Implementation of Virtual Design Reviews in the Generation of As-Built Information

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Abstract

Generation of as-built building information is a growing necessity for retrofitting and renovating existing facilities. As building information modeling (BIM) is increasingly adopted in the construction industry, the development of information-driven models is becoming a standard for existing buildings, even before the design phase starts. Additionally, it is essential to evaluate and review the generated information before the design can begin. Therefore, the goal of this paper is to provide an exploratory two-step study (i.e., process mapping followed by a proof-of-concept experiment) on the implementation and assessment of visualization tools. These tools were implemented for the design review in the generation process of as-built information. To achieve this goal, four residential retrofit projects that required the production of as-built information were selected. In the first step, it was identified, within the generation process, where designers and surveyors typically review information and drawings. This step was achieved by process mapping of the building information flow for a typical residential project. Then, visualization tools were implemented for two of the projects, while the other two served as a control. In the second step, the records for requests for information (RFI) issued by the engineers for each of the projects were recorded. Based on the results, the projects that included visualization tools not only did have fewer RFIs, such as the location of building elements. The paper provides a unique perspective on implementation of visualization technology for the design review of as-built information. This study adds to the existing body of knowledge related to visualization in design reviews, which has been leveraged mainly in new construction projects.

Keywords: As-builts; Visualization; Design reviews.

1. INTRODUCTION

The implementation and adoption of new technologies, such as building information modeling (BIM), in the architectural, engineering, and construction (AEC) industry is steadily growing (McGraw-Hill 2014). According to the McGraw-Hill SmartMarket Report on *The Business Value of BIM for Construction* (2014),77% of contractors in the U.S. have implemented BIM in institutional projects (such as universities) while 66% of them used this technology for commercial projects. The report also states that by 2015, contractor's BIM implementation would reach 79% in the United States. Despite the widespread use of the BIM in commercial and institutional projects, its utilization in residential projects is only 1%. This low implementation level could be due to the small size of most residential projects that may not justify the costs associated with BIM implementation (Silverio et al. 2015). Nevertheless, BIM is still suggested s a highly innovative technology for the residential projects especially when long-term goals such as sustainability are concerned (Bellisario et al. 2016; Silverio et al. 2015). In particular, the benefits of BIM could support cities or regions that are struggling to meet growing housing demand. For instance, in a recent report by the Bay Area Council Economic Institute, Bellisario et al. (2016) advocated retrofitting of existing housing projects in the San Francisco Bay Area, which, so far, have failed to match the economic growth of the region. In this respect, utilizing an innovative technology such as BIM might constitute a viable sustainable solution to meet the current demand for housing in the Bay Area. In particular, BIM can be leveraged to support the retrofitting process of existing housing through the generation of accurate as-built information.

BIM provides project teams with a vast array of solutions to realize the successful completion of a project (Eastman et al. 2011). BIM can be leveraged to gather, generate, communicate, analyze, and realize information for a project (Kreider 2013). One particular BIM Use is the development of Record Models, or as-built information, for new or existing facilities (Huber et al. 2011; Computer Integrated Construction Research Program 2010). The process to generate as-built information typically can vary from traditional methods to advanced technology. Traditional methods include the use of surveying tools, such as total stations. Meanwhile, advanced technology, like laser scanning, can generate point-cloud information of the existing structure, which then facilitates the model generation process. In this generation process, it is essential to evaluate and review the generated information before the new design phase can begin (Shih and Wu 2005) and BIM can be leveraged for this purpose.

A specific BIM Use for the review of generated information is Design Review (Computer Integrated Construction Research Program 2010). Design Review is used at various stages of a project, ranging from design to construction (Computer Integrated Construction Research Program 2010). Implementing virtual mockups during the design review process can benefit all stakeholders to make accurate design decisions and establish a collaborative platform (Computer Integrated Construction Research Program 2010). For example, virtual design reviews have been leveraged in the design of institutional and commercial projects (Castronovo et al. 2013; Dunston et al. 2007) and shown to help detect errors in design and analyze the construction process. Benefits of virtual design reviews have resulted in their adoption as a key step in the process of generating design and reviewing construction. However, most of the research related to design reviews has focused on the design and construction of new institutional or commercial projects, neglecting residential projects. Similarly, research on generation of as-built information has mainly focused on commercial or institutional projects. Therefore, there is a dearth of knowledge regarding the potential of virtual design reviews outside of the commercial or institutional context, and their role in the creation of as-built information for residential projects remains to be explored.

To address this research gap, the goal of this paper is to assess the value of performing virtual design reviews in the generation process of as-built information. In order to achieve this goal, two different types of design reviews, traditional and virtual, were compared. The researchers supported a team of surveyors and structural engineers in the process of generating as-built information for residential projects, through leveraging visualization software. Based on these results, the research team was able to take an in-depth look at the role that virtual design reviews play in the generation phases of as-built information for residential projects.

2. BACKGROUND

2.1. Visualization

One of the technologies that the construction industry has been steadily implementing in projects is computer-based visualization to improve the design and construction process (Castronovo et al. 2014). Visualization can support designers to create a strong communication platform and tackle problems prior the construction phase (Koo and Fischer 2000; Castronovo et al. 2014; Kuljis et al. 2001). For example, by combining different system models of a building (such as architectural, structural, and plumbing) construction managers and designers can solve any coordination issues before they arrive on the site (Khanzode et al. 2008). Furthermore, visualization can be leveraged to perform 4D simulations. 4D simulations support project teams in developing accurate construction scheduling and anticipate problems and constraints before the construction phase (Kamat and Martinez 2003). Visualization can also be used on the job site to improve communications of building information to field workers. According to Koo and Fischer (2000) the design, planning, and construction process can be faster, more accurate, and with fewer change-orders when visualization is used for each of these phases. These studies indicate that the functional utility of visualization is pertinent to the delivery of all project types.

2.2. Design Reviews

An essential BIM Use in the process of delivering a facility is to perform design reviews. The process of reviewing the design is an essential step during the generation of architectural, engineering, and construction information. Design review process has evolved throughout the years, from light tables and page flipping to visualization software for virtual walkthroughs (Rice 2003; Castronovo et al. 2013). In particular, a software solution that has been increasingly adopted is the use of game engines, such as Unity 3D, to visualize 3D building information (Kumar et al. 2011). The visualization of virtual mockups and walkthroughs have been used to review design during the planning phase, support the energy retrofitting of existing buildings, and train facility managers for nuclear power plants (Liu et al. 2014; Maldovan and Messner 2006; Whisker et al. 2003). This growing implementation is due to virtual design reviews' ability to give the reviewers an accurate sense of scale, depth, and volume, which reduces the overall cognitive demand of the design process. Research on design reviews has so far focused on leveraging design reviews for commercial and institutional projects; yet none, to the best of authors' knowledge, has explored the residential domain.

2.3. Developing As-Built Information

The development of as-built information is key to the maintenance and future retrofitting of a facility; and with the growing adoption of BIM, facilities managers now have the ability to receive as-built information in the form of a Record Model. According to the Computer Integrated Construction Research Program (2010), a Record Model is an accurate representation of the as-built conditions and assets of a facility. However, creating a Record Model of an existing building is a complex task, especially for existing structures (Lu and Lee 2016). Traditional methods include the use of surveying tools, such as total stations. Meanwhile, advanced technologies, like laser scanning, can generate point-cloud information of the existing structure, which can in turn facilitate the model generation process (Huber et al. 2011; Shih and Wu 2005). The feasibility of leveraging cellphone technology, such as Project Tango, in developing as-built information has also been assessed (Kalyan et al. 2016). While this technology can facilitate the generation of as-built information, such information must be analyzed. Since an essential step in the process of developing as-built models for retrofits is to examine the data generated from the process, visualization software might be a viable solution to review as-built information.

3. PURPOSE OF STUDY

The goal of this study was to evaluate the role and value of visualization in the review process of as-built information for existing residential buildings. Based on this research goal, the following research questions were formulated:

- *What is the process of generating as-built information and review with visualization software?*
- *How do RFI issuance process in the design review process using visualization software differ to when 2D drawings are used?*

To answer these questions, the research team collaborated with a design studio, specialized in the generation of as-built information of residential projects. First for the process-mapping step of the study, the authors observed the design studio in the as-built generation process. Second, in an experimental design, the design studio was asked to perform design reviews of as-built information of residential projects through different types of processes (visualization versus 2D drawings). This step was essential for the research team in evaluating when virtual design reviews could be performed within the process of generating as-built information. The second question aimed at evaluating the value of implementing virtual design reviews. In particular, the research team was interested in the nature of the Request-for-Information (RFI) within the design team.

4. METHODOLOGY

4.1 Participants

The participants involved in the experiment consisted of two structural engineers, with 16 years of combined professional experience. Additionally, the participants included two surveyors, with 8 years of combined work experience. The structural engineers were responsible for designing the current and new structural elements for existing buildings. The surveyors were responsible for providing as-built drawings that they created during the site survey.

4.2 Experimental Procedure

4.2.1 Comparison Experiment

To evaluate the value of leveraging virtual design reviews, the research team developed a comparative case study. In this case study, traditional review methods and virtual design reviews were compared. To achieve this comparison, four residential projects were selected to be evaluated. All projects were located in the city of San Francisco, California. The experiment started with the on-site development of BIM models, in Autodesk Revit 2015 by the surveyors. The surveyors then provided as-built plans to the engineers to review and evaluate with a different order (see Figure 1). Each engineer got to review two projects, one with the traditional methods, and one with the virtual design review method. The order of the projects was randomized to avoid any order effects. After each review, the engineers were given the opportunity to file additional RFIs. The traditional method of design review involved the review of AutoCAD drawings and pictures taken from surveyors. However, for the virtual design review, the engineers were provided with a Unity3D walkthrough and PlanGrid files, which included pictures taken from the surveyors.

4.2.2 Virtual Walkthrough Development

The development of the virtual design review started with the generation of a BIM model by using Autodesk Revit 2015. The model was then exported to Autodesk 3DS Max Design 2015. This step was performed to ensure that all of the material textures, coming from the BIM model, were maintained for the following steps. The model was then imported into Unity game engine. In the game engine, mesh colliders were applied to floors and walls, to assure that the reviewer would fall through the provided geometry. Furthermore, the Unity project included a first-person camera view, to allow a review to walk through the model. The Unity project was then exported as an executable that could be opened on any personal computer.

4.3 Apparatus

As mentioned in the experimental procedure, the participants had to perform on-site surveys and off-site design reviews. During the on-site surveying, the hardware that the surveyors used were: laptops, laser scanner, tape measures, cameras, and a total station (Topcon GPT-3502). Autodesk Revit and Autodesk AutoCAD were used as the review software. Specifically, Autodesk Revit was used for the generation of the model and providing as-built detailed drawings. PlanGrid was adopted to attach pictures to the 2D drawings, to identify the location of the building elements. Lastly, AutoCAD was used to generate any additional details.

During the off-site design reviews, the researchers used virtual reality capable laptops to visualize the models. The software used to perform the virtual walkthrough was Unity 3D. Additionally, PlanGrid for the engineers to see the drawings, and AutoCAD to generate new structural drawings.

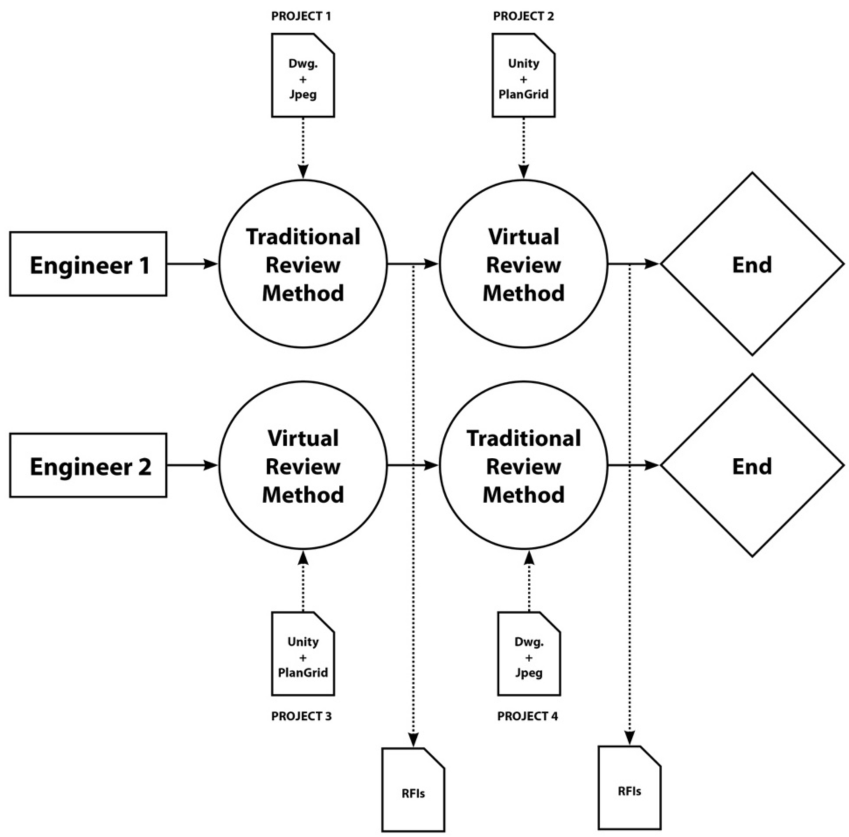

Figure 1. Experimental Procedure

5. RESULTS AND ANALYSIS
5.1 Process Map

What is the process of generating as-built information and review with visualization software?

As the first step in answering the research questions, the research team worked together with the studio members in mapping the generation process of as-built information. By performing this step, the research team was able to identify where with-in the process the studio team could implement virtual design reviews before the experiment could be performed. To generate this map the authors attended the generation process for four residential projects. Based on the analysis, the authors and surveyors mapped the generation process, as seen in Figure 2.

The first phase of the process included the site visit, where the surveyors survey the building and site, to generate a BIM model with Revit, and document the process by taking pictures and linking them to the drawings with PlanGrid. Before the second phase, the surveyors performed a first review of the file, while still on site. In the second phase, the surveyors transferred CAD drawings to the structural engineers so they could generate structural information for the residential project. During this step, the engineers reviewed the surveyors' drawings through a traditional page-flip.

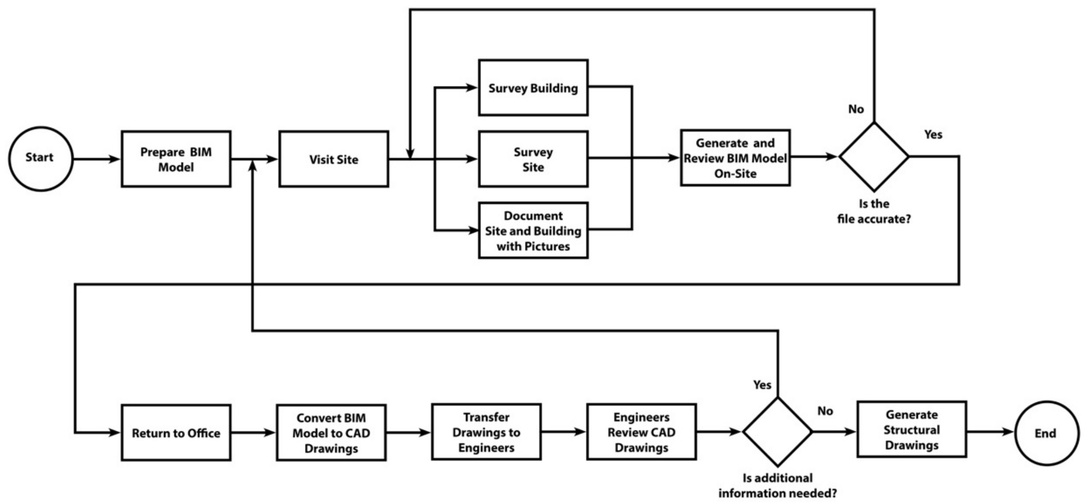

Figure 2. Studio As-Built Information Generation Process With CAD Drawings

Based on the process map, the research and studio team were able to identify where virtual design reviews could be applied. The engineers of the studio team highlighted that the review step of the CAD drawings generated a significant number of RFIs and wanted to evaluate if a virtual walkthrough could reduce such numbers. Therefore, the teams decided to perform a virtual walkthrough during the second phase of the generation process, see Figure 3.

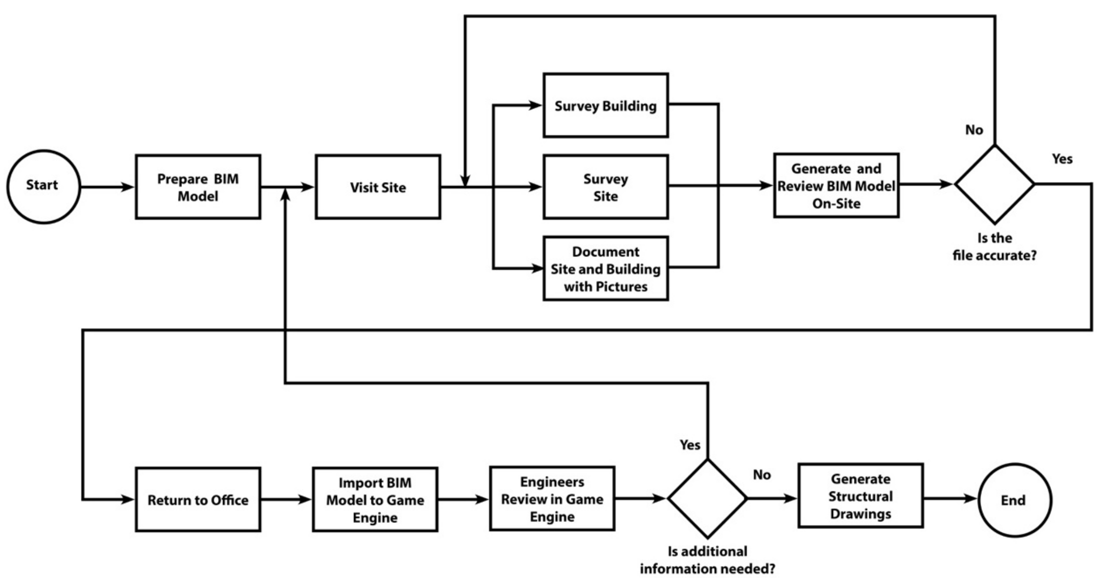

Figure 3. Studio As-Built Information Generation Process with Game Engine

5.2 Experimental Results

What is the difference in requests for information by the selected engineers in the design review process while using either visualization software or 2D drawings?

To answer the second research question, the research team collected RFIs from the design review process of four projects as shown in Table 1. Two of the projects leveraged virtual design reviews, while the other projects were reviewed through the studio's traditional process. Based on the RFIs collected, the research team coded for the type (e.g. location, details) and number of the request. The total number of RFIs from the traditional design review was 21, while the number of the virtual design review was 2. The nature of the RFIs was also different between the two processes. In the traditional review process, the engineers requested information related to the building elements' material and location. Similarly, the engineers asked about the stair's layout and the elevation changes of the foundation systems. The only RFI that the engineers submitted in both review processes was related to the structural details of the building's structural elements.

Table 1. Requests for Information Generated During Design Review

Virtual Design Review		Traditional Design Review (Page Flip)	
Number of RFIs	**Topic of RFI**	**Number of RFIs**	**Topics of RFI**
2	Structural Details	4	Pictures Location
		4	Building Elements' Material
		5	Building Elements' Location (piping, openings, etc.)
		2	Structural Details
		4	Elevation Changes in the Foundation
		2	Stairs layout

6. CONCLUSIONS

As mentioned in the introduction, the adoption rate of Building Information Modeling in residential projects is at a very low 1% and needs to grow. In particular, BIM's benefits must be especially exploited to support the growing demand for new and retrofitted housing projects in the San Francisco Bay Area. To support such processes, BIM can be used for the generation of accurate as-built information. For example, a project team can perform virtual design reviews to accelerate the generation and improve the accuracy of record models. Therefore, the authors set forward the goal of assessing the value of virtual design reviews in the process of generating accurate as-built information, to support the growing housing demand in the Bay Area.

The findings of this study are a first step in assessing the value of virtual design reviews in the process of generating as-built information. In particular, these findings provide a framework for future residential designers and surveyors in implementing BIM technology to generate and review as-built information. Also, this study illustrates that by implementing virtual design reviews designers can reduce the number of RFIs while generating new information for residential projects. This finding is of particular interest for the residential design community, which is struggling to meet current housing demands.

While these findings provide an initial insight into the value that virtual design reviews can bring in the generation of as-built information, the researchers must address some study limitations in future research. First, future research can focus on recruiting a larger number of participants and widen the population to include not just structural designers. Similarly, research is still needed to address the generalization of the findings by performing additional studies and increasing the number of residential projects.

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