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Current State of Practice Associated with the Use of Building Information Modeling (BIM) in the Custom Home Building Industry

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ABSTRACT

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Building Information Modeling (BIM) has entered the construction industry and has permeated the commercial sector. Research is continually performed to expand the capabilities and applications within the industry. However, research has historically been mostly limited to the commercial sector and has seen little expansion to other sectors of the industry including the residential sector. The potential cause for this may be the limited number of industry professionals who utilize the software to the benefit of their companies. The focus of this study was specifically the custom home building sector of residential construction in the United States because of the unique and potentially complex nature of each project.

The study was performed using a Delphi Panel, which utilizes a panel of experts to reach a consensus on a given subject. In this study, the goal was to reach a consensus on the most common uses challenges and benefits of BIM within the residential sector. In the first questionnaires, the experts were asked to identify, with a series of demographic questions including the number of employees in their company, the number of homes they build each year, and the average sale price of each home. Each expert's responses to the demographic questions were cross-referenced with the responses concerning uses, benefits, and challenges to provide other industry members wishing to implement with relatable demographic references to compare with their own company demographics. The experts then identified how they used BIM, what benefits they had seen, and any challenges they faced. The uses, benefits, and challenges identified in this questionnaire were ranked in the following questionnaire to identify the most common uses, greatest benefits, and greatest challenges.

The top uses identified by this expert panel were design and visualization, the creation of construction documents, and quantity take-offs. The most common benefits identified by this panel were client visualization, plan accuracy, improved client communication, and ease of plan revisions. The most common challenges identified by this panel were high software costs, the steep learning curve when training employees, and the time-consuming nature of creating and maintain models correctly.

Keywords: building information modeling [BIM], custom home building, residential construction, delphi

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1 INTRODUCTION

1.1 Background

As the construction industry has grown, the means of communicating the construction

documents, and any revisions to them, have changed (Rosenbloom, 2011 & Beveridge, 2012).

Technology and digital construction documents are at the forefront due to the sheer volume and

increasingly complex nature of construction projects (Eveland, 2016). With the introduction of

computer-aided design (CAD) in 1963 (Cadazz, 2004 & Mark, 2008), the ability to digitally

communicate and revise construction documents entered the industry. The technology has

improved and evolved to a three-dimensional Building Information Modeling (BIM).

Building Information Modeling (BIM) is "the process of creating and using digital models

for design, construction and/or operations of projects" (McGraw-Hill, 2009). It is also defined as

"a digital representation of physical and functional characteristics of a [building]" that provides a

"basis for decision making during its lifecycle…" (buildingSMARTalliance, 2015). These

models can be used to aid design, assess risks, identify constructability issues, etc. (Beveridge,

2012). This software has permeated the construction industry and multiple benefits have been

identified and used to the advantage of construction projects worldwide (McGraw-Hill, 2009).

The construction sector can be divided into five subsectors; commercial, highway, heavy

industrial, municipal utility, and residential.

The value of BIM has been noted by government entities like the United Kingdom, who mandated in 2011 that by 2016 all government-procured projects would utilize fully-collaborative BIM. In their 2016 report, most departments had met that mandate (The Infrastructure and Projects Authority, 2016). States like Tennessee, Ohio, and Wisconsin have also implemented BIM Standards (TNF&A, 2015 & Ohio DAS General Services Division, 2010 & WIDOA, 2009). Therefore, private commercial contractors, as well as governments, have recognized the value of BIM. Most commercial projects are unique in nature and BIM has become a key tool for managing each aspect of those unique projects. However, while the popularity of this software is increasing within the residential sector (Ford, 2016), it is not being utilized to the same degree.

1.2   Nature of the Problem

Residential construction represents approximately 40% of the construction value placed in December of 2016 (U. S. Census Bureau, 2016). With residential construction accounting for this much of the construction market in the United States, the use of BIM could provide immense benefits. While it is anticipated that all residential construction could benefit from BIM, the focus of this research was on the custom home sector. Like commercial construction, custom homes are unique and potentially just as complex as commercial construction. According to the NAHB, custom homes are defined as "one-of-a-kind, upscale creations that come with luxury upgrades and unique architectural design" (NAHB, 2017). Some government entities, while defining architectural fees, classify custom residential construction as complex and other residential construction as simple (New Mexico Administrative Code, 1.5.18.9 & ADECA, 2015). The reasons for the slow adoption rate of BIM are varied and range from unawareness (NAHB, 2014) to high software costs (Nellis, 2012 & Robinson, 2006). The software is,

however, steadily entering the market. In a 2014 study, the National Association of Home Builders (NAHB) found that 15% of members were familiar with BIM, with 27% of those familiar with BIM currently using it. An additional 47% of members were interested in using the software in the future (NAHB, 2014). In a similar study conducted by the NAHB in 2016, they found that those numbers had increased to 26% of members who were familiar with BIM and 47% of those who were familiar with BIM currently using it (NAHB, 2016). The proposed research is to identify experts within the industry who currently utilize BIM and further identify how it is being implemented and any benefits and/or challenges in their processes of implementation.

Due to the limited use of BIM in single-family residential construction there has been little research performed pertaining to its use. Thus, there are limited resources for contractors wishing to implement BIM. In order to establish the need for and significance of this research, the review of the literature will identify the definition, uses, benefits, and risks of BIM as they pertain to the construction industry. Because of the relatively widespread use of BIM within the commercial construction sector and the respective similarities between it and residential construction, commercial construction provided the basis of comparison for the purposes of this study. Potential benefits to residential construction were identified. The differences between commercial and residential construction were also identified.

1.3   Purpose of the Research

The purpose of this research was to identify current best practices, benefits, and challenges associated with the use of BIM in custom home building companies in the United States. This provides a basis of understanding for companies desiring to implement BIM. The research questions were as follows:

- What BIM software is being used?

- What is the best implementation process?

- What are the most common uses of BIM?

- What are the most common benefits of BIM?

- What are the most common challenges associated with BIM use?

2   REVIEW OF THE LITERATURE

2.1   Introduction

The literature available on the use of BIM in residential construction is limited due to its

relative adolescence in the single-family residential sector (Cambeiro, 2014). Literature specific

to custom home building is limited even further. This may be caused by the low adoption rate by

small to medium enterprises (Bhoir, 2015). A small to medium size enterprise is defined as a

company with less than 500 employees and according to the United States Census Bureau, in

2014 the number of construction companies with less than 500 employees was 653,598 while the

number of construction companies with more than 500 employees was 979 (U. S. Census

Bureau, 2014). This data includes all construction companies. According to the NAHB, in 2009

the average number of employees in single-family home builder companies was 7.5 (Quint,

2010). Some research has been performed to identify resources for small home-building

enterprises who would like to implement BIM. The study performed by Garcia and his associates

provides data on software and provides guidelines for effective adoption of BIM. These

guidelines include:

- External coaching during the initial adoption

- Creating BIM expertise either through training or hiring

- Retention and motivation of BIM experts through increased levels of autonomy, task sharing among disciplines (architectural, structural, MEP), shared goals, and public recognition for good performance

- Participation in BIM knowledge sharing networks

The research performed by Garcia and his associates also states that BIM impacts residential companies through increased productivity, profitability, and competitive advantage, however, does not extend to actual practices within the industry (Garcia, 2016).

The Manrique study was performed with the perspective of how the use of BIM in the home design phase effects the creation of accurate shop drawings that in turn aids in the pre-fabrication of residential construction components as an offsite construction method (Manrique, 2015).

2.2   Definition of BIM

According to the National BIM Standard, BIM represents three distinct but related functions. It is a business process, a digital representation, and organization and control. The business process includes generating and leveraging the building data to design, construct and operate the building throughout its lifecycle. The digital representation provides the physical and functional characteristics that form a reliable basis for decision making throughout the lifecycle. Organization and control utilizes the digital prototype to benefit the sharing of information pertaining to many aspects of the buildings life including efficient design, site control, project documentation, etc. (buildingSMARTalliance, 2015).

BIM has also been defined by multiple studies (Eastman, 2008 & McGraw-Hill, 2009 & Woo, 2010 & Succar, 2009). McGraw Hill (2009), for example, defines BIM as "the process of

creating and using digital models for design, construction and/or operations of projects." For this

research, the study performed by Zuppa best defined BIM as "a tool for visualizing and

coordinating AEC work and avoiding errors and omissions and improving the productivity,

schedule, safety, cost, and quality of construction projects" (Zuppa, 2009).

2.3   Uses of BIM

As described by the National BIM Standard, BIM is a function that aids decision making

and building operation throughout the building lifecycle. This is generally divided into three

timeframes; pre-construction, during construction, and post-construction or operation

(buildingSMARTalliance, 2015). Similarly, in 2011, the Computer Integrated Construction

(CIC) Research program compiled a list of 25 uses of BIM through a series of interviews with

industry experts, analysis of implementation, and a review of the literature. The CIC research

also compiled descriptions of each use. They grouped each use in the following 4 phases:

- Plan

- Design

- Construct

- Operate

Some uses, however, have some carryover through multiple phases of construction as

indicated by the following diagram from the CIC website.
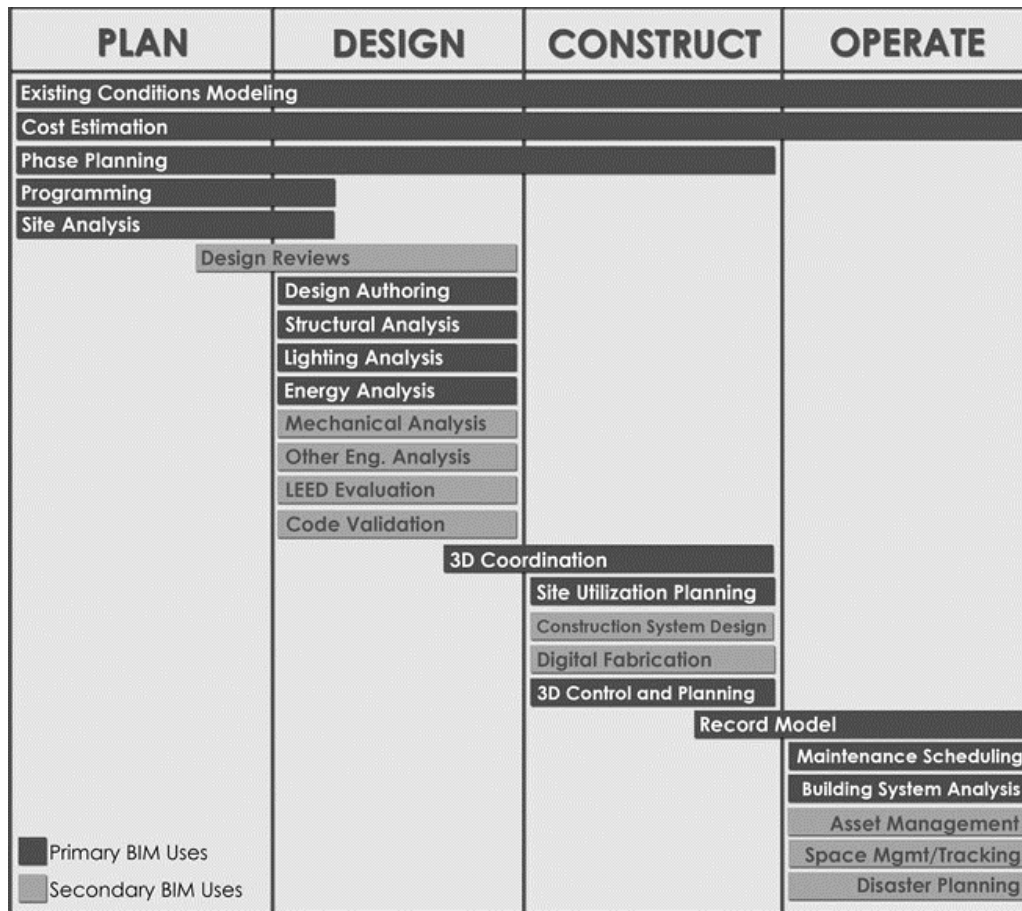
Figure 1: BIM Uses Within the Project Execution Plan (CIC,2011)

For the purposes of this research, the plan and design categories were combined to create the pre-construction phase. Specific focus was placed on the primary uses of BIM identified in the above diagram.

2.3.1 Pre-Construction Uses

BIM is used in preconstruction for clash detection, quantity take-offs and design conceptualization (Eastman, 2008). The model can also be used in project scheduling analysis and cost estimation, commonly referred as 4D and 5D (Succar, 2009). The CIC also lists existing

conditions modeling, programming, site analysis, structural analysis, lighting analysis, and energy analysis as other uses of BIM.

Clash detection identifies spatial conflicts such as a duct and conduit occupying the same space as structural elements (Levy, 2006). A 2012 study identified clash detection as one of the most common uses of BIM among general commercial contractors (Beveridge, 2012).

Quantity take-offs, cost estimation, or any other project related financial processes through BIM potentially provides quick and accurate material quantities and costs data that could aid significantly in design and other decision-making processes throughout the product lifecycle (CIC, 2011).

Design conceptualization was a common use of BIM which allows for better visualization using a 3D model for stakeholders. This increased the collaboration between stakeholders that contributed to the increased transparency during the design processes. This transparency can even extend to the cost and scheduling activities of a project (CIC, 2011).

Existing conditions modeling involves the creation of a model through either manual creation via conventional surveying methods or the use of laser-scanning technologies to create a model that can be used for many purposes including future modeling, design coordination, or remodel/renovation activities (CIC, 2011). This is also closely related to site analysis, which can aid in the determination of the optimal location for a project on a site and can then be used to decrease costs related to demolition and utility demand (CIC, 2011).

The structural, electrical, and energy analysis uses of BIM are used to improve the design and energy consumption of a facility throughout its lifecycle. This can potentially translate to higher returns on investment for stakeholders by reducing life-cycle costs.

2.3.2   Construction Uses

The uses during construction have been identified as the following: project coordination and management, and offsite fabrication (Eastman, 2008). The CIC also defines project site planning, 3D control, and planning.

Project coordination and management and site planning, in conjunction with phase planning, provide increased productivity and efficiency. BIM allows for the creation of feasible construction schemes and recognition of potential conflicts with site space and time. This can include clash detection and other coordination activities. As BIM improves coordination and design, the potential for offsite fabrication of construction materials and elements may reduce waste and improve efficiency. BIM also allows for 3D elements to be applied to "real-world" coordinates which can reduce language barriers and reduce field errors and rework because each element of the project has a control point that can be derived from the model.

2.3.3   Post-Construction or Operations Uses

Facility management processes were improved significantly with an accurate model through real-time energy-related data (Woo, 2010). The CIC also defines building maintenance scheduling and system analysis as operations uses. BIM aids in the management and creation of maintenance schedules because all of the elements of a facility have been input into a model where product life and maintenance requirements can be stored. Because all systems have been included in the model, energy analysis may be performed. The efficiency of maintenance personnel may also increase because the physical location of all systems components may be found in the model.

2.4 Benefits of BIM

BIM benefits construction in the processes of preconstruction, design, construction and post-construction (Eastman, 2008). Through a review of the literature, the benefits of BIM that have been identified by previous research are:

- Increased project quality (Bryde, 2013 & Manrique, 2015 & Suermann, 2009)

- Reduced project costs (Azhar, 2011 & Borup, 2007 & Bryde, 2013 & Giel, 2013 & Manrique, 2015 & Suermann, 2009 & Traynor, 2009 & Chong, 2016)

- Decreased project schedule (Bryde, 2013 & Manrique, 2015 & Suermann, 2009 & Chong, 2016)

- Increased productivity (Borup, 2007 & Francom, 2015 & Manrique, 2015 & Suermann, 2009)

- Increased jobsite safety (Suermann, 2009)

- Increased trade coordination (Bryde, 2013 & Bynum, 2013 & Hanna, 2013 & Lu, 2015 & Woo, 2010 & Gourlis, 2017 & Sibert, 2013)

- Increased communication (Bryde, 2013 & Borup, 2007 & Childress, 2014 & Francom, 2015 & McGraw Hill Construction, 2014 & Poirier, 2015)

Many of these benefits can be found in multiple stages of a project and throughout the entirety of a project's life-cycle.

2.4.1 Benefits According to Industry Sector

According to the North American Industry Classification System (NAICS) list found on the United States Department of Labor: Bureau of Labor Statistics (BLS) website, the construction sector is divided into two main sub-sectors: building construction and heavy and

civil engineering construction (NAICS, 2017). The NAICS further divides the industry into smaller subsectors. Building construction is divided into residential and non-residential. Non-residential is then divided into commercial and industrial construction. Heavy and civil engineering construction is divided into utility system, land subdivision, and highway (BLS, 2017). Table 2.1 identifies the benefits of BIM in the various subsectors.

Table 2.1 presents a list of benefits that have been identified through a review of the literature. It is not a comprehensive list. Any blank spaces in the table indicate a lack of data relating to that respective sector. While this study is not a comprehensive literature review on the global benefits of BIM throughout the construction industry, it does provide a valuable overview of the benefits that have been identified and identifies several future research needs. It also provided useful data to further establish the need for this study.

Scholarly resources for commercial construction are abundant. Those resources acknowledge the benefits of BIM to varying degrees. BIM has been found to positively impact the following key performance indicators: (1) quality, (2) cost, (3) schedule, (4) productivity, and (5) safety, with quality and cost receiving the greatest impact (Suermann, 2009). Per Bryde, (2013), the use of BIM also produces a positive effect on quality, coordination, communication and time (with time being measured from project conception to completion). BIM has also been found to benefit consumer involvement and overall productivity (Borup, 2007 & Francom, 2015). Project owners/consumers have identified increased communication and coordination as a key (McGraw Hill Construction, 2014 & Childress, 2014 & Poirier, 2015).

Benefits are also identified specifically in the design stage (Eastman, 2008), the longest and most frequent use of BIM (McGraw Hill Construction, 2012). The design stage is shorter due to BIM "providing a platform for examination of design options, early involvement of all

Table 2.1: Benefits for Each NAICS Construction Subsector

Benefit	Residential	Commercial	Industrial	Utility	Land Subdivision	Highway
Increased Project Quality	Manrique, 2015	Suerman, 2009 Bryde, 2013				Chong, 2016
Reduced Project Costs	Manrique, 2015	Suerman, 2009 Azhar, 2011 Bryde, 2013 Giel, 2013		Traynor, 2009		
Decreased Project Schedule	Manrique, 2015	Suerman, 2009 Bryde, 2013				Chong, 2016
Increased Productivity	Manrique, 2015	Suerman, 2009 Borup, 2007 Francom, 2015				
Increased Jobsite Safety		Suerman, 2009				
Increased Trade Coordination		Bryde, 2013 Lu, 2015 Bynum, 2013 Woo, 2010 Hanna, 2013	Gourlis, 2017			Sibert, 2013
Increased Communication		Bryde, 2013 Childress, 2014 McGraw Hill Construction, 2014 Poirier et al. 2015				

team members, and open information sharing" (Lu, 2015). BIM fosters collaboration and eases the transition from design to construction (Bynum, 2013).

The financial benefits for commercial products have been studied and determined to produce a positive return on investment (Azhar, 2011 & Bryde, 2013 & Giel, 2013 & McGraw-Hill, 2009). Azhar also quantified benefits to projects in a series of case studies in which they identified clashes and collisions which resulted in significant project benefits to cost and time savings. Cost and time savings were also found in the reduction of costly redesign throughout the project life cycle.

2.4.2   Potential Benefits for Residential Construction

Though residential construction has many differences in means and methods, the complexity of projects, specifically custom homes, can be similar to, if not greater than, commercial projects (ADECA, 2015 & New Mexico Administrative Code, 1.5.18.9). According to the National Association of Home Builders (NAHB), BIM can benefit residential construction through consistent drawings, accurate cost estimates, accurate bills of materials and spatial conflict and system clash detection (NAHB 2012).

According to the NAHB, between the years of 2007 and 2012, the number of residential builders dropped by over 50% (Quint, 2015). It is recognized that due to the economic recession that occurred during this period of time, many firms were unable to stay in business. However, there were many that were able to remain open. Success factors have been identified that could have contributed to these companies' abilities to stay open. In a 2005 study that aimed to identify success factors of small-volume home builders, 78 factors were identified. It is important to note that quality workmanship and products, customer communications and relations,

scheduling/cycle time, and focus on product design were listed among the top ten factors of success (Hutchings, 2005).

The factors of success identified by the Hutchings study are particularly pertinent to the use of BIM for residential construction because of related key benefits of BIM found in commercial construction. For example, increased comunication and collaboration could greatly affect the success factor of customer communications and relations (McGraw Hill Construction, 2014 & Poirier, 2015 & Borup, 2007 & Childress, 2014 & Bynum, 2013). Increased quality and decreased costs due to early detection of defects and fewer change orders could affect the success factors of quality workmanship and products as well as scheduling and cycle-time (Borup, 2007 & Suermann, 2009 & Francom, 2015 & Hanna, 2013). Benefits to the overall schedule clearly affect the success factor of scheduling and cycle time (Suermann, 2009 & Bryde, 2013). The design elements inherent in the use of BIM affect the focus on product design (McGraw Hill Construction, 2012 & Suermann, 2009 & Francom, 2015). The comparison between these success factors and the benefits identified provide evidence for the potential benefit to residential construction.

2.5   Risks Found in Commercial Applications

Risks associated with BIM have been identified and classified as both legal and technical (Azhar, 2011). The following legal risks have been identified (Thomson, 2016):

- Ownership of BIM data with its associated copyright concerns
- Licensing issues
- Control of data entry and responsibility of inaccuracies

- Blurred level of responsibility and fault for concerns

- Responsibility for the technological interface between various programs

Technological risks are as follows: "The need for well-defined transactional construction process models to eliminate data interoperability issues, the requirement that digital design data be computable, and the need for well-developed practical strategies for the purposeful exchange and integration of meaningful information among the building information model components" (Azhar 2011). Eastman, (2008) also defines a number of challenges that accompany the use of BIM.

2.6   Differences Between Commercial and Residential

According to the textbook *Construction Management Jump Start,* by Barbara J. Jackson (2010), Commercial and Residential construction have numerous differences in means, methods, and materials. They also employ different equipment types, structural frameworks, manufacturers, suppliers, specialty contractors, and sources of funding. The following table enumerates many of the crucial differences between the two sectors; however, it is assumed that the residential characteristics listed here apply mainly to production home builders and may not apply to the custom home-building sector that is the focus of this study.

Table 2.2: Differences Between Commercial and Residential Construction

AREAS OF INTEREST	COMMERCIAL	RESIDENTIAL
FUNDING	Private, public, or private-public partnership. Large sums of money. Corporations, agencies, or the government.	Private individuals or developers
PROJECT DURATION	Can take 3 years or more	Typically 3-6 months
SPECIALTY CONTRACTORS NEEDED	Yes (ex. Ironworkers, pipefitters, glaziers)	Not typically
SPECIALTY ENGINEERS NEEDED	Yes	No
PRIMARY TOOLS AND EQUIPMENT NEEDED	Commonly seen: Cranes, pile drivers, concrete pumps, and welding machines, concrete casting beds, cofferdams, and slip forms	Commonly seen: pneumatic air nailers, nails, drills, saws
EASE OF ENTRY		Relatively easy
PRIMARY STRUCTURAL MATERIALS	Concrete and steel	Small wood framing members.
PRIMARY EXTERIOR FINISH MATERIALS	Glass, brick, concrete, stone, aluminum, steel, Exterior insulation panel.	Wood or vinyl siding, brick or stone, stucco
PRIMARY ROOF MATERIALS	Flat roof covered in a bituminous membrane with a gravel ballast or a vinyl or rubber covering, pitched roofs of commercial buildings covered with prefinished metal roofing.	Pitched roof with shingles made of asphalt, clay, concrete, or slate
PRIMARY INTERIOR FINISH MATERIALS	Light gauge steel studs covered in drywall, paint, wall, coverings, carpet, tile marble, granite, and acoustical ceiling tiles.	Drywall partitions and ceilings with paint or wall coverings. Carpet, tile, hardwood, laminate, or sheet vinyl flooring
CLIENTELE CHARACTERISTICS	Less personal, the owners are less concerned with day-to-day operations but rather meeting the schedule and getting into the building to use it for its intended purpose.	Individual families, emotional, inexperienced
SCOPE OF KNOWLEDGE NEEDED	A deep understanding of construction processes and techniques. Construction managers are rarely involved in sales or marketing or land acquisition.	Sales, marketing, financing, land development, entitlement, building codes, purchasing, construction operations, customer service, and warranty

3 METHODOLOGY OF THE RESEARCH

3.1 Selected Research Methodology

The selected method of research to obtain the data required to define the current state of practice with the use of BIM in the custom home building industry was the Delphi method. This method utilizes multiple questionnaires in sequence to obtain consensus among a panel of experts. The research design selected relies on a moderately sized sample that is comprised of experts who take part in a series of questionnaires to obtain a consensus. Therefore, the sample must remain small to moderate in size to minimize the risk of not reaching consensus. The sample size was also dependent on availability and contains extra participants to account for non-respondents.

The characteristics of Delphi (Sourani, 2015) are defined as:

- Anonymity: Opinions are gathered by means of a questionnaire that is kept anonymous from the other participants and can be changed by experts without public scrutiny. This anonymity must be maintained at all levels.

- Iteration with controlled feedback: The use of consecutive rounds to first obtain exploratory data which was codified and returned to experts.

- Statistical group response: The codified data was ranked by level of importance in subsequent questionnaires until a minimum of three practices and issues were identified.

3.2   Research Design

The intent of this research was to identify the current best practices, benefits, and challenges that accompany the use of BIM in custom home building. An excellent source for these best practices were experts in the field who have successfully implemented this technology. For the purposes of this research, an expert was defined as an industry professional who utilizes BIM and uses it as a feature of their home building process. Therefore, they provided qualified insight and opinion on its application in residential construction. The recruitment process began through examination of company websites to build a preliminary list of possible experts. Once the list had been compiled through the initial examination of websites, each expert was called over the phone to confirm their use of BIM and to obtain their consent to participate.

The risks to the participants were minimal. They were asked to identify limited demographics such as the number of employees and number of homes completed each year.

The Delphi method was used to first gain exploratory data that identifies current practices. The exploratory data was then coded. As responses were read, preliminary categories were established per frequent words and phrases used by participants. The responses were then coded by the categories that were established. After the responses were coded, the categories and codes were reviewed to verify the accuracy of coding and ensure categories were appropriate. A second follow-up questionnaire was populated by the categories identified in the analysis of the first questionnaire. The categories were sent to the participants who ranked them in order of importance. Analysis of this data was performed through a calculation of the mean of the responses. A third questionnaire, was formulated using the results from the previous questionnaire. Using a Likert-type scale ranging from either 1 to 4 or 1 to 5, the participants stated their level of agreement with the rankings determined in the second questionnaire. The

scales are based on question type. A 1-4 scale is used for questions with a level of accuracy rating with the following categories:

1. Completely Accurate

2. Accurate

3. Inaccurate

4. Completely Inaccurate

A 1-5 scale is used for questions with a level of agreement rating with the following categories:

1. Completely Agree

2. Mostly Agree

3. Neither Agree nor Disagree

4. Mostly Disagree

5. Completely Disagree

The analysis of questionnaire 3 was similar to the second questionnaire. Consensus was identified as 75% or more of participants ranking a category the same (Sourani, 2015).

The process outlined in Figure 2.1 was implemented to obtain, rank and seek a consensus concerning the data (Smith 2011).

The Delphi method was selected because it provides an effective means of obtaining accurate information that is currently unavailable, studies an area where there is little-agreed knowledge, "combining fragmentary perspectives into a collective understanding," and models a real-world phenomenon with a range of viewpoints and "little established quantitative evidence" (Sourani & Sohail, 2015).
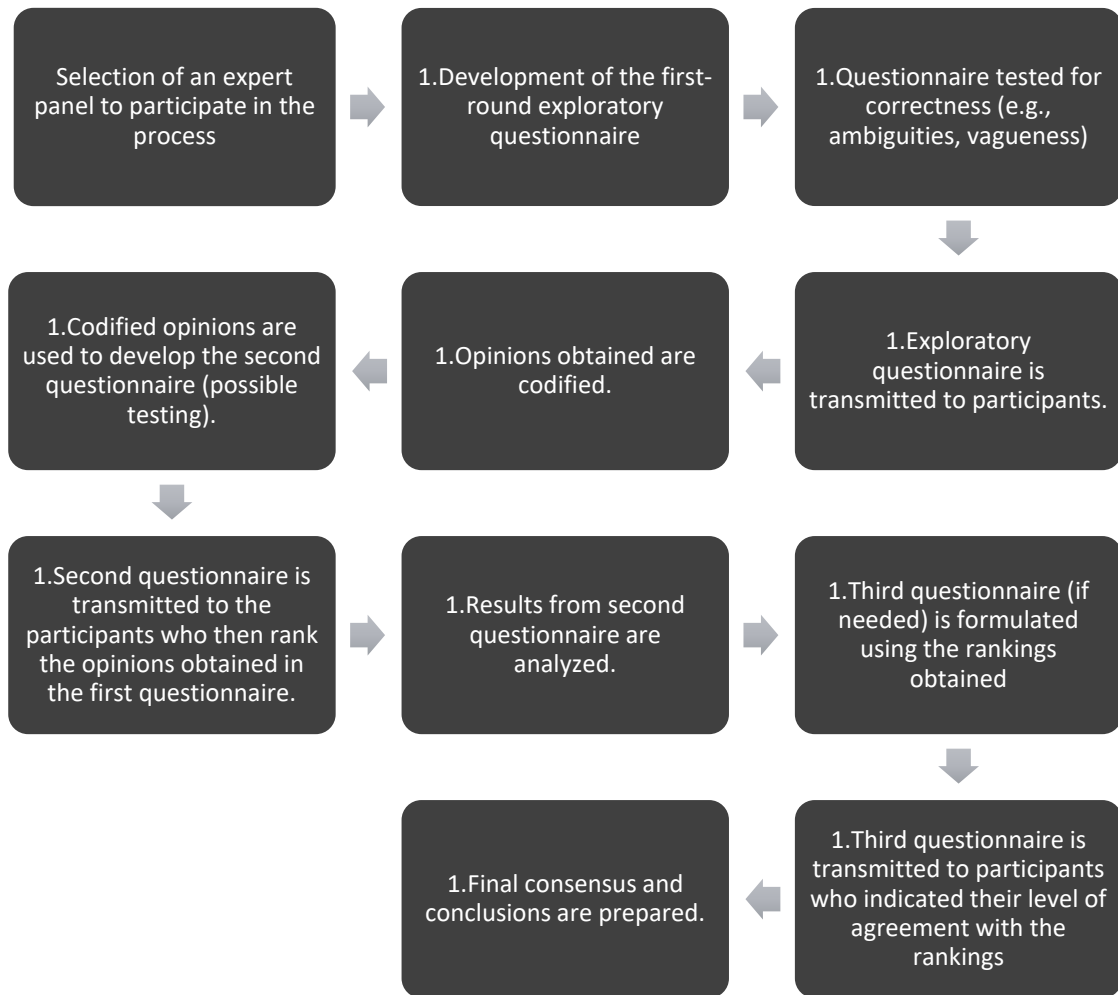
Figure 2.1: The Selected Delphi Process

3.3 Research Limitations

Because of the selected research design, there are limitations inherent in the process. The

Delphi panel requires a small sample size of experts. The small sample size does not allow for

data that can be generalized to the market. As such the data does not allow us to make

population inferences. Additionally, all participants of this study were located in the United

States.

4   RESULTS

4.1   Delphi Study Details

This chapter defines the results of the Delphi study performed in this research. Initially 53 contractors and designers were contacted who currently use BIM in their business practices. For a list of the contractors who initially agreed to participate, see Appendix A. 18 experts agreed to participate and completed the first questionnaire. The second questionnaire had a response rate of 83% with 15 of 18 participants responding. The third and final questionnaire had a response rate of 56% with 10 of 18 participants responding. The research purpose was achieved with three rounds of questionnaires and therefore no further questionnaires were administered.

4.2   Questionnaire One Design

Questionnaire 1 (see Appendix B) was designed as an exploratory questionnaire comprised of mainly open-ended questions based on company demographics, BIM implementation, BIM use, benefits of BIM and challenges of BIM use. The answers to these questions provided the basis of study for the following questionnaires. The open-ended nature of the questions allowed for the participants to direct the study without being influenced by the questionnaire.

4.3   Questionnaire One Results

The following sections outline the results of each individual question. The question topics were as follows:

- Demographics
  - Company Location
  - Number of Employees
  - Number of Homes Completed Each Year
  - Average Sale Price of Homes Sold
  - Area of Specialization within the Industry
- What Software is Utilized
- Process of Implementation
- BIM Uses
- Benefits of BIM
- Challenges or Issues Associated with BIM Use

4.3.1 Company Demographic Data

The participants were asked to identify where their company is located based on region. Participants were permitted to select multiple locations to allow for those who do business in multiple regions to indicate that. Most of the participants listed the Mountain West region as a location where they did business.

The participants were asked to identify their number of employees with the following ranges of 1-10, 11-25, 26-50, and 51+. Most of the participants had relatively small companies with 72% reporting 1-10 employees.

The participants were asked to identify the average number of homes their company completes each year using the following ranges: 0-10, 11-30, 31-60, and 61+. The majority of the participants, 68%, indicated that they only completed 1-10 homes per year.

The participants were asked to indicate the average sale price of their homes using the following ranges: Under $250,000; $250,001-$500,000; $500,001-$750,000; $750,001-$1,000,000; and $1,000,001+.

The final demographics question asked what subsector they specialized in, with the categories being: new home construction, home remodeling, and home additions. The participants were able to select multiple categories. Table 4.1 lists all the demographic data received from the panel.

The roles of the employees were also identified. Nine participants were company owners, four were BIM managers, three were designers, one was a project manager, and one was a purchasing manager. While attempts were made to have multiple roles from the same company participate in the study, there was only one participant from each company. For a comprehensive list of all participants, please refer to Appendix A.

Table 4.1: Company Demographics

Demographic Segment	Participants' Selections	%
Company Location*		
Mountain West	12	67%
West Coast	4	22%
Midwest	3	17%
South	2	11%
Number of Employees		
1-10	13	72%
11-25	3	17%
26-50	1	6%
51+	1	6%
Number of Homes Completed Each Year		
0-10	12	67%
11-30	5	28%
61+	1	6%
Average Home Sale Price		
$250,001-$500,000	7	39%
$1,000,001	6	33%
$500,001-$750,000	3	17%
$750,001-$1,000,000	2	11%
Company Specialty*		
New Home Construction	18	100%
Home Remodeling	6	33%
Home Renovation	5	28%
Participant Role		
Company Owner	9	50%
BIM Manager	4	22%
Designer	3	17%
Project Manager	1	6%
Purchasing Manager	1	6%

Some of the 18 total participants selected multiple of the provided options

4.3.2 BIM Processes

Following the demographics questions, participants were asked to identify what software they utilized within their company and the method(s) they used to implement BIM in their company.

The most common software platform for BIM in the residential market, as identified by this panel, is Autodesk® Revit®. There are however other platforms that are being utilized with some success.

The participants were asked to identify what process they used to implement BIM within their company. The implementation processes which were identified can be found in Table 4.2. The chart also shows the number, and resultant percentage, of participants who listed each process and the number and percentage of experts, in this panel, who use a given software.

Table 4.2: Software and Implementation Process Utilized

Software and processes	Listed software and processes	%
BIM Software Platforms*		
Revit®	9	50%
Sketchup®**	6	33%
ArchiCAD®	2	11%
Chief Architect®	2	11%
AutoCAD®**	2	11%
Vectorworks®	1	6%
SolidBuilder®	1	6%
Implementation Process*		
Hired experienced employees	10	56%
Trained current employees	7	39%
Self-led education	4	22%
Hired experienced employees	1	6%
* Some of the 18 total Participants selected multiple software platforms		
** It is recognized that these platforms alone may not constitute BIM. However, in most cases, they were used in conjunction with other platforms increasing the Information component that is crucial for BIM.		

4.3.3 BIM Uses, Benefits, and Challenges

The participants were then asked to identify how BIM was used in their company as well as any benefits and/or challenges/issues they found as a result of its use. The purpose of these questions was simply to populate lists for use in the subsequent questionnaires, but some valuable analysis was performed on this primarily qualitative data.

The following uses were identified:
- Marketing
- Design and visualization
- Field management/corrections
- Creation of construction documents
- Design coordination and/or clash detection
- Scheduling
- Quantity take-offs or estimating

The following benefits were identified:
- Plan accuracy
- Client visualization
- Quicker, more accurate quantity take-off's or estimating
- Improved client communication
- Improved communication with/between trades
- Improved scheduling effectiveness
- Early identification of design errors
- Improved marketing materials (i.e. renderings)
- Ease of plan revisions
- Ability to show plan from different angles

The following challenges or issues were identified:
- High software costs
- Steep learning curve when training employees
- Time-consuming to create and maintain models correctly
- Overabundance of information can overwhelm or confuse clients
- Lots of training is required to maintain effectiveness
- Computer hardware requirements
- Different BIM platforms or versions are often incompatible
- BIM software seems catered to commercial construction
- Software platforms require updates for continued use
- Difficult to find qualified, experienced employees

4.3.4 Questionnaire 1 Cross-Tabulation Analysis

Cross-tabulations were performed that compared the demographic data to the uses, benefits, and challenges. Because participants were asked to identify the uses, benefits, and challenges, they had to be codified to be used in subsequent questionnaires. After all the responses were codified, the researcher counted which uses, benefits and challenges were listed under each demographic sector in which each member fell. The researcher then compared each demographic (Number of employees, Number of homes built per year and Average Sale Price per Home) individually with the uses, benefits, and challenges identified.

4.3.5 Number of Employees

The number of employees data indicated that within the 1-10 employee group, of which there were 13 members, the most common use was *quantity take-offs* with 46% percent of the participants listing that as a use. *Quantity take-offs* was followed by *design and visualization* and *field management/corrections* with 31% and 23%, respectively, of members listing them. The 11-25 employee group, consisting of three members, reported that the most common uses were *design and visualization* and *scheduling* each with 67% of the members listing them as common uses in their company. They were followed by *design coordination and/or clash detection* and *quantity take-offs* each with 33%, respectively. The 26-50 employee group, consisting of one member, reported that the most common uses of BIM were *design and visualization* and the *creation of construction documents*. The 51+ employee group, consisting of one member, listed *design, and visualization, design coordination and/or clash detection*, and *quantity take-offs* as the main uses.

Table 4.3: BIM Uses Organized by Number of Employees

Number of Employees		Listed Uses of BIM	%
1-10		**13 Total Respondents**	
	Quantity take-offs	6	46%
	Design and visualization	4	31%
	Field management/corrections	3	23%
	Marketing	2	15%
	Creation of construction documents	2	15%
	Design coordination and/or clash detection	2	15%
	Scheduling	2	15%
11-25		**3 Total Respondents**	
	Design and visualization	2	67%
	Scheduling	2	67%
	Design coordination and/or clash detection	1	33%
	Quantity take-offs	1	33%
26-50		**1 Total Respondent**	
	Design and visualization	1	100%
	Creation of construction documents	1	100%
51+		**1 Total Respondent**	
	Design and visualization	1	100%
	Design coordination and/or clash detection	1	100%
	Quantity take-offs	1	100%

The number of employees data also indicated that within the 1-10 employee group, the most common benefit of BIM was *client visualization* with 46% of the participants listing it as a benefit. *Client visualization* was followed by *plan accuracy*, *improved client communication* and *improved communication with/between trades*, each with 31% of members listing it as a benefit. The only benefits listed by the 11-25 employee group were *plan accuracy* and *quicker, more accurate quantity take-offs*. The benefits listed by the 26-50 group, which consisted of one member, were *plan accuracy*, *client visualization*, *improved communication with/between trades* and the *ease of plan revisions*. The 51+ employee group, also consisting of one member, reported that their benefits were *client visualization*, *quicker, more accurate quantity take-offs*, *improved client communication* and *early identification of design errors*.

Table 4.4: BIM Benefits Organized by Number of Employees

Number of Employees	Listed Benefits of BIM	%
1-10	**13 Total Respondents**	
Client visualization	6	46%
Plan accuracy	4	31%
Improved client communication	4	31%
Improved communication with/between trades	4	31%
Quicker, more accurate quantity take-off's or estimating	3	23%
Early identification of design errors	3	23%
Improves scheduling effectiveness	1	8%
Improved marketing materials (i.e. renderings)	1	8%
Ability to show plan from different angles	1	8%
11-25	**3 Total Respondents**	
Plan accuracy	1	33%
Quicker, more accurate quantity take-off's or estimating	1	33%
26-50	**1 Total Respondent**	
Plan accuracy	1	100%
Client visualization	1	100%
Improved communication with/between trades	1	100%
Ease of plan revisions	1	100%
51+	**1 Total Respondent**	
Client visualization	1	100%
Quicker, more accurate quantity take-off's or estimating	1	100%
Improved client communication	1	100%
Early identification of design errors	1	100%

The cross-tabulation data for this demographic series indicated that within the 1-10 employee group, consisting of 13 members, the most common challenge was that it *is time-consuming to create and maintain models correctly* with 46% if participants listing it as a challenge. The rest of the challenges identified were relatively uniform in their distribution among the responses. The 11-25 employee group identified the *steep learning curve when training employees* and the *extensive amounts of training required to maintain effectiveness* as there most common challenges. The 26-50 employee group listed that *BIM software seems catered to commercial construction* and *software platforms require updates for continued use* as

their most common challenges. The member that constituted 51+ employee group reported that *the steep learning curve when training employees*, *the amount of training required to maintain effectiveness*, and *different BIM platforms or versions are often incompatible* were their most common challenges.

Table 4.5: BIM Challenges Organized by Number of Employees

Number of Employees	Listed Challenges of BIM	%
1-10	**13 Total Respondents**	
Time-consuming to create and maintain models correctly	6	46%
High software costs	1	8%
Steep learning curve when training employees	1	8%
Overabundance of information can overwhelm or confuse clients	1	8%
Lots of training is required to maintain effectiveness	1	8%
Computer hardware needs to be substantial	1	8%
Difficult to find qualified, experienced employees	1	8%
11-25	**3 Total Respondents**	
Steep learning curve when training employees	1	33%
Lots of training is required to maintain effectiveness	1	33%
26-50	**1 Total Respondent**	
BIM software seems catered to commercial construction	1	100%
Software platforms require updates for continued use	1	100%
51+	**1 Total Respondent**	
Steep learning curve when training employees	1	100%
Time-consuming to create and maintain models correctly	1	100%
Different BIM platforms or versions are often incompatible	1	100%

4.3.6 Number of Homes

The number of homes built per year data indicates that the 0-10 homes group, consisting of 12 members, reported that *quantity take-offs* and *design and visualization* are the top uses with 50% and 33% of members listing them. The 11-30 homes group, consisting of five members, listed *design and visualization* and *field management/corrections* with 60% and 40% of the

members listing each. The 31-60 homes group did not have any participants and, therefore, there

is no data for this group. The 61+ homes group, consisting of one member, listed their main uses

as *design and visualization*, the *creation of construction documents*, *design coordination and/or

clash detection*, and *quantity take-offs*.

Table 4.6: BIM Uses Organized by Number of Homes

Number of Homes	Listed Uses of BIM	%
0-10	**12 Total Respondents**	
Quantity take-offs	6	50%
Design and visualization	4	33%
Design coordination and/or clash detection	3	25%
Scheduling	3	25%
Marketing	1	8%
Field management/corrections	1	8%
Creation of construction documents	1	8%
11-30	**5 Total Respondents**	
Design and visualization	3	60%
Field management/corrections	2	40%
Marketing	1	20%
Creation of construction documents	1	20%
Scheduling	1	20%
Quantity take-offs	1	20%
61+	**1 Total Respondent**	
Design and visualization	1	100%
Creation of construction documents	1	100%
Design coordination and/or clash detection	1	100%
Quantity take-offs	1	100%

The benefits for this demographic group were defined as follows. The main benefits listed

by the 0-10 homes per year group were *client visualization* and *improved client communication*

with 33% each, followed by *plan accuracy* and *quicker, more accurate quantity take-offs* with

25% of the members listing them as benefits. The benefits were almost uniformly distributed

among the 11-30 homes per year group. The 61+ homes group, consisting of one member,

reported *plan accuracy*, *client visualization*, and *quicker, more accurate quantity take-offs or estimating* as their main benefits.

Table 4.7: BIM Benefits Organized by Number of Homes

Number of Homes	Listed Benefits of BIM	%
0-10	**12 Total Respondents**	
Client visualization	4	33%
Improved client communication	4	33%
Plan accuracy	3	25%
Quicker, more accurate quantity take-off's or estimating	3	25%
Improved communication with/between trades	2	17%
Improves scheduling effectiveness	2	17%
Early identification of design errors	2	17%
Improved marketing materials (i.e. renderings)	1	8%
Ability to show plan from different angles	1	8%
11-30	**5 Total Respondents**	
Client visualization	2	40%
Plan accuracy	1	20%
Quicker, more accurate quantity take-off's or estimating	1	20%
Improved client communication	1	20%
Improved communication with/between trades	1	20%
Improves scheduling effectiveness	1	20%
Early identification of design errors	1	20%
Improved marketing materials (i.e. renderings)	1	20%
Ease of plan revisions	1	20%
61+	**1 Total Respondent**	
Plan accuracy	1	100%
Client visualization	1	100%
Quicker, more accurate quantity take-off's or estimating	1	100%

The challenges reported for this demographic group were reported by the 0-10 homes per year group to be that it is *time-consuming to create and maintain models correctly* and that there is a *steep learning curve when training employees* with 42% and 33%, respectively, of the members listing them as challenges. The 11-30 homes per year group listed that it is *time-consuming to create and maintain models correctly*, *computer hardware requirements can be*

substantial, BIM software seems catered to commercial construction and that it is difficult to *find qualified, experienced employees as their main challenges*. The 61+ homes per year group listed that it is *time-consuming to create and maintain models correctly* as their main challenge.

Table 4.8: BIM Challenges Organized by Number of Homes

Number of Homes	Listed Challenges of BIM	%
0-10	**12 Total Respondents**	
Time-consuming to create and maintain models correctly	5	42%
Steep learning curve when training employees	4	33%
High software costs	1	8%
Overabundance of information can overwhelm or confuse clients	1	8%
Lots of training is required to maintain effectiveness	1	8%
Different BIM platforms or versions are often incompatible	1	8%
Difficult to find qualified, experienced employees	1	8%
11-30	**5 Total Respondents**	
Time-consuming to create and maintain models correctly	1	20%
Computer hardware needs to be substantial	1	20%
BIM software seems catered to commercial construction	1	20%
Software platforms require updates for continued use	1	20%
Difficult to find qualified, experienced employees	1	20%
61+	**1 Total Respondent**	
Time-consuming to create and maintain models correctly	1	100%

4.3.7   Average Sale Price per Home

The average sale price per home groups began with the $250,001-$500,000 group, consisting of seven members, who reported that their most common uses of BIM are *design and visualization*, *field management/corrections*, and *quantity take-offs* with 43% of members listing them. The $500,001-$750,000 group, consisting of three members, most commonly listed *design and visualization* as a use utilized by their company with two of the three members listing it. The $750,001-$1,000,000 group, consisting of two members, listed *design and visualization* and the *creation of construction documents* as uses. The $1,000,001+ group was comprised of six

members. The following uses were all listed by two of the members, which constituted the highest concentration of listings: *design and visualization*, *design coordination and/or clash detection*, *scheduling*, and *quantity take-offs*.

Table 4.9: BIM Uses Organized by Average Sale Price

Average Sale Price	Listed Uses of BIM	%
$250,001-$500,000	**7 Total Respondents**	
Design and visualization	3	43%
Field management/corrections	3	43%
Quantity take-offs	3	43%
Marketing	2	29%
Creation of construction documents	2	29%
Design coordination and/or clash detection	1	14%
Scheduling	1	14%
$500,001-$750,000	**3 Total Respondents**	
Design and visualization	2	67%
Marketing	1	33%
Field management/corrections	1	33%
Design coordination and/or clash detection	1	33%
Scheduling	1	33%
Quantity take-offs	1	33%
$750,001-$1,000,000	**2 Total Respondents**	
Design and visualization	1	50%
Creation of construction documents	1	50%
$1,000,001+	**6 Total Respondents**	
Design and visualization	2	33%
Design coordination and/or clash detection	2	33%
Scheduling	2	33%
Quantity take-offs	2	33%
Field management/corrections	1	17%

The most commonly listed benefits by the $250,001-$500,000 group were *plan accuracy* and *client visualization* with 43% of members listing them. The $500,001-$750,000 group listed *client visualization* and *improved client communication*, each with two of the three members listing them, as their most common benefits. The $750,001-$1,000,000 group reported that their

most common benefits were *plan accuracy*, *client visualization*, *improved communication with/between trades*, the *ease of plan revisions*, and the *ability to show the plan from different angles*. The $1,000,001+ group listed *client visualization* and *improved client communication* as their most common benefits.

Table 4.10: BIM Benefits Organized by Average Sale Price

Average Sale Price	Listed Benefits of BIM	%
$250,001-$500,000	**7 Total Respondents**	
Plan accuracy	3	43%
Client visualization	3	43%
Quicker, more accurate quantity take-off's or estimating	2	29%
Improved client communication	2	29%
Improved communication with/between trades	2	29%
Improves scheduling effectiveness	1	14%
Early identification of design errors	1	14%
$500,001-$750,000	**3 Total Respondents**	
Client visualization	2	67%
Improved client communication	2	67%
Quicker, more accurate quantity take-off's or estimating	1	33%
Improved communication with/between trades	1	33%
Early identification of design errors	1	33%
Improved marketing materials (i.e. renderings)	1	33%
$750,001-$1,000,000	**2 Total Respondents**	
Plan accuracy	1	50%
Client visualization	1	50%
Improved communication with/between trades	1	50%
Ease of plan revisions	1	50%
Ability to show plan from different angles	1	50%
$1,000,001+	**6 Total Respondents**	
Client visualization	2	33%
Improved client communication	2	33%
Improved communication with/between trades	1	17%
Quicker, more accurate quantity take-off's or estimating	1	17%

The challenges identified by the $250,001-$500,000 group were that it *is time-consuming to create and maintain models correctly* with 57% of the members listing it. The $500,001-$750,000 group had no apparent commonly listed challenges. The $750,001-$1,000,000 group listed that it *is time-consuming to create and maintain the models correctly*, *BIM software seems catered to commercial construction*, and *software platforms require updates for continued use* as

their most common challenges. The most commonly listed challenge by the $1,000,001+ group was the *steep learning curve when training employees*.

Table 4.11: BIM Challenges Organized by Average Sale Price

Average Sale Price	Listed Challenges of BIM	%
$250,001-$500,000	7 Total Respondents	
Time-consuming to create and maintain models correctly	4	57%
Steep learning curve when training employees	2	29%
High software costs	1	14%
Overabundance of information can overwhelm or confuse clients	1	14%
Difficult to find qualified, experienced employees	1	14%
$500,001-$750,000	3 Total Respondents	
Steep learning curve when training employees	1	33%
Time-consuming to create and maintain models correctly	1	33%
Lots of training is required to maintain effectiveness	1	33%
Computer hardware needs to be substantial	1	33%
BIM software seems catered to commercial construction	1	33%
$750,001-$1,000,000	2 Total Respondents	
Time-consuming to create and maintain models correctly	1	50%
BIM software seems catered to commercial construction	1	50%
Software platforms require updates for continued use	1	50%
$1,000,001+	6 Total Respondents	
Steep learning curve when training employees	3	50%
Time-consuming to create and maintain models correctly	1	17%
Lots of training is required to maintain effectiveness	1	17%
Different BIM platforms or versions are often incompatible	1	17%
Software platforms require updates for continued use	1	17%
Difficult to find qualified, experienced employees	1	17%

4.4   Questionnaire 2 Design

Questionnaire 2 was drafted and designed from the responses obtained in questionnaire 1. Fifteen responses were received for the second questionnaire. The participants for this questionnaire consisted of eight owners, three BIM managers, two designers and one project manager. The participants were asked to rank the data obtained previously. The questions for this

questionnaire were related to implementation processes, uses of BIM, benefits of BIM, and challenges associated with BIM use.

4.4.1 Implementation Processes

The panel members were asked to rank the implementation processes identified in questionnaire 1 according to the likelihood that they would use that process if they were to repeat the implementation process. The implementation processes were ranked on a 1-4 Likert scale where 1=most likely to use and 4=least likely to use. The rankings were then averaged to identify the process that was most likely to be used overall. These rankings can be found in Table 4.12 below.

Table 4.12: Implementation Processes Ranked in Questionnaire 2

Processes	Average Ranking (1=most likely to be used, 4 =least likely to be used)
Attended or watched training courses	2.36
Trained current employees	2.43
Self-led education	2.64
Hired experienced employees	3.00
15 Total Respondents	

According to this ranking, there is no one clear best process for implementation. However, as indicated in Table 4.12, *attending or watching training courses* received the highest overall ranking. It is also important to note the difference between the implementation processes identified in questionnaire 1 and questionnaire 2. Questionnaire 1 identified *hiring experienced employees* as the most commonly used process, with 56% of participants listing it, and *attending or watching training courses* as the least utilized process, with 6% of participants listing it. Questionnaire 2, however, indicated that, while there was not a significant difference in ranking,

watching or attending training courses was the process most likely to be used and *hiring experienced employees* was the least likely to be used if the implementation process was repeated.

4.4.2 BIM Uses

The participants were asked to identify the top three uses utilized in their company. They then ranked those top three uses. The most commonly selected uses were *design and visualization*, the *creation of construction documents* and *quantity take-offs.*

Table 4.13: BIM Most Common Uses Listed Questionnaire 2

Uses	Listed Uses of BIM	%
Design and visualization	13	93%
Creation of construction documents	9	64%
Quantity take-offs	6	43%
Marketing	4	29%
Field management/corrections	3	21%
Scheduling	3	21%
Design coordination	2	14%

After the participants identified their top three uses, they then ranked those top three uses based on most used to least used where 1=most used and 3=least used. The findings were weighted to identify the most utilized use. The following weights were used: 0=40, 1=10, 2=20, 3=30. If a use was not listed by a participant it received the greatest weight and had the most significant impact on the results. The results indicate that *design and visualization* is the most common use of BIM followed by the *creation of construction documents*.

Table 4.14: BIM Most Commonly Utilized Uses Ranked in Questionnaire 2

Uses	Weighted Average*
Design and visualization	2.30
Creation of construction documents	3.30
Quantity take-offs	4.70
Marketing	5.10
Scheduling	5.10
Field management/corrections	5.20
Design coordination	5.40

*Those uses with the lowest weighted average most commonly received the highest ranking. As the weighted average increased, the ranking received decreased.

Participants were also asked to identify any uses that their company either does not use or rarely utilize. They were able to select any use that applied. The least utilized use identified by this group was *scheduling* followed by *design coordination*.

Table 4.15: Rarely or Not Used BIM Uses*

Uses	Listed Uses Of BIM	%
Scheduling	7	50%
Design coordination	5	36%
Marketing	4	29%
Field management/corrections	4	29%
Quantity take-offs	3	21%
Creation of construction documents	1	7%

*According to this panel

The participants were asked what use was the most under-utilized use within their company. According to this panel, the most under-utilized use of BIM is *quantity take-offs*.

Table 4.16: Most Under-Utilized Uses of BIM*

Uses	Listed Uses of BIM	%
Quantity take-offs	7	50%
Design coordination	5	36%
Scheduling	5	36%
Field management/corrections	4	29%
Marketing	3	21%
Creation of construction documents	2	14%
Design and visualization	1	7%
* According to this Panel		

4.4.3   Benefits of BIM

Similar to previous questions in this questionnaire, participants were asked to rank the benefits previously identified on a Likert scale where 1= most beneficial and 10=least beneficial. These rankings were averaged to find the lowest average ranking, thus identifying the most beneficial among all participants.

Table 4.17: BIM Benefits Ranked in Questionnaire 2

Benefits	Average Ranking (1=most beneficial, 10 =least beneficial)
Plan accuracy	2.50
Client visualization	2.50
Improved client communication	4.40
Ease of plan revisions	5.10
Early identification of design errors	5.20
Ability to show plan from different angles	6.20
Quicker, more accurate quantity take-off's or estimating	6.50
Improved communication with/between trades	6.90
Improves scheduling effectiveness	7.50
Improved marketing materials (i.e. renderings)	8.10

The benefits that proved to be the most beneficial to the panel members and their companies were *plan accuracy* and *client visualization*.

4.4.4 Challenges Associated with BIM Use

The participants were similarly asked to rank the challenges associated with the use of BIM on a Likert scale where 1=most challenging and 10=least challenging.

Table 4.18: BIM Challenges Ranked in Questionnaire 2

Challenges	Average Ranking (1=most beneficial, 10 =least beneficial)
Steep learning curve when training employees	3.30
High software costs	3.90
Time-consuming to create and maintain models correctly	4.00
Lots of training is required to maintain effectiveness	5.30
Computer hardware requirements	5.60
Difficult to find qualified, experienced employees	5.60
BIM software seems catered to commercial construction	6.00
Overabundance of information can overwhelm or confuse clients	6.90
Different BIM platforms or versions are often incompatible	6.90
Software platforms require updates for continued use	7.30

The most common challenges associated with BIM use are the *steep learning curve when training employees* and the *high software costs*, followed very closely by how *time-consuming it is to create and maintain models correctly*.

4.4.5 Questionnaire 2 Cross-Tabulation Analysis

Similar to questionnaire 1, the cross-tabulation analysis was performed comparing the ranking data obtained in questionnaire 2 and the demographic data obtained in questionnaire 1.

The purpose of this analysis was to identify any trends within any given demographic and also to corroborate the data received in questionnaire 1. The cross-tabulations for this questionnaire compare the same sets of data as the previous cross-tabulations, namely, the average sale price per home, number of employees, and number of homes built per year with the ranking data relating to the uses, benefits, and challenges identified by the panel in the previous questionnaire. The uses data was analyzed according to the number of times a use was listed by the panel while the benefits and challenges rankings data was analyzed using an average ranking.

4.4.6   Number of Employees: Questionnaire 2

The panel members belonging to the 1-10 employee group, consisting of 11 members, listed *design and visualization* most often as one of their most common uses of BIM, with 10 of 11 participants listing it as a common use. This was followed by the *creation of construction documents*, with seven of eleven participants listing it. *Design coordination and/or clash detection* and *scheduling* received the fewest listings within this group, indicating that these are the least used uses by this demographic. The panel members in the 11-25 employee group, consisting of two members, indicated that *design and visualization*, as well as *scheduling*, were the most common uses with each of the two members listing them. These members each listed one other use. *Marketing, field management/corrections,* and *design coordination and/or clash detection* were not listed by this group. The 26-50 employee group, which consisted of only one member, selected as their top three uses the *creation of construction documents*, *design and visualization*, and *marketing*. They were also ranked in the order listed here. This group, however, did not list *field management/corrections, design coordination and/or clash detection, scheduling,* or *quantity take-offs*.

Table 4.19: Most Common BIM Uses Organized by Number of Employees

Number of Employees	Listed Uses of BIM	%
1-10	**11 Total Respondents**	
Design and visualization	10	91%
Creation of construction documents	7	64%
Quantity take-offs	5	45%
Marketing	3	27%
Field management/corrections	3	27%
Design coordination and/or clash detection	2	18%
Scheduling	1	9%
11-25	**2 Total Respondents**	
Design and visualization	2	100%
Scheduling	2	100%
Creation of construction documents	1	50%
Quantity take-offs	1	50%
26-50	**1 Total Respondent**	
Marketing	1	100%
Design and visualization	1	100%
Creation of construction documents	1	100%

The benefits rankings for the 1-10 employee group indicated that the benefit that was most beneficial to this group was *client visualizations* followed by *plan accuracy*. The average ranking of *client visualization* was 2.36 and *plan accuracy* was 2.64. This group also ranked *improved marketing materials* and *improved scheduling effectiveness* as the least beneficial. The 11-25 employee ranked *plan accuracy* as their top benefit, with an average ranking of 2.5, followed by *client visualization* and the *improvement of scheduling effectiveness*, each with an average ranking of 3 out of 10 with 1 being the highest. This group ranked *early identification of design errors* and *improved marketing materials* as the least beneficial. The top three benefits ranked, in the following order, by the 26-50 group, were *plan accuracy*, *ease of plan revisions*, and *client visualization*. This group ranked quicker, more accurate quantity take-offs and improved scheduling effectiveness as the least beneficial.

Table 4.20: Ranked BIM Benefits Organized by Number of Employees

Number of Employees	Average Ranking (1=most beneficial, 10 =least beneficial)
1-10	**11 Total Respondents**
Client visualization	2.36
Plan accuracy	2.64
Improved client communication	4.36
Early identification of design errors	4.82
Ease of plan revisions	5.09
Ability to show plan from different angles	6.27
Quicker, more accurate quantity take-off's or estimating	6.45
Improved communication with/between trades	7.00
Improved marketing materials (i.e. renderings)	7.91
Improves scheduling effectiveness	8.09
11-25	**2 Total Respondents**
Plan accuracy	2.50
Client visualization	3.00
Improves scheduling effectiveness	3.00
Improved client communication	5.00
Quicker, more accurate quantity take-off's or estimating	5.50
Improved communication with/between trades	6.00
Ability to show plan from different angles	6.00
Ease of plan revisions	7.00
Early identification of design errors	7.50
Improved marketing materials (i.e. renderings)	9.50
26-50	**1 Total Respondent**
Plan accuracy	1.00
Ease of plan revisions	2.00
Client visualization	3.00
Improved client communication	4.00
Early identification of design errors	5.00
Ability to show plan from different angles	6.00
Improved marketing materials (i.e. renderings)	7.00
Improved communication with/between trades	8.00
Quicker, more accurate quantity take-off's or estimating	9.00
Improves scheduling effectiveness	10.00

The challenges ranking by the 1-10 employee group indicates that the greatest challenge identified by this group was *high software costs* with an average ranking of 3.82, followed by how *time-consuming it is to create and maintain models correctly* with an average ranking of 3.91. This group identified *different BIM platforms or versions are often incompatible* and *software platforms require updates for continued use* as their least difficult challenges. The most difficult challenges identified by the 11-25 employee group were the *steep learning curve when training employees* and the *time-consuming nature of creating and maintaining models correctly*

with average rankings of 1 and 2.5 respectively. This group also ranked *overabundance of information can overwhelm or confuse clients* and *software platforms require updates for continued use* as their least difficult challenges. The top three challenges ranked, in the following order, by the 26-50 employee group were *high software cost*, the *steep learning curve when training employees*, and the *computer hardware requirements*. This group ranked *lots of training is required to maintain effectiveness* and *overabundance of information can overwhelm or confuse clients* as their least difficult challenges. These rankings were based on a 1-10 scale with one being the highest possible ranking.

Table 4.21: Ranked BIM Challenges Organized by Number of Employees

Number of Employees	Average Ranking (1=most beneficial, 10 =least beneficial)
1-10	**11 Total Respondents**
High software costs	3.82
Steep learning curve when training employees	3.91
Time-consuming to create and maintain models correctly	4.00
Lots of training is required to maintain effectiveness	5.27
Computer hardware needs to be substantial	5.64
Difficult to find qualified, experienced employees	5.64
Overabundance of information can overwhelm or confuse clients	6.36
BIM software seems catered to commercial construction	6.36
Different BIM platforms or versions are often incompatible	6.91
Software platforms require updates for continued use	7.09
11-25	**2 Total Respondents**
Steep learning curve when training employees	1.00
Time-consuming to create and maintain models correctly	2.50
Lots of training is required to maintain effectiveness	3.50
BIM software seems catered to commercial construction	5.50
High software costs	6.00
Difficult to find qualified, experienced employees	6.00
Computer hardware needs to be substantial	7.00
Different BIM platforms or versions are often incompatible	7.00
Overabundance of information can overwhelm or confuse clients	8.00
Software platforms require updates for continued use	8.50
26-50	**1 Total Respondent**
High software costs	1.00
Steep learning curve when training employees	2.00
Computer hardware needs to be substantial	3.00
BIM software seems catered to commercial construction	4.00
Difficult to find qualified, experienced employees	5.00
Different BIM platforms or versions are often incompatible	6.00
Time-consuming to create and maintain models correctly	7.00
Software platforms require updates for continued use	8.00
Lots of training is required to maintain effectiveness	9.00
Overabundance of information can overwhelm or confuse clients	10.00

4.4.7   Number of Homes: Questionnaire 2

Within the number of homes demographic in questionnaire 2, data was received from all the same groups represented in questionnaire l. Nine responses were received from the 0-10 homes group, four from the 11-30 homes group, none from the 31-60 homes group, and one from the 61+ homes group. The data from these groups is summarized below.

The 0-10 homes group identified their top three uses as *design and visualization*, the *creation of construction documents* and *quantity takeoffs*. Eight out of the nine members of the group listed *design and visualization* as one of their most common uses. Six of the nine participants in this group listed *creation of construction documents* and five out of nine participants listed *quantity take-offs*. This group did not list *marketing*, indicating that it is not a common use within this demographic. The 11-30 homes group most commonly listed *design and visualization*, *marketing*, the *creation of construction documents*, and *field management/corrections* as their top three uses. *Design and visualization* was listed by all four participants in this group. *Marketing* was listed by three of the four participants. The *creation of construction documents* and *field management/corrections* were both listed by two of the four participants. This group did not list *design coordination and/or clash detection* or *scheduling.* The 61+ homes group, which only had one member responding, listed *marketing*, *design and visualization*, and the *creation of construction documents*. This member did not list *field management/corrections, design coordination and/or clash detection, scheduling,* or *quantity take-offs*.

Table 4.22: Most Common BIM Uses Organized by Number of Homes

Number of Homes	Listed Uses of BIM	%
0-10		**9 Total Respondents**
Design and visualization	8	89%
Creation of construction documents	6	67%
Quantity take-offs	5	56%
Design coordination and/or clash detection	2	22%
Field management/corrections	1	11%
Scheduling	1	11%
11-30		**4 Total Respondents**
Design and visualization	4	100%
Marketing	3	75%
Field management/corrections	2	50%
Creation of construction documents	2	50%
Quantity take-offs	1	25%
61+		**1 Total Respondent**
Marketing	1	100%
Design and visualization	1	100%
Creation of construction documents	1	100%

The 0-10 homes group identified *client visualization*, *plan accuracy* and *improved client communication* as their top three benefits. Those benefits each received average rankings of 2.33, 3.11, and 4.67 respectively. The 11-30 employee group ranked *plan accuracy*, *client visualization,* and *improved client communication* as their most beneficial with each receiving and an average ranking of 1.5, 2.25 and 3.25 respectively. The 61+ homes group ranked, in this order, *plan accuracy*, *ease of plan revisions*, and *early identification of design errors* as providing the greatest benefit.

Table 4.23: Ranked BIM Benefits Organized by Number of Homes

Number of Homes	Average Ranking (1=most beneficial, 10 =least beneficial)
1-10	**9 Total Respondents**
Client visualization	2.33
Plan accuracy	3.11
Improved client communication	4.67
Ease of plan revisions	5.00
Early identification of design errors	5.22
Ability to show plan from different angles	5.89
Quicker, more accurate quantity take-off's or estimating	6.00
Improves scheduling effectiveness	6.89
Improved communication with/between trades	7.11
Improved marketing materials (i.e. renderings)	8.78
11-30	**4 Total Respondents**
Plan accuracy	1.50
Client visualization	2.25
Improved client communication	3.25
Early identification of design errors	5.75
Ability to show plan from different angles	6.00
Improved communication with/between trades	6.25
Ease of plan revisions	6.25
Improved marketing materials (i.e. renderings)	7.50
Quicker, more accurate quantity take-off's or estimating	7.75
Improves scheduling effectiveness	8.50
61+	**1 Total Respondent**
Plan accuracy	1.00
Ease of plan revisions	2.00
Early identification of design errors	3.00
Improved marketing materials (i.e. renderings)	4.00
Client visualization	5.00
Quicker, more accurate quantity take-off's or estimating	6.00
Improved client communication	7.00
Improved communication with/between trades	8.00
Improves scheduling effectiveness	9.00
Ability to show plan from different angles	10.00

The top three challenges identified by the 0-10 homes group were the *steep learning curve when training employees*, *high software costs*, and the *time-consuming nature of creating*

and maintaining models correctly which each received an average ranking of 2.67,4.00 and 4.11 respectively. The 11-30 homes group ranked *high software costs* as their top challenge with an average ranking of 2.5 followed by *computer hardware requirements* with an average ranking of 4.25. The *steep learning curve when training employees* and the *time-consuming nature of creating and maintaining models correctly* were next with average ranking of 4.5 each. The 61+ homes group ranked, in this order, the *time-consuming nature of creating and maintaining models correctly*, that *different BIM platforms are often incompatible*, and that *extensive training is required to maintain effectiveness* as their top challenges.

Table 4.24: Challenges of BIM as Ranked and organized by Number of Homes

Number of Homes	Average Ranking (1=most beneficial, 10 =least beneficial)
0-10	**9 Total Respondents**
Steep learning curve when training employees	2.67
High software costs	4.00
Time-consuming to create and maintain models correctly	4.11
Lots of training is required to maintain effectiveness	4.78
Difficult to find qualified, experienced employees	5.11
BIM software seems catered to commercial construction	6.33
Computer hardware needs to be substantial	6.44
Overabundance of information can overwhelm or confuse clients	7.00
Different BIM platforms or versions are often incompatible	7.11
Software platforms require updates for continued use	7.44
11-30	**4 Total Respondents**
High software costs	2.50
Computer hardware needs to be substantial	4.25
Steep learning curve when training employees	4.50
Time-consuming to create and maintain models correctly	4.50
BIM software seems catered to commercial construction	5.50
Overabundance of information can overwhelm or confuse clients	5.75
Difficult to find qualified, experienced employees	6.00
Lots of training is required to maintain effectiveness	7.00
Different BIM platforms or versions are often incompatible	7.50
Software platforms require updates for continued use	8.50
61+	**1 Total Respondent**
Time-consuming to create and maintain models correctly	1.00
Different BIM platforms or versions are often incompatible	2.00
Lots of training is required to maintain effectiveness	3.00
Computer hardware needs to be substantial	4.00
Steep learning curve when training employees	5.00
BIM software seems catered to commercial construction	6.00
Software platforms require updates for continued use	7.00
Difficult to find qualified, experienced employees	8.00
High Software Costs	9.00
Overabundance of information can overwhelm or confuse clients	10.00

4.4.8 Average Sale Price: Questionnaire 2

Responses were collected from all average sale price demographic groups represented in questionnaire 1. Seven responses were received from the $250,001-$500,000 group. Two responses were received from the $500,001-$7500,000 group. One response was received from the $750,001-$1,000,000 group. Four responses were received from the from the $1,000,001+ group.

The $250,001-$500,000 group listed *design and visualization* and the *creation of construction documents* as their most common uses with six of seven participants listing each use followed by *quantity take-offs* with three listings. *Marketing*, *field management/corrections*, *design coordination and/or clash detection*, and *scheduling* were the least commonly listed uses. The $500-001-$750,000 group listed *design and visualization* as their top use with both participants in the group listing it as a top use. This group also listed *marketing*, *field management/corrections*, the *creation of construction documents*, and *quantity take-offs* as uses, each with one listing. This group, however, did not list *design coordination and/or clash detection*, or *scheduling* within their most common uses. The $750,001-$1,000,000 group listed *marketing*, *design and visualization*, and the *creation of construction documents* as their top three uses. This group did not list *field management/corrections, design coordination and/or clash detection, scheduling,* or *quantity take-offs.* The $1,000,001+ group most commonly listed *design and visualization*, and *quantity take-offs* as their top uses with *design and visualization* receiving four of four listings and *quantity take-offs* receiving two of four listings. The rest of the uses each received one listing which were the least commonly listed uses.

Table 4.25: Most Common BIM Uses Organized by Average Sale Price

Average Sale Price	Listed Uses of BIM	%
$250,001-$500,000	**7 Total Respondents**	
Design and visualization	6	86%
Creation of construction documents	6	86%
Quantity take-offs	3	43%
Marketing	1	14%
Field management/corrections	1	14%
Design coordination and/or clash detection	1	14%
Scheduling	1	14%
$500,001-$750,000	**2 Total Respondents**	
Design and visualization	2	100%
Marketing	1	50%
Field management/corrections	1	50%
Creation of construction documents	1	50%
Quantity take-offs	1	50%
$750,001-$1,000,000	**1 Total Respondent**	
Marketing	1	100%
Design and visualization	1	100%
Creation of construction documents	1	100%
$1,000,001+	**4 Total Respondents**	
Design and visualization	4	100%
Quantity take-offs	2	50%
Marketing	1	25%
Field management/corrections	1	25%
Creation of construction documents	1	25%
Design coordination and/or clash detection	1	25%
Scheduling	1	25%

The $250,001-$500,000 group ranked *plan accuracy*, which received an average ranking of 2.29, *client visualization*, which received an average ranking of 2.71, and *ease of plan revisions*, which received an average ranking of 3.43, as their greatest benefits. The $500-001-$750,000 group ranked *plan accuracy* and *client visualization* as their top benefits each with an average ranking of 2.00, followed *by improved client communication* with an average ranking of 3.00. The $750,001-$1,000,000 group ranked, in the following order, *plan accuracy*, *ease of plan revisions*, and *client visualization* as their top three benefits. The $1,000,001+ group ranked

client visualization, which received an average ranking of 2.25, *plan accuracy*, which received

an average ranking of 3.50, *improved client communication* and *improved scheduling*

effectiveness, which each received rankings of 4.50, as their greatest benefits.

Table 4.26: Benefits of BIM as Ranked and organized by Average Sale Price

Average Sale Price	Average Ranking (1=most beneficial, 10 =least beneficial)
$250,001-$500,000	**7 Total Respondents**
Plan accuracy	2.29
Client visualization	2.71
Ease of plan revisions	3.43
Early identification of design errors	4.71
Improved client communication	4.86
Ability to show plan from different angles	6.29
Quicker, more accurate quantity take-off's or estimating	6.57
Improved marketing materials (i.e. renderings)	7.71
Improved communication with/between trades	8.00
Improves scheduling effectiveness	8.43
$500,001-$750,000	**2 Total Respondents**
Plan accuracy	2.00
Client visualization	2.00
Improved client communication	3.00
Early identification of design errors	5.50
Quicker, more accurate quantity take-off's or estimating	6.00
Improved communication with/between trades	6.00
Ease of plan revisions	7.00
Ability to show plan from different angles	7.00
Improved marketing materials (i.e. renderings)	7.50
Improves scheduling effectiveness	9.00
$750,001-$1,000,000	**1 Total Respondent**
Plan accuracy	1.00
Ease of plan revisions	2.00
Client visualization	3.00
Improved client communication	4.00
Early identification of design errors	5.00
Ability to show plan from different angles	6.00
Improved marketing materials (i.e. renderings)	7.00
Improved communication with/between trades	8.00
Quicker, more accurate quantity take-off's or estimating	9.00
Improves scheduling effectiveness	10.00
$1,000,001+	**4 Total Respondents**
Client visualization	2.25
Plan accuracy	3.50
Improved client communication	4.50
Improves scheduling effectiveness	4.50
Improved communication with/between trades	5.25
Ability to show plan from different angles	5.75
Quicker, more accurate quantity take-off's or estimating	6.00
Early identification of design errors	6.00
Ease of plan revisions	8.00
Improved marketing materials (i.e. renderings)	9.25

The $250,001-$500,000 group ranked the *steep learning curve when training employees*, which received an average ranking of 3.14, the *time-consuming nature of creating and maintaining models correctly*, which received an average ranking of 3.86, and *high software costs*, which received an average ranking of 4.14, as their greatest challenges. This group also ranked *Software platforms require updates for continued use* and *BIM software seems catered to commercial construction* as their least difficult challenges. The $500-001-$750,000 group ranked the *overabundance of information that confuses clients*, which received an average ranking of 2.00, *high software costs*, which received an average ranking of 3.50, the *time-consuming nature of creating and maintaining models correctly* and *computer hardware requirements*, each with an average ranking of 5.00, as their greatest challenges. This group ranked *different BIM platforms or versions are often incompatible* and *difficult to find qualified, experienced employees* as their least difficult challenges. The $750,001-$1,000,000 group ranked, in the following order, *high software costs*, the *steep learning curve when training employees*, and *computer hardware requirements* as their greatest challenges. This member ranked *lots of training is required to maintain effectiveness* and *overabundance of information can overwhelm or confuse clients* as their least difficult challenge. The $1,000,001+ group ranked the *steep learning curve when training employees* and *the time-consuming nature of creating and maintaining the model correctly*, which each received an average ranking of 3.00, the *difficulty of finding qualified, experienced employees*, which received an average ranking of 4.25, *and high software costs*, which received an average ranking of 4.50, as their greatest challenges. This group also ranked *software platforms require updates for continued use* and *overabundance of information can overwhelm or confuse clients* as their least difficult challenges.

Table 4.27: Ranked BIM Challenges Organized by Average Sale Price

Average Sale Price	Average Ranking (1=most beneficial, 10 =least beneficial)
$250,001-$500,000	**7 Total Respondents**
Steep learning curve when training employees	3.14
Time-consuming to create and maintain models correctly	3.86
High software costs	4.14
Lots of training is required to maintain effectiveness	4.57
Difficult to find qualified, experienced employees	5.71
Different BIM platforms or versions are often incompatible	6.29
Overabundance of information can overwhelm or confuse clients	6.71
Computer hardware needs to be substantial	6.71
Software platforms require updates for continued use	6.86
BIM software seems catered to commercial construction	7.00
$500,001-$750,000	**2 Total Respondents**
Overabundance of information can overwhelm or confuse clients	2.00
High software costs	3.50
Time-consuming to create and maintain models correctly	5.00
Computer hardware needs to be substantial	5.00
Steep learning curve when training employees	5.50
BIM software seems catered to commercial construction	5.50
Lots of training is required to maintain effectiveness	6.50
Software platforms require updates for continued use	6.50
Different BIM platforms or versions are often incompatible	7.00
Difficult to find qualified, experienced employees	8.50
$750,001-$1,000,000	**1 Total Respondent**
High software costs	1.00
Steep learning curve when training employees	2.00
Computer hardware needs to be substantial	3.00
BIM software seems catered to commercial construction	4.00
Difficult to find qualified, experienced employees	5.00
Different BIM platforms or versions are often incompatible	6.00
Time-consuming to create and maintain models correctly	7.00
Software platforms require updates for continued use	8.00
Lots of training is required to maintain effectiveness	9.00
Overabundance of information can overwhelm or confuse clients	10.00
$1,000,001+	**4 Total Respondents**
Time-consuming to create and maintain models correctly	3.00
Steep learning curve when training employees	3.00
Difficult to find qualified, experienced employees	4.25
High software costs	4.50
Computer hardware needs to be substantial	4.75
Lots of training is required to maintain effectiveness	5.00
BIM software seems catered to commercial construction	5.25
Different BIM platforms or versions are often incompatible	8.00
Software platforms require updates for continued use	8.50
Overabundance of information can overwhelm or confuse clients	8.75

4.5   Questionnaire 3 Results

The final questionnaire in this study was distributed in an effort to obtain consensus concerning all the data received in the first two questionnaires. We received 10 responses to questionnaire 3. The participants who responded consisted of five owners, three BIM managers, and two designers. The experts were asked to indicate their agreement with the various rankings and commonalities identified in questionnaire 2. The results of this questionnaire indicate that consensus was obtained in all but one area. The question concerning the most under-utilized use of BIM received only 50% consensus. None of the participants indicated why they disagreed with the ranking but one participant indicated that he mostly agreed, while stating that he "would love to develop this further."

Table 4.28: Questionnaire 3 Results

Question	Average Agreement	% of experts (10 Total) who ranked as					% of experts who ranked as	
		5	4	3	2	1	Agree	Disagree
Indicate your agreement with the implementation process rankings.	4.1 out of 5	10	90	0	0	0	100	0
Indicate your agreement with the ranking of the 3 most common uses of BIM in Custom Home Building.	4.4 out of 5	50	40	10	0	0	90	0
Indicate your agreement with the ranking of the benefits of BIM in Custom Home Building.	4.3 out of 5	50	30	20	0	0	80	0
Indicate your agreement with the ranking of the Challenges of BIM in Custom Home Building.	4 out of 5	30	40	30	0	0	70	0
Indicate your agreement with the statement "the 3 most common uses of BIM in Custom Home building are Design and Visualization, the creation of construction Documents and Quantity Take-offs."	3.7 out of 4	N/A	30	70	0	0	100	0
Indicate your agreement with the statement, "the most common under-utilized use of BIM in Custom Home Building is Quantity Take-offs."	2.8 out of 4	N/A	40	10	40	10	50	50

5 CONCLUSION

The overall purpose of this study was to identify current best practices, benefits, and challenges associated with the use of BIM in custom home building companies in the United States. This provides a basis of understanding for companies desiring to implement BIM. This basis of understanding provided by experts within the industry would improve their chances for successful implementation.

5.1 BIM in Custom Home Building

Communication is crucial to the success of any project. This fact is perhaps even more poignant when applied to the construction industry. Many technological advances have taken place that increase the ease and effectiveness of communication in construction. One key technological advance that improves communication and overall project efficiency is Building Information Modeling or BIM. BIM has become a common tool among commercial general contractors worldwide and has provided multiple benefits to the industry. However, while BIM has been a key tool in commercial construction projects, it has yet to find its place in the residential construction sector.

The residential construction sector accounts for a significant portion of the construction that takes place in the United States and the segment of custom home building is defined as being similar to commercial construction in complexity. It is anticipated that BIM could provide

similar benefits to the residential custom home construction sector as it does to the commercial sector. Therefore, the purpose of this study was to provide a basis of understanding for industry members seeking to implement BIM by identifying experts within the industry who currently utilize BIM to benefit their companies and receive answers to the following questions:

- What BIM software is being used?

- What is the best implementation process?

- What are the most common uses of BIM?

- What are the most common benefits of BIM?

- What are the most common challenges associated with BIM use?

These questions were answered through the Delphi method which utilizes a panel of experts and a series of questionnaires that are developed based on the responses to the preceding questionnaire. The goal of the panel was to achieve consensus on the topic in question. These experts were initially asked a series of demographic questions that would place them in various categories that would be easily identifiable for other home builders to compare with. The participants were asked to identify their location of business, the number of employees within their companies, the number of homes they complete each year, and the average sale price of their homes. As the locations of the participants were mainly limited to the Mountain West, South, and West Coast regions, there is potential application for other locations. It is also important to note that due to the selected research methodology, the panel size was small and the uses, benefits, and/or challenges identified by each demographic sector may not be generalized to the market. However, because the participants consisted of industry experts, the data provides a reference point because of their related experiences.

5.2   BIM Software

There are multiple BIM software platforms available to the industry, but some are more popular than others. For a comprehensive list of BIM platforms that are available and a list of platforms that are more efficient for home builders, refer to the dissertation by Garcia and his associates entitled "Adoption of Building Information Modeling in Small Size Home-Building-Businesses." (Garcia, Mollaoglu (Korkmaz) and Syal 2016) The software identified by this panel as being used the most was Autodesk Revit®. However, other platforms like Chief Architect® or ArchiCAD® were also identified by the panel.

5.3   Implementation Process

The research performed did not provide a distinct "best" implementation process for those wishing to implement BIM. All processes received an average ranking with only a one-point difference between the highest ranking and lowest ranking. However, it is important to note that, in questionnaire 1, while the number one implementation process that was utilized to implement BIM within the participant's companies was to *hire experienced employees* and the least utilized was to *attend or watch training courses*, the results from questionnaire 2 were the opposite from questionnaire 1. This difference is between the implementation originally utilized by the participants as compared to the process they would use if they were to repeat the implementation process.

The number one ranked implementation process that they would utilize if they were to repeat the implementation process was to *attend or watch training courses* which could imply that company upper management is wanting to understand the process before expecting those who work for them to understand the process. It is understood that it is common practice in the

commercial construction sector to have a BIM department with a BIM Coordinator who is responsible for the learning and dissemination of BIM knowledge. Thus, the upper management of a commercial company may have limited knowledge of BIM uses and benefits. This may be due to the size of the company and the sheer volume of work being performed. However, the data from this study could suggest that the upper management of smaller-volume home building companies wish to understand the process because BIM is potentially being used as an "all-purpose" tool by the company for marketing, visualization, etc. Also, because of the relatively small number of home builders using BIM, this gives them a competitive advantage. Thus, BIM is a company-wide tool and could essentially be seen as an essential driver for success.

5.4 Most Common Uses of BIM

The following uses of BIM were identified by this panel.

- Marketing
- Design and visualization
- Field management/corrections
- Creation of construction documents
- Design coordination and/or clash detection
- Scheduling
- Quantity take-offs or estimating

All uses identified in the study received a top three ranking by at least one participant signifying that they are being used to the benefit to the industry. However, the participants clearly indicate that their most common use of BIM was *design and visualization* across all demographic groups represented. *Design and visualization* received over a hundred percent higher ranking than the next closest ranked use identified by this panel. The *creation of*

construction documents and *quantity take-offs* were also listed consistently throughout the study as common uses among all demographics. *Design and visualization,* the *creation of construction documents*, and *quantity take-offs* will be discussed in conjunction with benefits and challenges that could be associated with each use after the overall benefits and challenges have been discussed.

However, it is valuable to note that the most underutilized use of BIM identified by this panel was *quantity take-offs*, implying that there is a need for further development of that use within the industry.

The uses identified in this study correlate to the uses identified in the literature review. *Design and visualization* correlates with *design authoring*, *field management/corrections* correlates with *3D control and planning*, *design coordination* correlates with *3D coordination*, and *quantity take-offs* correlates with *cost estimation*. There is likely additional correlation between each list of uses but this simply shows some of the correlation between what has been identified in the literature and what the panel identified.

5.5   Most Common Benefits of BIM

Among this panel, *client visualization*, *plan accuracy*, *improved client communication*, and *ease of plan revisions* were ranked among the top benefits across all demographics. This correlates with the uses of BIM identified by this group. *Design and visualization* directly influences *client visualization* and *improved client communication*; and *creation of construction* documents directly influences the *accuracy of plans* and *ease of plan revisions*.

These benefits correlate to the benefits of BIM identified in the review of the literature. Table 2.1, which lists the benefits for each NAICS Construction Subsector, revealed a lack of

research in the residential construction sector. This research provides support to the benefit of *increased communication*. This panel identified *improved client communication*, *improved communication with/between trades*, and other benefits specifically related to plans that could contribute to *increased communication*. While they do not correlate directly in name, the other benefits identified by this panel include *increased project quality*, *increased trade coordination, increased productivity* and *reduced project costs*. *Improved communication* and increased *accuracy of plans* may assist in improving the coordination between trades. Another example of this could be *early identification of design errors* and *quicker, more accurate quantity take-off's or estimating* reducing project costs. The only benefits identified in the literature review that had no potential relation to the benefits identified in this study was *increased jobsite safety*. The participants in this study did not indicate any benefits related to safety.

Table 5.1: Potential Relation of Benefits

Benefits identified in Literature Review	Benefits identified by this panel
Increased Project Quality	Early identification of design errors
Reduced Project Costs	Early identification of design errors; Quicker, more accurate Quantity Take-off's or estimating
Decreased Project Schedule	Improves Scheduling effectiveness; Quicker, more accurate Quantity Take-off's or estimating; Ease of Plan Revisions
Increased Productivity	Improved Client communication; Improved communication with/between trades; Early identification of design errors; Ease of Plan Revisions
Increased Jobsite Safety	
Increased Trade Coordination	Improved communication with/between trades; Ability to show plan from different angles
Increased Communication	Client Visualization; Improved Client communication; Improved communication with/between trades; Ability to show plan from different angles

Table 5.2: Effects of this Study on Table 2.1

Benefit	Residential	Commercial	Industrial	Utility	Land Subdivision	Highway
Increased Project Quality	Manrique, 2015 TS*	Suerman, 2009 Bryde, 2013				Chong et al, 2016
Reduced Project Costs	Manrique, 2015 TS*	Suerman, 2009 Azhar, 2011 Bryde, 2013 Giel, 2013		Traynor, 2009		
Decreased Project Schedule	Manrique, 2015 TS*	Suerman, 2009 Bryde, 2013				Chong et al, 2016
Increased Productivity	Manrique, 2015 TS*	Suerman, 2009 Borup, 2007 Francom, 2015				
Increased Jobsite Safety		Suerman, 2009				
Increased Trade Coordination	TS*	Bryde, 2013 Lu, 2015 Bynum, 2013 Woo, 2010 Hanna, 2013	Gourlis, 2017			Sibert, 2013
Increased Communication	TS*	Bryde, 2013 Childress, 2014 McGraw Hill Construction, 2014; Poirier, 2015				

*TS indicates the findings of this study and their potential relation.

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5.6   Most Common BIM Challenges

While the *steep learning curve when training employees* was the challenge that was ranked the highest by the panel, each demographic group selected their own individual greatest challenge. Eight of the challenges identified by this panel were ranked in the top three by at least one of the demographic groups. There are two challenges that were not ranked within the top three by any of the demographic groups, that *BIM seems catered to commercial construction* and that *software platforms require updates for continued use*. However, *high software costs*, the *steep learning curve when training employees*, and the *time-consuming nature of creating and maintaining models correctly*, were ranked among the top challenges faced by a majority of the panel.

5.7   Further Discussion

Every benefit identified by the panel is a potential result of at least one of the uses identified by the panel. However, many of the benefits and some of the challenges are potential results of just the top three uses identified. The top three uses and any potential resultant benefits and challenges were identified. The importance of any possible correlation identified here lies in how the affect the success factors identified by the 2005 study performed by Hutchings and Christofferson (Hutchings and Christofferson 2005). The uses and benefits that have been identified could directly affect these success factors and greatly improve a company's ability to perform their work.

5.7.1   Design and Visualization

Design and Visualization was by far the top use identified and only one of the participants did not list it as one of their top uses. This use can be directly tied to the benefit of *client*

visualization, which was the top benefit identified by the panel and by a majority of the demographic groups represented within the panel. Because BIM features a 3D model of the product, a home in this case, clients are able to view homes in a 3D sphere, allowing them to get a more accurate picture of what the design looks like in a near life-like manner. This 3D sphere in relation to *design and visualization* also could be seen to result in the *ability to show the plan from different angles*. Clients are able to view other areas of the plan that would not otherwise be shown on traditional 2D plans, thus enhancing their ability to visualize what is being designed and make decisions. Because of the ability to show a plan from different angles and enhance the visualization aspect, *design and visualization* also has a correlation with *improved client communication*. However, this use could also be attributed with one of the challenges identified, *the over-abundance of information that can confuse clients*. *Design and visualization* applies to more than just the client, however. It also applies to the homebuilder and the trade contractors. *Design and visualization* could also result in *improved communication with/between trades* because the ability to show the plan from different angle as well as being able to visualize the plan in a 3D atmosphere enables the trades to see a fuller picture of the design.

The success factors that could be directly affected by this use and any subsequent benefits are a *focus on product design* and *customer relations and communication*. *Design and visualization* directly influences a focus on design and more likely is the driver of a focus on design. The customer relations and communications are improved because of the customer's ability to see graphically in 3D what may not necessarily be understood from a 2D plan view perspective. One could also argue that schedule/cycle time could also improve because of the ability to visualize the product and communicate more effectively any changes or decisions that needed to be made. Because these changes or decisions are being communicated more

effectively, it could translate to being completed more quickly. However, as mentioned earlier, there may be a concern with too much information for clients. If there is too much information, there is potential for the client to get distracted by all the details and be unable to focus on specific decisions or needs of the project. An example of this was stated by a participant: "If we provide a BIM experience for a client in a draft phase of the design, certain clients can't see past an exposed 2x4 and we can't get good feedback on more important issues."

5.7.2   Creation of Construction Documents

The *creation of construction documents* could potentially be seen to produce a number of the benefits identified by the panel. Those benefits could include *plan accuracy*, *early identification of design errors,* and *ease of plan revisions*. These items are potentially correlated because of the nature of creating a BIM model. Because a model is created in 3D, any changes made in one area of a model are automatically updated in any other view where that area is shown. This increases the overall accuracy of construction documents, specifically where plan sheets have any cross-over in what is shown, makes revisions simpler because changes are automatically propagated throughout all views, and aids in the discovery of design errors because of the ability to view the plan from different angles. Similar to *design and visualization*, the *creation of construction documents* may also produce the benefits of *improved client communication* and *improved communication with/between trades* because they are able to see a fuller picture. One could also claim that this use could also benefit from the *ability to show the plan from different angles* because any 3D view can be translated to a 2D plan sheet. As one of the participants state in their description of the *creation of construction documents* use, "2D pages are a snap-shot of a detailed 3D model." However, creating a detailed 3D model takes time

and, therefore, may result in the challenge that it is *time consuming to create and maintain models correctly.*

One can see how the use of the *creation of construction documents* could potentially improve the efficiency of the process as a whole. Fewer errors in the plans and a fuller picture of the project means less confusion during construction and a shorter construction process. But as mentioned earlier, the real importance lies in how these uses and benefits affect the success factors identified by Hutchings and Christofferson (Hutchings and Christofferson 2005). The success factors that may be affected by the use of the *creation of construction documents* are *quality workmanship and products*, *customer communications and relations*, and *scheduling/cycle time.* These success factors were affected because as plans become more accurate, the chances for confusion, both by the clients and the trades, decrease. As confusion decreases, quality increases, less errors occur in the field, and relations with the clients improve. This also decreases the cycle time because of the decrease in errors.

5.7.3   Quantity Take-offs

The use of BIM for *quantity take-offs* may have a more obvious correlation with the benefit of *quicker, more accurate quantity take-offs or estimating*. However, this quicker, more accurate take-off is reliant on an accurate model. Therefore, if the benefit of *plan accuracy* is not being seen then *quantity take-offs* may not be effective. This benefit was also listed as the most under-utilized, implying that more research is needed to identify how to improve the usefulness of BIM quantity take-offs within the industry. One participant stated that "Currently, it is just quicker, easier, and more accurate to do takeoffs by hand," and that "[he] would love to develop this further."

This use and its benefit directly affects the success factor of *competitive pricing/ product affordability* because as quantity take-offs become more and more accurate, the need for contingencies and waste factors used while estimating decreases, which decreases the price to build. This improves the pricing and overall affordability of the product.

5.8   Final Discussion and Recommendations

The inter-relatability between the various uses, benefits and challenges can be substantial and should be considered. One use alone will not likely produce the desired return. Because the uses of BIM utilize a single model, the training and time required to utilize multiple uses may be considered minimal and the likelihood of a positive return on investment improves. Therefore, successful implementation may be based on the company's ability to learn and understand BIM uses, whether that is accomplished through hiring experienced employees, training current employees or self-led education of upper management. That understanding includes what the uses are, how they are used, and the benefits associated with each use.

It is recognized that some of the challenges identified by this group may pose a significant hurdle for BIM implementation. Therefore, it is recommended that those wishing to implement BIM utilize those uses identified by this study as providing the most benefit, namely, *design and visualization*, *creation of construction documents*, and *quantity take-offs*. Successful implementation has been achieved by the panel participants and may be possible for others wishing to implement BIM.

5.9   Future Research Needs

Following this research, a study that includes a larger sample that can be generalized to the market, as a whole, is necessary to determine market trends. Similarly, a study that seeks to

identify why BIM is not being utilized within the residential sector to the same degree as commercial construction may be necessary to determine market concerns. A study that analyzes homeowners' perceptions and experiences as clients of home builders who utilize BIM in their processes would also provide crucial insight into the benefits of BIM from the perspective of the client. Research specific to the use of BIM for quantity take-offs was also mentioned specifically by the panel as an area were development is needed. In addition, any blank spaces in Table 2.1: Benefits identified in each NAICS Construction Subsector constitutes a need for research on the data corresponding to each blank space.

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APPENDICES

APPENDIX A.   LIST OF EXPERT PANEL MEMBERS

Company Name	Expert	State of Primary Location
Van Sickle Design	Bill Van Sickle	Utah
Cardinal Crest Homes	Joe Christensen	Kansas
Ezra Lee Design Build	Kelly	Utah
Heartwood Design Build	Tomas Salinas	California
Jeff Watson Homes	Ken Doocy	Texas
Markay Johnson Construction	Chad Broadhead	Utah
Montana Heritage Home Builders	Allen Ream	Montana
Natural Builders LLC	Thomas Soule	New Mexico
Pioneer West Homes	Kristi Grabill	Colorado
South Fork Design Group	Ray	Idaho
Trails End Home Builders	Shawn	Colorado
Tresidio Homes	Dallin Fogle	Idaho
Trilogy Partners	Lars Zimmerman	Colorado
Green Design Build	Larry	Texas
Jenkins Design Build	Mark Lakins	Texas
RA Nelson	Ryan Lavire	Colorado
Starwood Custom Homes	Travis Allen	Arizona
Sun Forest Construction	Laurie Moar	Oregon

APPENDIX B.   QUESTIONNAIRE 1

Building Information Modeling Questionnaire 1

Where are you located? (Select all that apply)

☐ West Coast

☐ Midwest

☐ Mountain West

☐ Gulf Coast

☐ East Coast

☐ South

☐ Other (please list) _____

How many people does your company employ?

○ 1-10

○ 11-25

○ 26-50

○ 50+

How many homes do you complete each year?

○ 0-10

○ 11-30

○ 31-60

○ 61+

What is the average sale price of your homes?

○ Up to $250,000

○ $250,001-$500,000

○ $500,001-$750,000

○ $750,001-$1,000,000

○ $1,000,001+

What does your company specialize in? (select all that apply)

☐ New home construction

☐ Remodels

☐ Home additions

What software platforms do you use?

☐ ArchiCAD

☐ Bentley

☐ Vectorworks

☐ DataCAD

☐ Revit

☐ Sketchup

☐ Other (please specify) _____

What was your process for implementing BIM? (i.e. trained a current employee, hired an experienced employee, etc.)

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_____

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_____

How is BIM used in your company? (multiple answers encouraged if applicable)

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What benefits of BIM use have you identified in your company?

Benefit 1

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Benefit 2

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Benefit 3

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Benefit 4

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Benefit 5

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Benefit 6

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Benefit 7

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Benefit 8

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Benefit 9

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Benefit 10

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What challenges related to BIM use have you identified in your company?

Challenge 1

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Challenge 2

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Challenge 3

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Challenge 4

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Challenge 5

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Challenge 6

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Challenge 7

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Challenge 8

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Challenge 9

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Challenge 10

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If you have any other comments, you may write them here.

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APPENDIX C.　　　　**QUESTIONNAIRE 2**

Building Information Modeling Questionnaire 2

Thank you for your continued involvement in this study on the current state of BIM implementation within the custom home building industry. The questions in this questionnaire were developed from the responses received previously in questionnaire 1. Your answers will help clarify and expand on the information gathered during questionnaire 1.

Based on your experience, what process would you use to implement BIM if you were to have to do it again? Please rank the different methods below from 1 = *most likely to use* to 4 = *least likely to use.*

_____ Self-led education
_____ Hire experienced employees
_____ Train current employees
_____ Attend or watch training courses

Please select the three (3) most common uses of BIM within your company.

☐ Marketing

☐ Design and visualization

☐ Field management/corrections

☐ Creation of construction documents

☐ Design coordination and/or clash detection

☐ Scheduling

☐ Quantity take-offs or estimating

Please rank your top three uses: 1 = *most commonly utilized* to 3 = *least commonly utilized.*

_____ Marketing
_____ Design and visualization
_____ Field management/corrections
_____ Creation of construction documents
_____ Design coordination and/or clash detection
_____ Scheduling
_____ Quantity take-offs or estimating

Are there any of the uses listed below that your company either does not or rarely utilizes? Please select all that apply.

- ☐ Marketing

- ☐ Design and visualization

- ☐ Field management/corrections

- ☐ Creation of construction documents

- ☐ Design coordination and/or clash detection

- ☐ Scheduling

- ☐ Quantity take-offs or estimating

Are there any of the uses listed below that are under-utilized within your company? Please select all that apply.

- ☐ Marketing

- ☐ Design and visualization

- ☐ Field management/corrections

- ☐ Creation of construction documents

- ☐ Design coordination and/or clash detection

- ☐ Scheduling

- ☐ Quantity take-offs or estimating

Rank the benefits listed below from 1 = *most beneficial* to 10 = *least beneficial* to your organization.

_____ Plan accuracy
_____ Client visualization
_____ Quicker, more accurate quantity take-off's or estimating
_____ Improved client communication
_____ Improved communication with/between trades
_____ Improves scheduling effectiveness
_____ Early identification of design errors
_____ Improved marketing materials (i.e. renderings)
_____ Ease of plan revisions
_____ Ability to show plan from different angles

Rank the challenges listed below from 1 = *most challenging* to 10 = *least challenging* for your organization.

_____ High software costs
_____ Steep learning curve when training employees
_____ Time consuming to create and maintain models correctly
_____ Overabundance of information can overwhelm or confuse clients
_____ Lots of training is required to maintain effectiveness
_____ Computer hardware needs to be substantial
_____ Different BIM platforms or versions are often incompatible
_____ Bim software seems catered to commercial construction
_____ Software platforms require updates for continued use
_____ Difficult to find qualified, experienced employees

If you have any other comments, you may write them here.

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APPENDIX D. QUESTIONNAIRE 3

Building Information Modeling Questionnaire 3

Thank you for your continued involvement in this study on the current state of BIM implementation within the custom home building industry. This will be the final questionnaire in the study. The goal of this final questionnaire is to assess the level of consensus within the group. The questions in this questionnaire were developed from the responses received previously in questionnaire 2. Your answers will help clarify and expand on the information gathered during questionnaire 2.

According to the data gathered related to the question in questionnaire 2 concerning what method would be used if you were to go through the implementation process again, the methods of implementation were ranked as follows: (1=most preferred method and 4=least preferred method):

1. Attend or watch training courses
2. Hire an experienced employee
3. Train current employees
4. Self-led education

Please indicate the level of your agreement with this ranking.

○ Completely Disagree

○ Mostly Disagree

○ Neither Agree nor Disagree

○ Mostly Agree

○ Completely Agree

If you have any comments that describe why you agree or disagree, you may write them here. (Optional)

_____
_____
_____
_____
_____

According to this expert panel, the three most common uses of BIM in custom home building are:

1. Design visualization
2. Creation of construction documents
3. Quantity take-offs.

   Please indicate the accuracy of this statement based on your experience.

○ Completely Inaccurate

○ Mostly Inaccurate

○ Mostly Accurate

○ Completely Accurate

The three most common uses were ranked as follows:

1. Design visualization
2. Creation of construction documents
3. Quantity take-offs

   Please indicate your agreement with this ranking.

○ Completely Disagree

○ Mostly Disagree

○ Neither Agree nor Disagree

○ Mostly Agree

○ Completely Agree

If you have any comments that describe why you agree or disagree, you may write them here. (Optional)

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According to this panel, the most common under-utilized use of BIM in custom home building is quantity take-offs.

Please indicate the accuracy of this statement, based on your experience.

○ Completely Inaccurate

○ Mostly Inaccurate

○ Mostly Accurate

○ Completely Accurate

If you have any comments that describe why you agree or disagree, you may write them here. (Optional)

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According to data received in questionnaire 2, the previously identified benefits of BIM were ranked as follows:

1. Client visualization
2. Plan accuracy
3. Improved client communication
4. Early identification of design errors
5. Ease of plan revisions
6. Ability to show plans from different angles
7. Quicker, more accurate quantity take-offs or estimating
8. Improved communication with/between trades
9. Improved schedule effectiveness
10. Improved marketing materials (i.e. renderings)

Please indicate your agreement with this ranking.

○ Completely Disagree

○ Mostly Disagree

○ Neither Agree nor Disagree

○ Mostly Agree

○ Completely Agree

If you have any final thoughts about the benefits of BIM you may write them here. (Optional)

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According to data received in questionnaire 2, the previously identified issues or challenges of BIM were ranked as follows:

1. Steep learning curve when training employees
2. Time-consuming to create and maintain models correctly
3. High software costs
4. Lots of training required to maintain effectiveness
5. Computer hardware requirements
6. Difficult to find qualified, experienced employees
7. BIM software seems catered to commercial construction
8. Different BIM platforms or versions are often incompatible
9. Overabundance of information can overwhelm or confuse clients
10. Software platforms require updates for continued use

Please indicate your agreement with this ranking.

○ Completely Disagree

○ Mostly Disagree

○ Neither Agree nor Disagree

○ Mostly Agree

○ Completely Agree

If you have any comments that describe why you agree or disagree, you may write them here. (Optional)

_____

_____

_____

_____

_____

Would you like to receive a copy of the final results of this study?

○ Yes

○ No

Please list the email you would like these results sent to.

○ Email: _____