Building Information Modeling in the Custom Home Building Industry

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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 been mostly limited to the commercial sector with minimal advancement in residential applications. One potential cause for this may be the limited number of residential contractors who utilize the software. 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. A sample of residential contractors utilizing BIM in their businesses were identified and surveyed. The purpose of this study was to identify what software is being used and how it is being used, in addition to identifying the benefits and challenges associated with the use of BIM in the custom residential sector. Common uses identified were marketing, design and visualization, the creation of construction documents, design coordination, field management/corrections, and quantity take-offs. Common benefits identified were early identification of design errors, improved marketing materials, client visualization, plan accuracy, improved client communication, and ease of plan revisions. Lastly, common challenges identified were high software costs, computer hardware requirements, available software catered to commercial construction, the steep learning curve when training employees, and the time-consuming nature of creating and maintaining models correctly.

Key Words: Building Information Modeling, Residential, Custom Homes, Best Practices

Introduction

As the construction industry has grown, the method for communicating construction documents, and any revisions to them, has changed (Beveridge, 2012). Technology and digital construction documents are at the forefront, partially due the increasingly complex nature of construction projects. Beginning with the introduction of computer-aided design (CAD) in 1963 (Earl et al., 2008), the ability to digitally communicate and revise construction documents has steadily increased and improved in the industry. Recently, the technology has evolved into information-infused three-dimensional models known as Building Information Models (BIM).

BIM is defined as "the process of creating and using digital models for design, construction and/or operations of projects" (McGraw-Hill, 2009). These models can be used to aid design, assess risks, identify constructability issues, etc. (Beveridge, 2012). This software has permeated the commercial construction industry and a plethora of benefits have been identified and taken advantage of on construction projects worldwide (McGraw-Hill, 2009).

While the popularity of this software is increasing within the residential sector (Ford, 2016), it is not being utilized to the same degree. According to existing research, possible reasons for the slow adoption rate of BIM in residential construction are varied and range from a lack of awareness (NAHB, 2016) to high software costs prohibitive to the average home builder (Nellis, 2012). Despite these inhibitors, BIM is steadily entering the residential 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. In a similar study conducted by the NAHB in 2016, they found that those numbers had increased to 26% of members being familiar with BIM and 47% of those who were familiar with BIM currently using it (NAHB, 2016).

Since residential construction represents approximately 40% of the construction value placed in December of 2016 (United States Census Bureau, 2016), the use of BIM could provide immense benefits within this industry. 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 similar in complexity to some commercial construction. The purpose of this research was to identify how BIM is being used in custom residential construction. The specific research questions supporting this purpose were as follows:

- What BIM software is being used?
- What are the uses of BIM?
- What are the benefits of using BIM?
- What are the challenges of using BIM?

Due to the limited use of BIM in single-family residential construction there has been comparatively minimal research performed pertaining to its use (Cambeiro et al., 2014). Thus, there are limited scholarly resources for residential contractors wishing to implement BIM. This research is significant because it provides a basic understanding of the current state of BIM implementation and can support and inform decisions being made by interested home builders considering BIM.

Literature Review

BIM in Commercial Construction

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 (CIC, 2011). Uses were grouped into four categories: Plan, Design, Construct, and Operate. The data provided did not distinguish between industries so it is unclear whether or not residential contractors were included in the sample of respondents. A variety of other studies have identified key benefits of BIM found in commercial construction as follows:

- Increased project quality (Bryde, 2013; Manrique, 2015; Suermann, 2009)
- Reduced project costs (Azhar, 2011; Borup, 2007; Bryde, 2013)
- Decreased project schedule (Bryde, 2013, Manrique, 2015; Suermann, 2009)
- Increased productivity (Borup, 2007; Francom, 2015; Manrique 2015; Suermann, 2009)
- Increased jobsite safety (Suermann, 2009)
- Increased trade coordination (Bryde, 2013; Bynum, 2013)
- Increased communication (Bryde, 2013; Borup, 2007; Childress, 2014; Francom, 2015, Poirier, 2015)

Though residential construction has many differences in means and methods, some jurisdictions recognize that the complexity of projects, specifically custom homes, can be similar to commercial projects (Alabama Department of Economic and Community Affairs, 2015). These similarities between custom home building and commercial construction provide an appropriate stepping stone between the BIM-related research in the commercial industry, and their potential application to the residential sector.

BIM in Residential Construction

Some research has been performed to identify resources for small home-building enterprises who would like to implement BIM. A study performed by Garcia and his associates (2016) provides data on software and guidelines for effective adoption of BIM. These guidelines include:

- Need for 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.

Potential Benefits of BIM in Custom Residential Construction. 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). The research performed by Garcia and his associates also states that BIM benefits residential companies through increased productivity, profitability, and by providing a competitive advantage (Garcia et al., 2016).

During the economic recession between the years of 2007 and 2012, the number of residential builders dropped by over 50% (Quint, 2015). Hutchings and Christofferson (2005) identified factors that contributed to the success of small-volume home builders that survived. A few of the top ten factors from this list are particularly pertinent to the use of BIM for residential construction because of related key benefits of BIM previously listed. For example, the benefit BIM provides of *increased communication* could greatly affect the residential builder success factor of *customer communications and relations*. *Increased project quality* could impact the success factors of *quality workmanship and products* as well as *scheduling and cycle-time*. *Decreased project schedule* can clearly affect the success factor of *scheduling and cycle time*. The comparison between these success factors and the benefits identified provide support for the potential positive impact a wider implementation of BIM in residential construction could make.

Methodology

As this was the initial phase of an overarching multi-phase research project, the research design adopted for this particular portion of the study was interviews followed by a brief qualitative open-ended survey. The exploratory design of the questions in the survey discouraged response bias, which also allowed for a comparison of responses to reported uses/benefits/challenges described in the literature review previously. Given the relative lack of BIM application by residential contractors, this project relies on a moderately sized sample of respondents that is comprised of custom home builders who utilize BIM during any phase of their home building process. Respondents were selected based initially on a review of websites searching for companies that claimed BIM application. Once the list had been compiled, each organization was called to confirm their use of BIM and to obtain a relevant individual's consent to participate. Where necessary, the contact information of the appropriate company individuals were requested and additional phone calls were made until those responsible for and/or involved in BIM implementation within each organization were identified. 53 custom home builders were initially contacted based on the review of websites and 18 individuals were ultimately interviewed and electronically surveyed. All respondents are located within the contiguous United States of America.

The risks to participants were minimal and although demographic information was collected, identifiable information was not associated with their responses. Limitations include the relatively low number of final respondents making generalizability (external validity) difficult, and the self-report nature of the survey allows for potential misrepresentation by respondents. To maximize internal validity despite this limitation, survey responses were not associated with identifiable information and open-ended questions allowed for minimal instrument bias. Given the relatively small population of home builders implementing BIM that were willing to participate in this study, the project proceeded in an effort to establish some baseline understanding of current practice. Despite limitations, it is the author's opinion that this project provides a starting place for research related to BIM in residential construction. It is important for the residential industry to gain the efficiencies and benefits of BIM, and this project is an academic starting point for that effort.

Results

Table 1 details the participant demographic responses. Participants were permitted to select multiple operating locations and subsector specializations to allow for those who do business in multiple regions/subsectors to correctly represent themselves.

Table 1

Demographic Profile of Respondents

Demographic Segment	*N*	%
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%
50+	1	6%
Homes Completed Annually		
1-10	12	67%
11-30	5	28%
31-60	0	0%
61+	1	6%
Average Sale Price		
$250,000-$500,000	7	39%
$500,001-$750,000	3	17%
$750,001-$1,000,000	2	11%
$1,000,000+	6	33%
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%

Following the demographics questions, participants were asked to identify what software they utilized within their company. It is recognized that some software platforms on their own may not constitute full BIM capabilities (e.g., Sketchup, AutoCAD), however in most cases, they were generally used in conjunction with other platforms increasing the "information" component that is crucial for BIM. Table 2 identifies the software used and the number and percentage of respondents who used each reported software. Respondents were allowed to select more than one software.

Table 2

BIM Software Utilized by Respondents

Software Platform	*N*	%
Revit®	9	50%
Sketchup®	6	33%
ArchiCAD®	2	11%
Chief Architect®	2	11%
AutoCAD®	2	11%
Vectorworks®	1	6%
SolidBuilder®	1	6%

Participants were then asked to identify how BIM was used in their company as well as any benefits and/or challenges they experienced. Responses were collected and combined into the following general uses:

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

Respondents identified the following benefits:

- Plan accuracy
- Client visualization
- Quicker, more accurate quantity take-offs or estimating
- Improved client communication
- Improved communication with and 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

Lastly, the following challenges were also identified by the respondents:

- 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
- Amount of required training 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

Discussion

The collected qualitative data was codified and analyzed to allow for a comparison between the demographic variable and the respondent provided uses, benefits, and challenges. This analysis compared each demographic variable against the uses, benefits, and challenges identified to ascertain if certain demographics appeared to have substantively different responses. Due to space restrictions, noteworthy highlights were selected and included in this paper.

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 it as a use. *Quantity take-offs* was followed by *design and visualization* and *field management/corrections* with 31% and 23%, respectively. A similar trend was seen with 0-10 homes group which also described *quantity take-off* as their most common use. This data is surprising in that anecdotally, respondents are generally hesitant to rely heavily on BIM-provided quantity takeoff due to a lack of standards and inconsistency in the creation of the model itself. However, the potential for gains in efficiency and productivity with BIM-based quantity take-off is widely recognized and appreciated. The other three categories of respondents each had *design and visualization* as the most common use within their respective organizations.

Perhaps clarifying this apparent inconsistency in the data, the most common benefit provided by the 1-10 employees group was *client visualization* with 46% of the participants listing it as a benefit. This suggests that even though respondents in this group are attempting to take advantage of the quantity take-off capabilities in BIM, they have not yet realized the full potential benefit of that practice. *Client visualization* was followed by *plan accuracy*, *improved client communication* and *improved communication with/between trades*, each with 31% of respondents in the 1-10 employees group listing it as a benefit. When compared along the demographic associated with average sale price per home, *design and visualization* became the most commonly reported use. Not surprisingly as a result, the most commonly recognized benefit was *client visualization*.

Across every demographic, the most common challenges provided related to training and maintenance of the model. Specifically, with only one exception, the demographic groups along every variable listed *steep learning curve when training employees, extensive amounts of training required to maintain effectiveness,* and *time consuming to create and maintain models correctly* as their main challenges. The only exception was the 26-50 employee group listed that *BIM software seems catered to commercial construction*.

Based on this simple analysis, it appears that custom home builders are experiencing benefits mostly related to the graphical/visual component of BIM. This suggests that the “information” component of a BIM model is not currently adding significant value, despite some contractors’ efforts to use the model for quantity take-off. Depending on the goals of the organization, this should be taken into account when considering software options and potential applications.

Table 3 compares the benefits identified in this study to those previously identified in extant literature. Perhaps not surprisingly to those familiar with residential construction, the only benefit claimed in previous literature that was not identified during this study was related to increased jobsite safety.

Table 3

Identified benefits compared to literature review

Literature Review Benefits	Benefits Identified in this Study
Increased project quality	Early identification of design errors
Reduced project costs	Early identification of design errors; Quicker, more accurate quantity takeoff
Decreased project schedule	Improved scheduling effectiveness, Quicker, more accurate quantity take-offs or estimating; Ease of plan revision

Literature Review Benefits	Benefits Identified in this Study
Increased productivity	Improved client communication; improved communication with/between trades; Early identification of design errors; Ease of plan revisions
Increased jobsite safety	NA
Increased trade coordination	Improved communication with/between trades; Ability to show plan from different angles
Increased communication	Client visualization; Improved client communication, Improved communication between trades; Ability to show plan from different angles

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.

Many of the challenges identified may pose a significant hurdle for BIM implementation. Therefore, those wishing to implement BIM should focus on uses identified in this study that relate to the most commonly identified benefits: *design and visualization*, *creation of construction documents*, and *quantity take-offs*. Successful implementation has been achieved by the survey respondents and may be more likely achievable for others wishing to implement BIM.

Recommendations for Future Work

Following this research, a study that includes a larger sample that can be generalized to the wider residential market is necessary to determine wider market trends. Similarly, a study including home builders not currently using BIM that seeks to identify why BIM is not being utilized may be necessary to determine market concerns. Additionally, given the apparent focus on client visualization as a key benefit, 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. Finally, research specific to the use of BIM for quantity take-off in residential has the potential to help builders take advantage of that perceived opportunity for efficiency gains.

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