34.36.38.39.40.41	1.3.15.17.28.29.30.31.32.33.35.36.37	15.17.31.33.36	
34	5.12.17.22.27.34.38.39.41	1.2.3.6.7.9.15.17.23.27.28.29.31.32.33.34.35.36.37.40	17.27.34	
35	3.8.9.23.27.33.34.35.36.37.38.39.40.41	3.19.27.29.35.36.37	3.27.35.36	
36	3.4.6.7.8.10.12.14.15.18.22.23.25.26.27.28.29.30.31.32.33.34.35.36.38.39.41	1.2.3.6.7.9.10.14.31.33.35.36.37.40	3.6.7.10.14.31.33.35.36	
37	3.4.5.7.8.9.12.14.15.20.23.25.26.27.28.29.31.32.33.34.35.36.37.38.39.40.41	3.14.15.27.35.37.40	3.14.15.27.35.37.40	
38	20.21.38	4.15.17.18.23.25.26.27.28.29.31.33.34.35.36.37.38	38	
39	39.41	1.2.3.5.6.7.9.10.12.15.22.23.26.27.28.29.31.32.33.34.35.36.37.39.40	39	4
40	3.4.5.7.8.17.20.23.25.27.29.31.34.36.37.39.40.41	1.6.7.9.10.15.27.29.31.33.35.37.40	7.27.29.31.37.40	
41	17.21.25.41	3.7.9.14.15.27.28.29.30.31.32.33.34.35.36.37.39.40.41	41	

Table 46. Iteration 5

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.2.3.4.5.7.12.17.20.22.23.29.33.34.36.36.40	1.2.3.8.15.18.27	1.2.3	
2	1.2.5.8.9.10.12.18.20.22.23.28.34.36	1.2.6.7.31.32	1.2	
3	1.3.4.7.8.9.12.14.15.17.20.22.23.25.26.29.31.32.33.34.35.36.37.39.41	1.3.21.27.35.36.37.40	3.35.36.37	
4	4.17.20.38	1.3.4.5.6.7.8.9.10.15.20.22.23.26.27.29.30.31.33.36.37.40	4.2	
5	4.5.12.18.20.22	1.2.5.6.7.8.9.10.15.23.28.30.31.32.34.37.40	5	
6	2.4.5.6.8.18.20.22.28.31.34.36.40	6.15.26.31.36.37	6.31.36	
7	2.4.5.7.8.9.10.12.18.20.22.23.27.29.34.36.40.41	1.3.7.14.25.31.36.37.40	7.36.40	
8	1.4.5.8.14.15.20.22.25.26	2.3.6.7.8.9.10.14.15.17.20.23.26.27.28.29.32.33.35.36.37.40	8.14.15.20.26	
9	4.5.8.9.10.12.17.18.20.22.23.25.27.29.34.36.40.41	2.3.7.9.10.14.15.18.31.33.35.37	9.10.18	
10	4.5.8.9.10.20.22.29.36.40	2.7.9.10.12.23.31.36	9.10.36	
12	10.12.17.20.22	1.2.3.5.7.12.14.20.27.29.31.34.36.37	12.2	
14	7.8.9.12.14.20.23.27.31.36.37.41	3.8.14.15.36.37	8.14.36.37	
15	1.4.5.6.8.9.14.15.17.20.22.23.27.28.32.33.34.37.38.40.41	3.8.15.30.31.33.36.37	8.9.15.37	
17	8.17.23.25.26.27.29.33.34.38	1.3.4.9.12.15.17.20.23.26.27.29.31.33.34.40.41	17.23.26.27.29.33.34	
18	1.9.18.20.38	2.5.6.7.9.18.20.28.31.35	9.18.20	
20	4.8.12.17.18.20.22.23	1.2.3.4.5.6.7.8.9.10.12.14.15.18.20.20.23.26.27.28.29.30.31.32.33.37.38.40	4.8.12.18.20.23	
22	4.22	1.2.3.5.6.7.8.9.10.12.15.20.22.23.25.27.28.31.32.33.34.36	22	5
23	4.5.8.10.17.20.22.23.26.34.38	1.2.3.7.9.14.15.17.20.23.27.28.31.32.33.35.36.37.40	17.20.23	
25	7.22.25.38	3.8.9.17.25.27.28.29.31.32.33.36.37.40.41	25	
26	4.6.8.17.20.25.26.38	3.8.17.23.26.36.37	8.17.26	
27	1.3.4.8.12.17.20.22.23.25.27.34.35.37.38.40.41	7.15.27.28.32.36.37	27.37	
28	5.8.18.20.22.23.25.28.33.34.38.41	2.6.15.28.32.36.37	28	
29	4.8.12.15.17.20.25.27.29.33.34.35.38.40.41	1.3.7.9.10.17.29.30.31.36.37.40	17.29.40	
30	4.5.15.20.29.30.32.33.41	30.36	30	
31	2.4.5.6.7.9.10.12.15.17.20.22.23.25.27.29.31.32.33.34.36.38.40.41	3.6.14.31.33.36.37.40	6.31.33.36.40	
32	2.5.8.18.20.22.23.25.27.28.32.33.34.41	3.15.30.31.32.36.37	32	
33	4.8.9.15.17.20.22.23.25.27.31.33.34.36.38.40.41	1.3.15.17.28.29.30.31.32.33.35.36.37	15.17.31.33.36	
34	5.12.17.22.27.34.38.41	1.2.3.6.7.9.15.17.23.27.28.29.31.32.33.34.35.36.37.40	17.27.34	
35	3.8.9.23.27.33.34.35.36.37.38.40.41	3.19.27.29.35.36.37	3.27.35.36	
36	3.4.6.7.8.10.12.14.15.18.22.23.25.26.27.28.29.30.31.32.33.34.35.36.38.41	1.2.3.6.7.9.10.14.31.33.35.36.37.40	3.6.7.10.14.31.33.35.36	
37	3.4.5.7.8.9.12.14.15.20.23.25.26.27.28.29.31.32.33.34.35.36.37.38.40.41	3.14.15.27.35.37.40	3.14.15.27.35.37.40	
38	20.38	4.15.17.18.23.25.26.27.28.29.31.33.34.35.36.37.38	38	5
40	3.4.5.7.8.17.20.23.25.27.29.31.34.36.37.40.41	1.6.7.9.10.15.27.29.31.33.35.37.40	7.27.29.31.37.40	
41	17.21.25.41	3.7.9.14.15.27.28.29.30.31.32.33.34.35.36.37.40.41	41	

Table 47. Iteration 6

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.2.3.4.5.7.12.17.20.23.29.33.34.36.36.40	1.2.3.8.15.18.27	1.2.3	
2	1.2.5.8.9.10.12.18.20.23.28.34.36	1.2.6.7.31.32	1.2	
3	1.3.4.7.8.9.12.14.15.17.20.23.25.26.29.31.32.33.34.35.36.37.41	1.3.21.27.35.36.37.40	3.35.36.37	
4	4.17.20	1.3.4.5.6.7.8.9.10.15.20.22.23.26.27.29.30.31.33.36.37.40	4.20.	6
5	4.5.12.18.20	1.2.5.6.7.8.9.10.15.23.28.30.31.32.34.37.40	5	
6	2.4.5.6.8.18.20.28.31.34.36.40	6.15.26.31.36.37	6.31.36	
7	2.4.5.7.8.9.10.12.18.20.23.27.29.34.36.40.41	1.3.7.14.25.31.36.37.40	7.36.40	
8	1.4.5.8.14.15.20.25.26	2.3.6.7.8.9.10.14.15.17.20.23.26.27.28.29.32.33.35.36.37.40	8.14.15.20.26	
9	4.5.8.9.10.12.17.18.20.23.25.27.29.34.36.40.41	2.3.7.9.10.14.15.18.31.33.35.37	9.10.18	
10	4.5.8.9.10.20.29.36.40	2.7.9.10.12.23.31.36	9.10.36	
12	10.12.17.20	1.2.3.5.7.12.14.20.27.29.31.34.36.37	12.2	
14	7.8.9.12.14.20.23.27.31.36.37.41	3.8.14.15.36.37	8.14.36.37	
15	1.4.5.6.8.9.14.15.17.20.23.27.28.32.33.34.37.40.41	3.8.15.30.31.33.36.37	8.9.15.37	
17	8.17.23.25.26.27.29.33.34	1.3.4.9.12.15.17.20.23.26.27.29.31.33.34.40.41	17.23.26.27.29.33.34	
18	1.9.18.20	2.5.6.7.9.18.20.28.31.35	9.18.20	6
20	4.8.12.17.18.20.23	1.2.3.4.5.6.7.8.9.10.12.14.15.18.20.20.23.26.27.28.29.30.31.32.33.37.40	4.8.12.18.20.23	6
23	4.5.8.10.17.20.23.26.34	1.2.3.7.9.14.15.17.20.23.27.28.31.32.33.35.36.37.40	17.20.23	
25	7.22.25	3.8.9.17.25.27.28.29.31.32.33.36.37.40.41	25	
26	4.6.8.17.20.25.26	3.8.17.23.26.36.37	8.17.26	
27	1.3.4.8.12.17.20.23.25.27.34.35.37.40.41	7.15.27.28.32.36.37	27.37	
28	5.8.18.20.23.25.28.33.34.41	2.6.15.28.32.36.37	28	
29	4.8.12.15.17.20.25.27.29.33.34.35.40.41	1.3.7.9.10.17.29.30.31.36.37.40	17.29.40	
30	4.5.15.20.29.30.32.33.41	30.36	30	
31	2.4.5.6.7.9.10.12.15.17.20.23.25.27.29.31.32.33.34.36.40.41	3.6.14.31.33.36.37.40	6.31.33.36.40	
32	2.5.8.18.20.23.25.27.28.32.33.34.41	3.15.30.31.32.36.37	32	
33	4.8.9.15.17.20.23.25.27.31.33.34.36.40.41	1.3.15.17.28.29.30.31.32.33.35.36.37	15.17.31.33.36	
34	5.12.17.27.34.41	1.2.3.6.7.9.15.17.23.27.28.29.31.32.33.34.35.36.37.40	17.27.34	
35	3.8.9.23.27.33.34.35.36.37.40.41	3.19.27.29.35.36.37	3.27.35.36	
36	3.4.6.7.8.10.12.14.15.18.23.25.26.27.28.29.30.31.32.33.34.35.36.41	1.2.3.6.7.9.10.14.31.33.35.36.37.40	3.6.7.10.14.31.33.35.36	
37	3.4.5.7.8.9.12.14.15.20.23.25.26.27.28.29.31.32.33.34.35.36.37.40.41	3.14.15.27.35.37.40	3.14.15.27.35.37.40	
40	3.4.5.7.8.17.20.23.25.27.29.31.34.36.37.40.41	1.6.7.9.10.15.27.29.31.33.35.37.40	7.27.29.31.37.40	
41	17.21.25.41	3.7.9.14.15.27.28.29.30.31.32.33.34.35.36.37.40.41	41	

Table 48. Iteration 7

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.2.3.5.7.12.17.23.29.33.34.36.36.40	1.2.3.8.15.27	1.2.3	
2	1.2.5.8.9.10.12.23.28.34.36	1.2.6.7.31.32	1.2	
3	1.3.7.8.9.12.14.15.17.23.25.26.29.31.32.33.34.35.36.37.41	1.3.21.27.35.36.37.40	3.35.36.37	
5	4.5.12.	1.2.5.6.7.8.9.10.15.23.28.30.31.32.34.37.40	5	
6	2.5.6.8.28.31.34.36.40	6.15.26.31.36.37	6.31.36	
7	2.5.7.8.9.10.12.23.27.29.34.36.40.41	1.3.7.14.25.31.36.37.40	7.36.40	
8	1.5.8.14.15.25.26	2.3.6.7.8.9.10.14.15.17.23.26.27.28.29.32.33.35.36.37.40	8.14.15.26	
9	5.8.9.10.12.17.23.25.27.29.34.36.40.41	2.3.7.9.10.14.15.31.33.35.37	9.10.	
10	5.8.9.10.29.36.40	2.7.9.10.12.23.31.36	9.10.36	
12	10.12.17	1.2.3.5.7.12.14.27.29.31.34.36.37	12	
14	7.8.9.12.14.23.27.31.36.37.41	3.8.14.15.36.37	8.14.36.37	
15	1.5.6.8.9.14.15.17.23.27.28.32.33.34.37.40.41	3.8.15.30.31.33.36.37	8.9.15.37	
17	8.17.23.25.26.27.29.33.34	1.3.9.12.15.17.23.26.27.29.31.33.34.40.41	17.23.26.27.29.33.34	
23	5.8.10.17.23.26.34	1.2.3.7.9.14.15.17.23.27.28.31.32.33.35.36.37.40	17.23	
25	7.25	3.8.9.17.25.27.28.29.31.32.33.36.37.40.41	25	7
26	6.8.17.25.26	3.8.17.23.26.36.37	8.17.26	
27	1.3.8.12.17.23.25.27.34.35.37.40.41	7.15.27.28.32.36.37	27.37	
28	5.8.23.25.28.33.34.41	2.6.15.28.32.36.37	28	
29	8.12.15.17.25.27.29.33.34.35.40.41	1.3.7.9.10.17.29.30.31.36.37.40	17.29.40	
30	5.15.29.30.32.33.41	30.36	30	
31	2.5.6.7.9.10.12.15.17.23.25.27.29.31.32.33.34.36.40.41	3.6.14.31.33.36.37.40	6.31.33.36.40	
32	2.5.8.23.25.27.28.32.33.34.41	3.15.30.31.32.36.37	32	
33	8.9.15.17.23.25.27.31.33.34.36.40.41	1.3.15.17.28.29.30.31.32.33.35.36.37	15.17.31.33.36	
34	5.12.17.27.34.41	1.2.3.6.7.9.15.17.23.27.28.29.31.32.33.34.35.36.37.40	17.27.34	
35	3.8.9.23.27.33.34.35.36.37.40.41	3.19.27.29.35.36.37	3.27.35.36	
36	3.6.7.8.10.12.14.15.23.25.26.27.28.29.30.31.32.33.34.35.36.41	1.2.3.6.7.9.10.14.31.33.35.36.37.40	3.6.7.10.14.31.33.35.36	
37	3.5.7.8.9.12.14.15.23.25.26.27.28.29.31.32.33.34.35.36.37.40.41	3.14.15.27.35.37.40	3.14.15.27.35.37.40	
40	3.5.7.8.17.23.25.27.29.31.34.36.37.40.41	1.6.7.9.10.15.27.29.31.33.35.37.40	7.27.29.31.37.40	
41	17.21.25.41	3.7.9.14.15.27.28.29.30.31.32.33.34.35.36.37.40.41	41	

Table 49. Iteration 8

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.2.3.5.7.12.17.23.29.33.34.36.36.40	1.2.3.8.15.27	1.2.3	
2	1.2.5.8.9.10.12.23.28.34.36	1.2.6.7.31.32	1.2	
3	1.3.7.8.9.12.14.15.17.23.26.29.31.32.33.34.35.36.37.41	1.3.21.27.35.36.37.40	3.35.36.37	
5	4.5.12.	1.2.5.6.7.8.9.10.15.23.28.30.31.32.34.37.40	5	
6	2.5.6.8.28.31.34.36.40	6.15.26.31.36.37	6.31.36	
7	2.5.7.8.9.10.12.23.27.29.34.36.40.41	1.3.7.14.31.36.37.40	7.36.40	
8	1.5.8.14.15.26	2.3.6.7.8.9.10.14.15.17.23.26.27.28.29.32.33.35.36.37.40	8.14.15.26	
9	5.8.9.10.12.17.23.27.29.34.36.40.41	2.3.7.9.10.14.15.31.33.35.37	9.10.	
10	5.8.9.10.29.36.40	2.7.9.10.12.23.31.36	9.10.36	
12	10.12.17	1.2.3.5.7.12.14.27.29.31.34.36.37	12	
14	7.8.9.12.14.23.27.31.36.37.41	3.8.14.15.36.37	8.14.36.37	
15	1.5.6.8.9.14.15.17.23.27.28.32.33.34.37.40.41	3.8.15.30.31.33.36.37	8.9.15.37	
17	8.17.23.26.27.29.33.34	1.3.9.12.15.17.23.26.27.29.31.33.34.40.41	17.23.26.27.29.33.34	8
23	5.8.10.17.23.26.34	1.2.3.7.9.14.15.17.23.27.28.31.32.33.35.36.37.40	17.23	
26	6.8.17.26	3.8.17.23.26.36.37	8.17.26	8
27	1.3.8.12.17.23.27.34.35.37.40.41	7.15.27.28.32.36.37	27.37	
28	5.8.23.28.33.34.41	2.6.15.28.32.36.37	28	
29	8.12.15.17.27.29.33.34.35.40.41	1.3.7.9.10.17.29.30.31.36.37.40	17.29.40	
30	5.15.29.30.32.33.41	30.36	30	
31	2.5.6.7.9.10.12.15.17.23.27.29.31.32.33.34.36.40.41	3.6.14.31.33.36.37.40	6.31.33.36.40	
32	2.5.8.23.27.28.32.33.34.41	3.15.30.31.32.36.37	32	
33	8.9.15.17.23.27.31.33.34.36.40.41	1.3.15.17.28.29.30.31.32.33.35.36.37	15.17.31.33.36	
34	5.12.17.27.34.41	1.2.3.6.7.9.15.17.23.27.28.29.31.32.33.34.35.36.37.40	17.27.34	
35	3.8.9.23.27.33.34.35.36.37.40.41	3.19.27.29.35.36.37	3.27.35.36	
36	3.6.7.8.10.12.14.15.23.26.27.28.29.30.31.32.33.34.35.36.41	1.2.3.6.7.9.10.14.31.33.35.36.37.40	3.6.7.10.14.31.33.35.36	
37	3.5.7.8.9.12.14.15.23.26.27.28.29.31.32.33.34.35.36.37.40.41	3.14.15.27.35.37.40	3.14.15.27.35.37.40	
40	3.5.7.8.17.23.27.29.31.34.36.37.40.41	1.6.7.9.10.15.27.29.31.33.35.37.40	7.27.29.31.37.40	
41	17.21.41	3.7.9.14.15.27.28.29.30.31.32.33.34.35.36.37.40.41	41	

Table 50. Iteration 9

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.2.3.5.7.12.23.29.33.34.36.36.40	1.2.3.8.15.27	1.2.3	
2	1.2.5.8.9.10.12.23.28.34.36	1.2.6.7.31.32	1.2	
3	1.3.7.8.9.12.14.15.23.29.31.32.33.34.35.36.37.41	1.3.21.27.35.36.37.40	3.35.36.37	
5	4.5.12.	1.2.5.6.7.8.9.10.15.23.28.30.31.32.34.37.40	5	
6	2.5.6.8.28.31.34.36.40	6.15.26.31.36.37	6.31.36	
7	2.5.7.8.9.10.12.23.27.29.34.36.40.41	1.3.7.14.31.36.37.40	7.36.40	
8	1.5.8.14.15	2.3.6.7.8.9.10.14.15.23.27.28.29.32.33.35.36.37.40	8.14.15	
9	5.8.9.10.12.23.27.29.34.36.40.41	2.3.7.9.10.14.15.31.33.35.37	9.10.	
10	5.8.9.10.29.36.40	2.7.9.10.12.23.31.36	9.10.36	
12	10.12	1.2.3.5.7.12.14.27.29.31.34.36.37	12	9
14	7.8.9.12.14.23.27.31.36.37.41	3.8.14.15.36.37	8.14.36.37	
15	1.5.6.8.9.14.15.23.27.28.32.33.34.37.40.41	3.8.15.30.31.33.36.37	8.9.15.37	
23	5.8.10.23.34	1.2.3.7.9.14.15.23.27.28.31.32.33.35.36.37.40	23	
27	1.3.8.12.23.27.34.35.37.40.41	7.15.27.28.32.36.37	27.37	
28	5.8.23.28.33.34.41	2.6.15.28.32.36.37	28	
29	8.12.15.27.29.33.34.35.40.41	1.3.7.9.10.29.30.31.36.37.40	17.29.40	
30	5.15.29.30.32.33.41	30.36	30	
31	2.5.6.7.9.10.12.15.23.27.29.31.32.33.34.36.40.41	3.6.14.31.33.36.37.40	6.31.33.36.40	
32	2.5.8.23.27.28.32.33.34.41	3.15.30.31.32.36.37	32	
33	8.9.15.23.27.31.33.34.36.40.41	1.3.15.28.29.30.31.32.33.35.36.37	15.31.33.36	
34	5.12.27.34.41	1.2.3.6.7.9.15.23.27.28.29.31.32.33.34.35.36.37.40	27.34	
35	3.8.9.23.27.33.34.35.36.37.40.41	3.19.27.29.35.36.37	3.27.35.36	
36	3.6.7.8.10.12.14.15.23.27.28.29.30.31.32.33.34.35.36.41	1.2.3.6.7.9.10.14.31.33.35.36.37.40	3.6.7.10.14.31.33.35.36	
37	3.5.7.8.9.12.14.15.23.27.28.29.31.32.33.34.35.36.37.40.41	3.14.15.27.35.37.40	3.14.15.27.35.37.40	
40	3.5.7.8.23.29.31.34.36.37.40.41	1.6.7.9.10.15.27.29.31.33.35.37.40	7.27.29.31.37.40	
41	21.41	3.7.9.14.15.27.28.29.30.31.32.33.34.35.36.37.40.41	41	9

Table 51. Iteration 10

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.2.3.5.7.23.29.33.34.36.36.40	1.2.3.8.15.27	1.2.3	
2	1.2.5.8.9.10.23.28.34.36	1.2.6.7.31.32	1.2	
3	1.3.7.8.9.14.15.23.29.31.32.33.34.35.36.37	1.3.21.27.35.36.37.40	3.35.36.37	
5	4.5	1.2.5.6.7.8.9.10.15.23.28.30.31.32.34.37.40	5	10
6	2.5.6.8.28.31.34.36.40	6.15.26.31.36.37	6.31.36	
7	2.5.7.8.9.10.23.27.29.34.36.40	1.3.7.14.31.36.37.40	7.36.40	
8	1.5.8.14.15	2.3.6.7.8.9.10.14.15.23.27.28.29.32.33.35.36.37.40	8.14.15	
9	5.8.9.10.23.27.29.34.36.40	2.3.7.9.10.14.15.31.33.35.37	9.10.	
10	5.8.9.10.29.36.40	2.7.9.10.23.31.36	9.10.36	
14	7.8.9.14.23.27.31.36.37	3.8.14.15.36.37	8.14.36.37	
15	1.5.6.8.9.14.15.23.27.28.32.33.34.37.40	3.8.15.30.31.33.36.37	8.9.15.37	
23	5.8.10.23.34	1.2.3.7.9.14.15.23.27.28.31.32.33.35.36.37.40	23	
27	1.3.8.23.27.34.35.37.40	7.15.27.28.32.36.37	27.37	
28	5.8.23.28.33.34	2.6.15.28.32.36.37	28	
29	8.15.27.29.33.34.35.40	1.3.7.9.10.29.30.31.36.37.40	29.4	
30	5.15.29.30.32.33	30.36	30	
31	2.5.6.7.9.10.15.23.27.29.31.32.33.34.36.40	3.6.14.31.33.36.37.40	6.31.33.36.40	
32	2.5.8.23.27.28.32.33.34	3.15.30.31.32.36.37	32	
33	8.9.15.23.27.31.33.34.36.40	1.3.15.28.29.30.31.32.33.35.36.37	15.31.33.36	
34	5.27.34	1.2.3.6.7.9.15.23.27.28.29.31.32.33.34.35.36.37.40	27.34	10
35	3.8.9.23.27.33.34.35.36.37.40	3.19.27.29.35.36.37	3.27.35.36	
36	3.6.7.8.1014.15.23.27.28.29.30.31.32.33.34.35.36	1.2.3.6.7.9.10.14.31.33.35.36.37.40	3.6.7.10.14.31.33.35.36	
37	3.5.7.8.9.14.15.23.27.28.29.31.32.33.34.35.36.37.40	3.14.15.27.35.37.40	3.14.15.27.35.37.40	
40	3.5.7.8.23.29.31.34.36.37.40	1.6.7.9.10.15.27.29.31.33.35.37.40	7.27.29.31.37.40	

Table 52. Iteration 11

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.2.3.7.23.29.33.36.36.40	1.2.3.8.15.27	1.2.3	
2	1.2.8.9.10.23.28.36	1.2.6.7.31.32	1.2	
3	1.3.7.8.9.14.15.23.29.31.32.33.35.36.37	1.3.21.27.35.36.37.40	3.35.36.37	
6	2.6.8.28.31.36.40	6.15.26.31.36.37	6.31.36	
7	2.7.8.9.10.23.27.29.36.40	1.3.7.14.31.36.37.40	7.36.40	
8	1.8.14.15	2.3.6.7.8.9.10.14.15.23.27.28.29.32.33.35.36.37.40	8.14.15	11
9	8.9.10.23.27.29.36.40	2.3.7.9.10.14.15.31.33.35.37	9.10.	
10	8.9.10.29.36.40	2.7.9.10.23.31.36	9.10.36	
14	7.8.9.14.23.27.31.36.37	3.8.14.15.36.37	8.14.36.37	
15	1.6.8.9.14.15.23.27.28.32.33.37.40	3.8.15.30.31.33.36.37	8.9.15.37	
23	8.10.23	1.2.3.7.9.14.15.23.27.28.31.32.33.35.36.37.40	23	
27	1.3.8.23.27.35.37.40	7.15.27.28.32.36.37	27.37	
28	8.23.28.33	2.6.15.28.32.36.37	28	
29	8.15.27.29.33.35.40	1.3.7.9.10.29.30.31.36.37.40	29.4	
30	15.29.30.32.33	30.36	30	
31	2.6.7.9.10.15.23.27.29.31.32.33.36.40	3.6.14.31.33.36.37.40	6.31.33.36.40	
32	2.8.23.27.28.32.33	3.15.30.31.32.36.37	32	
33	8.9.15.23.27.31.33.36.40	1.3.15.28.29.30.31.32.33.35.36.37	15.31.33.36	
35	3.8.9.23.27.33.35.36.37.40	3.19.27.29.35.36.37	3.27.35.36	
36	3.6.7.8.1014.15.23.27.28.29.30.31.32.33.35.36	1.2.3.6.7.9.10.14.31.33.35.36.37.40	3.6.7.10.14.31.33.35.36	
37	3.7.8.9.14.15.23.27.28.29.31.32.33.35.36.37.40	3.14.15.27.35.37.40	3.14.15.27.35.37.40	
40	3.7.8.23.29.31.36.37.40	1.6.7.9.10.15.27.29.31.33.35.37.40	7.27.29.31.37.40	

Table 53. Iteration 11

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.2.3.7.23.29.33.36.36.40	1.2.3.15.27	1.2.3	
2	1.2.9.10.23.28.36	1.2.6.7.31.32	1.2	
3	1.3.7.9.14.15.23.29.31.32.33.35.36.37	1.3.21.27.35.36.37.40	3.35.36.37	
6	2.6.28.31.36.40	6.15.26.31.36.37	6.31.36	
7	2.7.9.10.23.27.29.36.40	1.3.7.14.31.36.37.40	7.36.40	
9	9.10.23.27.29.36.40	2.3.7.9.10.14.15.31.33.35.37	9.10.	
10	9.10.29.36.40	2.7.9.10.23.31.36	9.10.36	
14	7.9.14.23.27.31.36.37	3.14.15.36.37	14.36.37	
15	1.6.9.14.15.23.27.28.32.33.37.40	3.15.30.31.33.36.37	9.15.37	
23	10.23	1.2.3.7.9.14.15.23.27.28.31.32.33.35.36.37.40	23	12
27	1.3.23.27.35.37.40	7.15.27.28.32.36.37	27.37	
28	23.28.33	2.6.15.28.32.36.37	28	
29	15.27.29.33.35.40	1.3.7.9.10.29.30.31.36.37.40	29.4	
30	15.29.30.32.33	30.36	30	
31	2.6.7.9.10.15.23.27.29.31.32.33.36.40	3.6.14.31.33.36.37.40	6.31.33.36.40	
32	2.23.27.28.32.33	3.15.30.31.32.36.37	32	
33	9.15.23.27.31.33.36.40	1.3.15.28.29.30.31.32.33.35.36.37	15.31.33.36	
35	3.9.23.27.33.35.36.37.40	3.19.27.29.35.36.37	3.27.35.36	
36	3.6.7.1014.15.23.27.28.29.30.31.32.33.35.36	1.2.3.6.7.9.10.14.31.33.35.36.37.40	3.6.7.10.14.31.33.35.36	
37	3.7.9.14.15.23.27.28.29.31.32.33.35.36.37.40	3.14.15.27.35.37.40	3.14.15.27.35.37.40	
40	3.7.23.29.31.36.37.40	1.6.7.9.10.15.27.29.31.33.35.37.40	7.27.29.31.37.40	

Table 54. Iteration 13

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.2.3.7.29.33.36.36.40	1.2.3.15.27	1.2.3	
2	1.2.9.10.28.36	1.2.6.7.31.32	1.2	
3	1.3.7.9.14.15.29.31.32.33.35.36.37	1.3.21.27.35.36.37.40	3.35.36.37	
6	2.6.28.31.36.40	6.15.26.31.36.37	6.31.36	
7	2.7.9.10.27.29.36.40	1.3.7.14.31.36.37.40	7.36.40	
9	9.10.27.29.36.40	2.3.7.9.10.14.15.31.33.35.37	9.10.	
10	9.10.29.36.40	2.7.9.10.23.31.36	9.10.36	
14	7.9.14.27.31.36.37	3.14.15.36.37	14.36.37	
15	1.6.9.14.15.27.28.32.33.37.40	3.15.30.31.33.36.37	9.15.37	
27	1.3.27.35.37.40	7.15.27.28.32.36.37	27.37	
28	28.33	2.6.15.28.32.36.37	28	13
29	15.27.29.33.35.40	1.3.7.9.10.29.30.31.36.37.40	29.4	
30	15.29.30.32.33	30.36	30	
31	2.6.7.9.10.15.27.29.31.32.33.36.40	3.6.14.31.33.36.37.40	6.31.33.36.40	
32	2.27.28.32.33	3.15.30.31.32.36.37	32	
33	9.15.27.31.33.36.40	1.3.15.28.29.30.31.32.33.35.36.37	15.31.33.36	
35	3.9.27.33.35.36.37.40	3.19.27.29.35.36.37	3.27.35.36	
36	3.6.7.1014.15.27.28.29.30.31.32.33.35.36	1.2.3.6.7.9.10.14.31.33.35.36.37.40	3.6.7.10.14.31.33.35.36	
37	3.7.9.14.15.27.28.29.31.32.33.35.36.37.40	3.14.15.27.35.37.40	3.14.15.27.35.37.40	
40	3.7.29.31.36.37.40	1.6.7.9.10.15.27.29.31.33.35.37.40	7.27.29.31.37.40	13

Table 55. Iteration 14

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.2.3.7.29.33.36.36	1.2.3.15.27	1.2.3	
2	1.2.9.10.36	1.2.6.7.31.32	1.2	
3	1.3.7.9.14.15.29.31.32.33.35.36.37	1.3.21.27.35.36.37	3.35.36.37	
6	2.6.31.36	6.15.26.31.36.37	6.31.36	14
7	2.7.9.10.27.29.36	1.3.7.14.31.36.37	7.36	
9	9.10.27.29.36	2.3.7.9.10.14.15.31.33.35.37	9.10.	
10	9.10.29.36	2.7.9.10.23.31.36	9.10.36	14
14	7.9.14.27.31.36.37	3.14.15.36.37	14.36.37	
15	1.6.9.14.15.27.32.33.37	3.15.30.31.33.36.37	9.15.37	
27	1.3.27.35.37	7.15.27.32.36.37	27.37	
29	15.27.29.33.35	1.3.7.9.10.29.30.31.36.37	29	
30	15.29.30.32.33	30.36	30	
31	2.6.7.9.10.15.27.29.31.32.33.36	3.6.14.31.33.36.37	6.31.33.36	
32	2.27.32.33	3.15.30.31.32.36.37	32	
33	9.15.27.31.33.36	1.3.15.29.30.31.32.33.35.36.37	15.31.33.36	
35	3.9.27.33.35.36.37	3.19.27.29.35.36.37	3.27.35.36	
36	3.6.7.10.14.15.27.29.30.31.32.33.35.36	1.2.3.6.7.9.10.14.31.33.35.36.37	3.6.7.10.14.31.33.35.36	
37	3.7.9.14.15.27.29.31.32.33.35.36.37	3.14.15.27.35.37	3.14.15.27.35.37	

Table 56. Iteration 15

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.2.3.7.29.33.36.36	1.2.3.15.27	1.2.3	
2	1.2.9.36	1.2.7.31.32	1.2	15
3	1.3.7.9.14.15.29.31.32.33.35.36.37	1.3.21.27.35.36.37	3.35.36.37	
7	2.7.9.10.27.29.36	1.3.7.14.31.36.37	7.36	
9	9.27.29.36	2.3.7.9.14.15.31.33.35.37	9	
14	7.9.14.27.31.36.37	3.14.15.36.37	14.36.37	
15	1.9.14.15.27.32.33.37	3.15.30.31.33.36.37	9.15.37	
27	1.3.27.35.37	7.15.27.32.36.37	27.37	
29	15.27.29.33.35	1.3.7.9.10.29.30.31.36.37	29	
30	15.29.30.32.33	30.36	30	
31	2.7.9.15.27.29.31.32.33.36	3.14.31.33.36.37	31.33.36	
32	2.27.32.33	3.15.30.31.32.36.37	32	
33	9.15.27.31.33.36	1.3.15.29.30.31.32.33.35.36.37	15.31.33.36	15
35	3.9.27.33.35.36.37	3.19.27.29.35.36.37	3.27.35.36	
36	3.7.14.15.27.29.30.31.32.33.35.36	1.2.3.7.9.14.31.33.35.36.37	3.7.14.31.33.35.36	
37	3.7.9.14.15.27.29.31.32.33.35.36.37	3.14.15.27.35.37	3.14.15.27.35.37	

Table 57. Iteration 16

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.3.7.29.36.36	1.3.15.27	1.3	
3	1.3.7.9.14.15.29.31.32.35.36.37	1.3.21.27.35.36.37	3.35.36.37	
7	7.9.10.27.29.36	1.3.7.14.31.36.37	7.36	
9	9.27.29.36	3.7.9.14.15.31.35.37	9	
14	7.9.14.27.31.36.37	3.14.15.36.37	14.36.37	
15	1.9.14.15.27.32.37	3.15.30.31.36.37	9.15.37	
27	1.3.27.35.37	7.15.27.32.36.37	27.37	
29	15.27.29.35	1.3.7.9.10.29.30.31.36.37	29	
30	15.29.30.32	30.36	30	
31	7.9.15.27.29.31.32.36	3.14.31.33.36.37	31.36	
32	27.32	3.15.30.31.32.36.37	32	16
35	3.9.27.35.36.37	3.19.27.29.35.36.37	3.27.35.36	
36	3.7.14.15.27.29.30.31.32.35.36	1.2.3.7.9.14.31.35.36.37	3.7.14.31.35.36	
37	3.7.9.14.15.27.29.31.32.35.36.37	3.14.15.27.35.37	3.14.15.27.35.37	

Table 58. Iteration 17

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.3.7.29.36.36	1.3.15.27	1.3	
3	1.3.7.9.14.15.29.31.35.36.37	1.3.21.27.35.36.37	3.35.36.37	
7	7.9.10.27.29.36	1.3.7.14.31.36.37	7.36	
9	9.27.29.36	3.7.9.14.15.31.35.37	9	
14	7.9.14.27.31.36.37	3.14.15.36.37	14.36.37	
15	1.9.14.15.27.37	3.15.30.31.36.37	9.15.37	
27	1.3.27.35.37	7.15.27.36.37	27.37	
29	15.27.29.35	1.3.7.9.10.29.30.31.36.37	29	
30	15.29.30	30.36	30	17
31	7.9.15.27.29.31.36	3.14.31.33.36.37	31.36	
35	3.9.27.35.36.37	3.19.27.29.35.36.37	3.27.35.36	
36	3.7.14.15.27.29.30.31.35.36	1.2.3.7.9.14.31.35.36.37	3.7.14.31.35.36	
37	3.7.9.14.15.27.29.31.35.36.37	3.14.15.27.35.37	3.14.15.27.35.37	

Table 59. Iteration 18

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.3.7.29.36.36	1.3.15.27	1.3	
3	1.3.7.9.14.15.29.31.35.36.37	1.3.21.27.35.36.37	3.35.36.37	
7	7.9.10.27.29.36	1.3.7.14.31.36.37	7.36	
9	9.27.29.36	3.7.9.14.15.31.35.37	9	
14	7.9.14.27.31.36.37	3.14.15.36.37	14.36.37	
15	1.9.14.15.27.37	3.15.30.31.36.37	9.15.37	
27	1.3.27.35.37	7.15.27.36.37	27.37	
29	15.27.29.35	1.3.7.9.10.29.30.31.36.37	29	
31	7.9.15.27.29.31.36	3.14.31.33.36.37	31.36	
35	3.9.27.35.36.37	3.19.27.29.35.36.37	3.27.35.36	18
36	3.7.14.15.27.29.31.35.36	1.2.3.7.9.14.31.35.36.37	3.7.14.31.35.36	
37	3.7.9.14.15.27.29.31.35.36.37	3.14.15.27.35.37	3.14.15.27.35.37	

Table 60. Iteration 19

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.3.7.29.36.36	1.3.15.27	1.3	
3	1.3.7.9.14.15.29.31.36.37	1.3.21.27.36.37	3.36.37	
7	7.9.10.27.29.36	1.3.7.14.31.36.37	7.36	
9	9.27.29.36	3.7.9.14.15.31.35.37	9	
14	7.9.14.27.31.36.37	3.14.15.36.37	14.36.37	
15	1.9.14.15.27.37	3.15.30.31.36.37	9.15.37	
27	1.3.27.37	7.15.27.36.37	27.37	19
29	15.27.29	1.3.7.9.10.29.30.31.36.37	29	19
31	7.9.15.27.29.31.36	3.14.31.33.36.37	31.36	
36	3.7.14.15.27.29.31.36	1.2.3.7.9.14.31.36.37	3.7.14.31.36	
37	3.7.9.14.15.27.29.31.36.37	3.14.15.27.37	3.14.15.27.37	

Table 61. Iteration 20

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.3.7.36.36	1.3.15	1.3	
3	1.3.7.9.14.15.29.31.36.37	1.3.21.36.37	3.36.37	
7	7.9.10.36	1.3.7.14.31.36.37	7.36	
9	9.27.36	3.7.9.14.15.31.35.37	9	
14	7.9.14.31.36.37	3.14.15.36.37	14.36.37	
15	1.9.14.15.37	3.15.30.31.36.37	9.15.37	
31	7.9.15.31.36	3.14.31.33.36.37	31.36	
36	3.7.14.15.31.36	1.2.3.7.9.14.31.36.37	3.7.14.31.36	20
37	3.7.9.14.15.31.36.37	3.14.15.37	3.14.15.37	

Table 62. Iteration 21

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.3.7.36	1.3.15	1.3	
3	1.3.7.9.14.15.29.31.37	1.3.21.37	3..37	
7	7.9.10	1.3.7.14.31.37	7	
9	9	3.7.9.14.15.31.35.37	9	21
14	7.9.14.31.37	3.14.15.37	14.37	
15	1.9.14.15.37	3.15.30.31.37	9.15.37	
31	7.9.15.31	3.14.31.33.37	31	
37	3.7.9.14.15.31.37	3.14.15.37	3.14.15.37	

Table 63. Iteration 22

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.3.7.36	1.3.15	1.3	
3	1.3.714.15.29.31.37	1.3.21.37	3..37	
7	7.1	1.3.7.14.31.37	7	22
14	7.14.31.37	3.14.15.37	14.37	
15	1.14.15.37	3.15.30.31.37	15.37	
31	7.15.31	3.14.31.33.37	31	
37	3.7.14.15.31.37	3.14.15.37	3.14.15.37	

Table 64. Iteration 23

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1.3.36	1.3.15	1.3	23
3	1.3.14.15.29.31.37	1.3.21.37	3..37	
14	14.31.37	3.14.15.37	14.37	23
15	1.14.15.37	3.15.30.31.37	15.37	
31	15.31	3.14.31.33.37	31	23
37	3.14.15.31.37	3.14.15.37	3.14.15.37	23

Table 65. Iteration 24

	Reachability Set	Antecedent Set	Intersection Set	Level
3	3.15.	3	3	
15	15	3.15	15	24

Table 66. Iteration 25

	Reachability Set	Antecedent Set	Intersection Set	Level
3	3	3	3	25

4.5.3 MICMAC Analysis

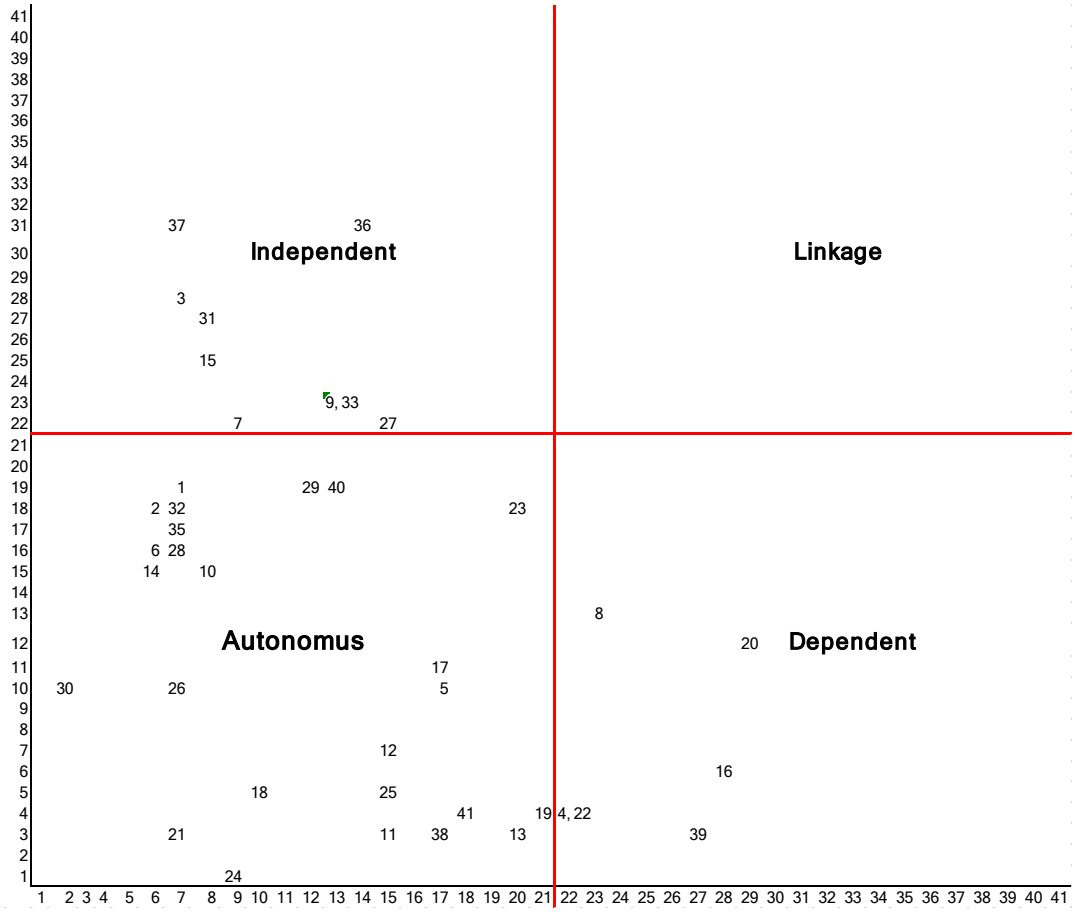


Figure 52. Intangible Benefits Clusters

The purpose of the MICMAC analysis "is to analyze the driver power and dependency power of each element" (Mandal and Deshmukh 1994, Iyer and Sagheer 2009, Talib, Rahman et al. 2011, Rajaprasad and Chalapathi 2015). In figure 52, we present four clusters. The first cluster is "Autonomous variables" which had weak driving and dependence power. The second cluster is "dependent variables" which had weak driving power and strong dependence. The third cluster is "Linkage variable" and these variables have strong driving and dependence power. The fourth cluster is "independent" which had strong driving and dependence power (Kumar, Luthra et al. 2013, Rajaprasad and Chalapathi 2015).

The ISM model and the MICMAC analysis have illustrate the interrelationship between the intangibles. The results of MICMAC analysis show that all the intangibles fall in the three clusters. Among 41 intangibles, 28 are "Autonomous", 6 are considered "dependent", and 9 are "independent". None of the intangibles were considered "Linkage" variables. 9 out of 41 intangibles have strong driving power, whereas 29 have weak driving and weak dependence powers.

CHAPTER 5: CONCLUSION & DISCUSSION

5.1 Introduction

The dissertation focused on the effects of Building Information Modeling on design and construction industry. It highlighted the major aspects that create the difference between BIM and the traditional methods. The dissertation is divided into two major parts; the first part is the general survey questionnaire, and the second part is experts' interviews. In this study, we have covered all the aspects that related to BIM. In the general survey, we have targeted the AEC professionals, Engineers, Architects, Contractors, and Owners. The need for research that covers all BIM issues is essential as most of the studies conducted on this area were based on case studies. The general survey was designed to understand BIM situations in AEC industry, and to test its effects on real life projects. To get a better image about BIM, we targeted all parties based on the market hierarchy.

The survey conducted the participants from the general understanding of BIM to broad detail in specific aspects. The survey consisted on 29 questions; based on multiple choices, open ended, ranking and Likert questions. Questions covered the following areas: BIM definitions, concerns, benefits, ROI, data sharing, software, motivations, success measures, investment needed, common metrics, BIM uses, and common metrics. The participants represented all market levels based on: role, experience, level of implementations, specialties, sectors, and the market level.

For the second part of the research, we have designed a structured interview that targeted all AEC parties. The interviews were considered as "subject matter interviews" and the chosen participants were BIM leaders in their organization and the whole BIM community. The interviews covered two major parts; BIM uses and Intangible benefits, being both parts derived from the general survey. The aim of this second part is to determine the effect of BIM uses on real life project, and to determine how the intangible benefits were valuable for the BIM users.

5.2 Research Strength

The dissertation tackled BIM issues in the AEC industry. The research methodology was distinct from the research conducted in the same area. The strength of this research include:

- General survey: the general survey was comprehensive, and the data collected originated form industry's professionals from many countries. The survey put the spot light into new research areas such as BIM uses and the intangible benefits. It demonstrates the whole picture of BIM on AEC market, taking into consideration the company's market situation.
- Participants: The survey targeted BIM mangers and coordinators to ensure the quality and the validity of the responses. Participants represented all levels of AEC market.
- Interviews: in the interviews we have discussed the effect of BIM uses and the intangible benefits. The questions covered the effect of BIM uses based

on: project's ROI, challenges, technical perspectives, effect during project progress, and needed features. In addition, we discovered the measurable intangibles, how BIM professional used to measure these benefits, and how they turn to be monetary benefits. Moreover, we have compared the coordination and collaboration process with old methods, and how BIM changed these processes during the project progress. These issues have not been raised in previous studies.

- Analysis: the general survey analysis is to find the relationship between the independent and outcome variables. Chi-square was used to test the significance between the variable since they are categorical. Statistical results show significance relationship between several variables. For the interviews, two methods were used: The interviews' transcripts were summarized by answers, and categorized by the role of the participant in the market. For the intangible part, we conducted an Interpretive Structural Modeling (ISM) to analyze the relationship between the intangibles. This kind of analysis has never been conducted in this area. The ISM model discovered how one intangible could achieve or alleviate the others. The ISM analysis can illustrate the dependency and the driving power of each intangible. Moreover, it categorizes the intangibles into four clusters based on the dependency and the driving power of each. The different views about BIM intangible, makes it essential to conduct a complex analysis such as ISM.

5.3 Major Findings

This research was divided into two parts. The following sections will discuss the major findings observed in each part.

5.3.1 General Survey

- The descriptive analysis showed that BIM professional in all different roles have experienced a positive ROI in the BIM project. The majority of survey participants have not used any method to calculate the ROI based on real project data.
- The use of BIM is varied, and the statistics showed that big companies are taking advantages of BIM uses and feature.
- Coordination tools are the strongest motivating aspect for AEC professionals to adopt BIM.
- The direct and the indirect cost are still considered as the main concern when adopting BIM.
- Companies show the needs for training as requirement for the adoption of BIM.
- Better communication, better coordination are the main objectives when establishing BIM project.
- The majority of AEC agrees that IPD is the best delivery method for BIM projects.

- 54.62% of the participants indicated that they are using Autodesk Revit as BIM software solution.
- 90.68% of the participants' consider BIM as a source for generating business.
- 91.52% indicates that BIM has a positive ROI, and the majority of respondents never calculate the project ROI.
- Change orders and the number of the RFIs is the major indication of the project's ROI.
- The value of prevented clashes is considered as the most valued benefit of BIM.
- Finishing on time is the most important factor for measuring the project's success.
- The 26 uses stated in the survey were chosen from the participants with different percentages. Built model was the most selected use, with 65.81%, and LEED certification was the least, with 10.26%.

5.3.2 Experts Interviews

- BIM uses contribute in the project ROI by avoiding costs after the detection of problems. Sub-contractors expect 5 to 7% of savings.
- BIM software solutions have significantly increased the design employers' productivity.
- BIM helps the contractors to improve the coordination process with design and construction.

- The model integration will help the owner to detect potential problems.
- The main challenge for BIM users is adoption, getting the company or the team to understand the benefits of BIM.
- Coordinating MEP trades with structure and architectural features is much more accurate and quicker with BIM.
- Interviews have identified several measurable intangibles. Reducing change order can measured by the quality of the work, and the reduction of duplicated work can be measured by eliminated value engineering and number of redesign.
- Increasing the understanding of the project can be measured by expediting the project execution and will reduce the errors.
- Data usage of components can be measured through model management.
- Better visualization of the project contributes in the project success.
- Intangibles equal up to better understanding of the overall project from design to construction.
- Increased employee engagement means better project, and money saving.
- Compared to old 2D style coordination, BIM coordination can be 100% accurate and many times faster.
- Interviewees have categorized the intangibles based on 9 metrics: BIM Management, Business, Cost, Schedule, quality, safety, Project delivery, procurement, and quality.
- The interviews showed that the participants have different views about the effect of these intangibles on the metrics.

- Sub-contractor and the Architects have agreed on seven intangibles categories among the 41. The Owner and the Architect have agreed on eleven intangibles, the Engineer and the Owner have five common categories, while the Engineer and the Architect agreed on same categories for twelve intangibles.
- The ISM analysis showed that the vast majority of the intangibles (33 out of 41) are "Autonomous", showing weak driving power and weak dependency.

5.4 Research Contributions

This is the first study to tackle the effect of the intangibles in BIM projects. The study determined all the possible intangibles that generated from the use of BIM. These intangibles were filtered based on certain metrics, and the study proved that several of these intangibles are measurable. In addition, the study showed how BIM professionals from different roles have their own ways to measure the intangible benefits. Owners, Architects, and the contractors have seen the effects of the intangible on real life projects, and measurement derived from their experience. This step I was extremely significant because the majority of BIM users have misunderstanding in how to measure the benefits of BIM. BIM users always rely on the fact that change orders and number of RFIs are the only factors that represent the benefits. However, in the interviews we have discovered a different set of measurement associated with the benefits. The listed intangibles were categorized on

9 different categories, and the interrelationship between them have been determined based on ISM analysis.

Additionally, this study is the first to focus on the effect of BIM uses and features. It proved that there is a significance relationship between BIM uses and the companies' role, level of implementation, duration of implementation, organizations'' experience, and organizations sector. Moreover, the study has tested the effect of BIM uses on the project success and ROI. It is also the first study to target all market levels, from micro scale to large scale companies. This step was essential to understand the whole picture of BIM in the AEC industry.

5.5 Implications on Saudi Construction Industry

The construction industry in Saudi Arabia is one of the biggest industries around the world. The main driver of this industry is the governmental project. Tens of billions of dollars have being spent in this market, and the outcomes raise many concerns in the cost, schedule, quality and other metrics. The construction industries are similar, and we can study the success of US industries implemented in Saudi industry. In US, BIM is dominating the AEC market, whereas in Saudi, BIM is still in early stages. Therefore, it is essential for the researcher to understand the whole picture of BIM, and pinpoint all aspects that contribute in its success as new method.

BIM adoption is one of the main challenges that the industry in Saudi Arabia faces. The lack of talented, experience BIM professionals makes the government hesitant to adopt BIM. This research has determined that the success of BIM is linked

to the level of knowledge among the users. The lack of knowledge might generate a new set of problems, more complex than the traditional ones. Additionally, this research illustrated that BIM is a package of tools, people, and contracts. Without the right set of contract, BIM will fail. We can conclude, that this research give us the information that will lead to better and successful implementation of BIM in Saudi Arabia.

5.6 Future Work

The research determined the effect of BIM on design and construction industry. Cases and interviews presented in this research show the side of BIM, and take it holistically. Future works can focus on the practical way when comparing between BIM and old method. The intangible benefits of BIM can be measured practically on real life projects. In the design side, future research could focus on the team work and the productivity of BIM compared to CAD. Two teams could work in identical design, and then the comparison will be clear in all aspects.

Every construction project is a unique case, therefore, future research should work in specific aspect in the field of construction. One of the possible future work, is measuring the productivity of the site workers when they use the digital model instead of printed drawings. The historical information about productivity is available in each company, therefore the comparison can be done. In addition, studying the effect of the new construction technology is a must. Visual simulation, drone survey, laser scanning are all new technologies that need proven effect.

APPENDIX: IRB LETTER

University of Central Florida Institutional Review Board
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Telephone: 407-882-2012, 407-882-0889 or 407-823-2508
www.research.ucf.edu/compliance/irb.html

From: **UCF Institutional Review Board**
FWA00000351, Exp. 7/24/2019, IRB00001138
To: **Yahya Alassaf CC: Dr. Amr A. Oloufa**
Date: **November 3rd, 2016**
Study Title: The Effect of Building Information Modeling on Design and Construction Industry

Thank you for contacting the IRB office regarding your Dissertation Project, as requested by Nathalia Bauer, Assistant Director of Communications, Thesis and Dissertation/Pathways to Success, and UCF College of Graduate Studies.

As you know, the IRB cannot provide an official determination letter for your research because it was not submitted into our iRIS electronic submission system prior to you completing the research.

However, if you had completed an iRIS submission, the IRB could make one of the following research determinations: "Not Human Subjects' Research," "Exempt," "Expedited" or "Full Board."

Based on the explanation provided by your Faculty Advisor, Dr. Amr A. Oloufa, the IRB determination most likely would have been Exempt.

If you have questions, please phone the IRB office at 407-882-2012.

Sincerely,

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cc: IRB file, Faculty Advisor

LIST OF REFERENCES

Affairs, M. P. A. M.-C. P. A. E. (2015). "Buidling Information Modeling For Vertical and Horizontal Costruction: Appendix A - MPA BIM Guidlines." 61.

Affairs, M. P. A. M. C. P. A. E. (2015). "Building Information Modeling for Vertical and Horizontal Contruction: Guidelines for Vertical and Horizontal Construction." 61.

Aibinu, A. and S. Venkatesh (2014). "Status of BIM Adoption and the BIM Experience of Cost Consultants in Australia." Journal of Professional Issues in Engineering Education and Practice **140**(3): 04013021.

Aranda-Mena, G., et al. (2009). "Building information modelling demystified: does it make business sense to adopt BIM?" International Journal of Managing Projects in Business **2**(3): 419-434.

AutoDesk (2015). "Building Information Modeling- What is BIM ".

Barlish, K. and K. Sullivan (2012). "How to measure the benefits of BIM — A case study approach." Automation in Construction **24**: 149-159.

Becerik-Gerber, B. and S. Rice (2010). "The perceived value of building information modeling in the US building industry." Journal of information technology in Construction **15**(2): 185-201.

BIMForum (2015). Level of Development Specification, BIM Forum, NISD, and BIM-M. **1:** 195.

Bryde, D., et al. (2013). "The project benefits of Building Information Modelling (BIM)." International Journal of Project Management **31**: 971-980.

BSI (2012). "roadmap (2012 update)." 2016, from www. bsigroup.com/en/sectorsandservices/Forms/BIM-reports/Confirmation-page-BIM-reports/ >.

Bureau, U. C. (2015). "Total Construction Spending." US Census Bureau, . Retrieved Mar 19, 2015, 2015, from https://www.census.gov/construction/c30/c30index.html.

Bynum, P., et al. (2013). "Building Information Modeling in Support of Sustainable Design and Construction." Journal of Construction Engineering & Management **139**(1): 24-34.

Chelson, D. E. (2010). The Effect of Building Information Modeling on Construction Site Productivity. Civil & Environmental Engineering, University of Maryland. **PhD:** 325.

CIFE (2013). "Key performance indicators." VDC and BIM Scorecard. 2015, from https://vdcscorecard.stanford.edu/content/key-performance-indicators.

Construction, M.-H. (2012). "The business value of BIM in North America: Multi-year trend analysis and user ratings (2007-2012)." Bedford, MA: McGraw-Hill Construction.

Construction, M. H. (2009). "The Business Value of BIM: Getting Building Information Modeling to the bottom line " Smart MarketReport.

Construction, M. H. (2013). "Building Information Modeling (BIM); Transforming Design and Construction to Achieve Greater Industry Productivity ".

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.

Crotty, R. (2013). The impact of building information modelling: transforming construction, Routledge.

Crouch, M. and H. McKenzie (2006). "The logic of small samples in interview-based qualitative research." Social Science Information **45**(4): 483-499.

D'Agostino, B., et al. (2007). "FMI/CMAA Eighth Annual Survey of Owners: The Perfect Storm–Construction Style." FMI/CMAA.

DuBois, D. and V. L. Shalin (2000). "Describing job expertise using cognitively oriented task analyses (COTA)." Cognitive task analysis: 41-56.

Eastman, C., et al. (2011). BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors, Wiley.

Eastman, C. M. (1992). "Modeling of buildings: evolution and concepts." Automation in Construction **1**(2): 99-109.

Finke, M. R. (1998). "A better way to estimate and mitigate disruption." Journal of Construction Engineering & Management **124**(6): 490.

Ford, B. (2011). "Overruns add millions to the cost of state road projects." New England National Centre for Investigative Reporting.

GCR and NIST (2004). "Cost analysis of inadequate interoperability in the US capital facilities industry." National Institute of Standards and Technology (NIST).

Giel, B. and R. R. A. Issa (2014). Framework for evaluating the BIM competencies of building owners. 2014 International Conference on Computing in Civil and Building Engineering, 23-25 June 2014, Reston, VA, USA, American Society of Civil Engineers.

Giel, B. K. and R. R. A. Issa (2013). "Return on Investment Analysis of Using Building Information Modeling in Construction." Journal of Computing in Civil Engineering **27**(5): 511-521.

Gilligan, B. and J. Kunz (2007). "VDC use in 2007: significant value, dramatic growth, and apparent business opportunity." Center for Integrated Facility Engineering, Report TR171.

Holness, G. V. R. (2006). "Building Information Modeling." ASHRAE Journal **48**(8): 38-46.

ISOStandard (2010). "Building Information Modeling — Information Delivery Manual — Part 1: Methodology and Format." ISO 29481-1:2010(E).

Iyer, K. and M. Sagheer (2009). "Hierarchical structuring of PPP risks using interpretative structural modeling." Journal of Construction Engineering and Management **136**(2): 151-159.

Jongeling, R. and T. Olofsson (2007). "A method for planning of work-flow by combined use of location-based scheduling and 4D CAD." Automation in Construction **16**(2): 189-198.

Kam, C., et al. (2013). "The VDC Scorecard: Formulation and Validation." Center for Integrated Facility Engineering: Stanford University.

Kam, C., et al. (2013). The VDC Scorecard: evaluation of AEC projects and industry trends, CIFE Working Paper.

Kaner, I., et al. (2008). Case studies of BIM adoption for precast concrete design by mid-sized structural engineering firms, ITcon.

Keller, T., et al. (2006). "Information visualizations for knowledge acquisition: The impact of dimensionality and color coding." Computers in Human Behavior **22**(1): 43-65.

Ketkar, S., et al. (2012). "Structural modeling and mapping of M-banking influencers in India." Journal of electronic commerce research **13**(1): 70.

Khanzode, A., et al. (2007). Challenges and benefits of implementing virtual design and construction technologies for coordination of mechanical, electrical, and plumbing systems on large healthcare project. Proceedings of CIB 24th W78 Conference.

Kumar, S., et al. (2013). "Customer involvement in greening the supply chain: an interpretive structural modeling methodology." Journal of Industrial Engineering International **9**(1): 1-13.

Kunz, J. and M. Fischer (2009). "Virtual design and construction: themes, case studies and implementation suggestions." Center for Integrated Facility Engineering (CIFE), Stanford University.

Linderoth, H. C. J. (2010). "Understanding adoption and use of BIM as the creation of actor networks." Automation in Construction **19**(1): 66-72.

Love, P. E., et al. (2011). "Design error reduction: toward the effective utilization of building information modeling." Research in Engineering Design **22**(3): 173-187.

Love, P. E. D., et al. (2014). "A benefits realization management building information modeling framework for asset owners." Automation in Construction **37**(0): 1-10.

Love, P. E. D., et al. (2013). "From justification to evaluation: Building information modeling for asset owners." Automation in Construction **35**(0): 208-216.

Lowe, R. H. and J. M. Muncey (2009). "ConsensusDOCS 301 BIM addendum." Constr. Law. **29**: 17.

Mandal, A. and S. Deshmukh (1994). "Vendor selection using interpretive structural modelling (ISM)." International Journal of Operations & Production Management **14**(6): 52-59.

Manning, R. and J. Messner (2008). Case studies in BIM implementation for programming of healthcare facilities, ITcon.

Massport (2015). BIM- Guideline for Virtical and Horizontal Construction- Appendix A MPA BIM Guideline

NBS (2014). "NBS National BIM Report ": 36.

Olofsson, T., et al. (2008). "Editorial-Case studies of BIM in use." IT in construction-Special Issue Case studies of BIM use **13**: 244-245.

Olofsson, T., et al. (2007). "Benefits and lessons learned of implementing building virtual design and construction (VDC) technologies for coordination of mechanical, electrical, and plumbing."

Oluwole Alfred, O. (2011). A preliminary review on the legal implications of BIM and model ownership, ITcon.

OmniClass (2015). "A Strategy for Classifying the Built Environment." 2016, from http://www.omniclass.org/about.asp.

Penttilä, H. (2006). Describing the changes in architectural information technology to understand design complexity and free-form architectural expression, ITcon.

Porwal, A. (2013). Construction waste management at source: a Building Information Modeling based system dynamic approach, University of British Columbia.

Porwal, A. and K. N. Hewage (2013). "Building Information Modeling (BIM) partnering framework for public construction projects." Automation in Construction **31**: 204-214.

Rajaprasad, S. V. S. and P. V. Chalapathi (2015). "Factors Influencing Implementation of OHSAS 18001 in Indian Construction Organizations: Interpretive Structural Modeling Approach." Safety and Health at Work **6**(3): 200-205.

Schwartzkopf, W. (2004). Calculating lost labor productivity in construction claims, Aspen Publishers Online.

Science, P. S. U.-E. C. o. (2016). "9.1 - Chi-Square Test of Independence." STAT 500. from https://onlinecourses.science.psu.edu/stat500/node/56.

SERAG, E. (2006). Change orders and productivity loss quantification using verifiable site data, University of Central Florida Orlando, Florida.

Shachak, A., et al. (2009). "Primary care physicians' use of an electronic medical record system: a cognitive task analysis." Journal of general internal medicine **24**(3): 341-348.

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

Succar, B., et al. (2012). "Measuring BIM performance: Five metrics." Architectural Engineering and Design Management **8**(2): 120-142.

Suermann, P. C. (2009). Evaluating the impact of building information modeling (BIM) on construction, University of Florida.

Suermann, P. C. and R. R. A. Issa (2009). "Evaluating industry perceptions of building information modeling (BIM) impact on construction." Electronic Journal of Information Technology in Construction **14**: 574-594.

Suremann, P. C. (2009). Evaluating the Impact of Buidling Information Modeling (BIM) on Construction University of Florida, University of Florida. **PhD**.

Talib, F., et al. (2011). "Analysis of interaction among the barriers to total quality management implementation using interpretive structural modeling approach." Benchmarking: An International Journal **18**(4): 563-587.

Teicholz, P., Goodrum, P., and Haas, C (2001). "U.S. Construction Labor Productivity Trends, 1970–1998." Journal of Construction Engineering and Management **127**(5): 427-429.

Volk, R., et al. (2014). "Building Information Modeling (BIM) for existing buildings — Literature review and future needs." Automation in Construction **38**(0): 109-127.

Waldron, B. (2011). Scope for improvement 2011—Project risk getting the right balance and outcomes.

Warfield, J. N. (1974). "Developing interconnection matrices in structural modeling." IEEE Transactions on Systems, Man, and Cybernetics(1): 81-87.

Woo, J., et al. (2010). Use of as-built building information modeling. Construction Research Congress.

Young, N., et al. (2009). "The Business Value of BIM-Getting Building Information Modeling to the Bottom Line." Bedford, MA: McGraw-Hill Construction.