Object Levels and Data Structure of Building Information Modeling in Historic Preservation

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Abstract. It is important to establish and maintain accurate records for historic buildings. 3D scanning technology together with Building Information Modeling (BIM) provides efficient and intelligent ways to collect and manage building-related data. But there still needs to have tremendous amount of manual input and interpretation. This research used a 3D scanning project done by students from Illinois State University on a historic building for the Town of Normal, IL. The paper also discussed the object levels and data structure of the scanning, modeling and analysis process. The data processing and management method will help with the efficiency and integration of the information management of historic preservation.

Introduction

The preservation of historic buildings involves efforts from multiple stake-holders, interested persons and parties, contributors, etc. There are benefits of keeping heritage intact. According to National Trust for Historic Preservation [1], there are practical reasons to save old buildings. For example, its intrinsic value may be better than its brand-new counterparts. Preservation and restoration plays a cultural role, because old buildings can teach the history that happened before and promote the respect for people who lived in different times and different societies. Sometimes, new businesses prefer older buildings [2]. The unique and detailed architectural monuments are great attractors of tourists. Historic buildings often remind people of the culture and complexity of a town or city. There has been some misunderstanding that to build new buildings instead of preserving the old ones is more simple, beneficial, sustainable and cheaper. Sometimes, historic buildings may seem to be crumbling shack and unattractive if not maintained well. Undoubtedly, restoring locally important historical structures requires more skills and knowledge than simple building. But there has been insufficient attention and endeavor to historic and architectural monuments around the world.

The implementations of Building Information Modeling (BIM) and 3D scanning technology provide parametric and intelligent ways to manage building-related data of historic buildings and facilities. The current problem of registering scanning data to BIM model is that efficient and accurate recording and integration of scanned data to BIM system has not yet been achieved [3, 4]. One of the main reasons is that it usually involves human intervention in interpreting scanned data when building a BIM model for a historic building; and accurate, real-situation information varies from building to building, which caused the difficulty in using standardized objects in the creation of BIM models. This mainly due to the fact that the 3D BIM design models don’t exist when people need to obtain or create accurate BIMs for existing historic buildings. In this case, the BIM model for a historic building would need to be made from scratch using 2D drawings, pictures, sometimes even hand sketches. In addition, the majority of the facility managers or owners are not yet fully informed of the benefits of BIM technology [5].

This research focused on the process of creating BIM models from 3D point cloud data for historic buildings. The authors studied the currently available, off-the-shelf, 3D-scanning software package, compared their features and applicable situations, and identified the system for scanning purpose on a historic building. There is significant amount of research in academia and in industry to automate
Scan-to-BIM process, but the manual user input is still the major technique in making BIM models out of point cloud data. This process is cumbersome and error prone. The goal of this paper is to supply a comprehensive and practical data structure in Scan-to-BIM process for historic buildings. The proposed data structure can save on the costs of creative project team, interior décor and other things that initially already exist in the old structures. This paper also identified challenges and possible implementations of BIM models in sustainability and preservation of historic buildings.

**Literature Review**

There are research projects on generating as-designed BIM (AD BIM) and as-built BIM models (AB BIM). For the implementations of BIM technology in historic buildings, the processes of implementation have similarities with that of AD BIM. Pătraucean, et al. [6] argued that the creation of an AB BIM involved two major steps of data collection and data modeling. The first step of data collection related to computer vision and/or 3D laser scanning techniques, with off-the-shelf tools for generating 3D models of scenes. The outputs of the first step consisted of a set of 3D points endowed with 3D Cartesian coordinates, which were called point clouds, and possible color information [7, 8]. On the other hand, the data modeling was deficient and labor-intensive. Brilakis, et al. [9] and Jung, et al. [10] argued that many commercial and academic tools to perform the conversion from the raw point clouds to a semantically rich BIM model required extensive human intervention, and was expensive and error-prone.

An example of using LADAR technology (surveying with laser light) is the Milan’s Teatro Lirico Opera House Renovation project [11]. The original building was inaugurated in August 1779 as the Teatro alla Canobbiana with comic opera. In 1890s, it had new owners and became the “Teatro Lirico Internazionale” (International Opera House) which hosted opera, ballet, and theatrical performances into the 20th century. In 1920s, the building was taken over by the city of Milan. The original building was destroyed by fire in 1938. It was rebuilt and reopened in 1939, closed in 1998 due to financial status, and started another renovation activity in 2009. Architect Antonio Cassi Ramelli commissioned to the design of the building, which got new shape and more modern look. After that, the municipality revoked renovation due to multiple problems. The estimated cost of the renovation project was more than 16 million euros. In 2015, a project was carried out by abc to understand the context the technology can be used in order to retrofit the traditional industry. Since the building has a particular shape and complexity, Autodesk Consulting worked with Comune di Milano Technical Office to take advantage of laser scanning, ReCap software, and Revit software to deliver a model faithful to the original, for renovation activity, visualization, and facility management. To scan the internal and external building of the opera house took 7 work days. A total of approximately 6.5 billion points were collected using laser scanner Leica P20 by Leica Geosystems Italia. The point clouds were imported through Cyclone software of Leica Geosystems and exported in PTG format. Then the PTG file was imported into Autodesk Recap software. After that, Autodesk Revit was used to manage point clouds from Recap software to control every single element for the determination of every aspect and characteristic, such as the comparison between the project model and actual situation, evaluation on project options, management of project complexity, stair renovation and simulation of evacuation ways, components localization, visualization, etc.

The critical link to convert the 3D point clouds to BIM models is a registration procedure aiming to bring different sets of data into the same coordinate system. Various research projects had, however, deformations induced by each system, and different features available to recover the deformations [6]. For the implementation of BIM technology in historic preservation or retrofitting, Murphy, et al. [4] suggested a prototype library of parametric BIM objects, containing historic architectural data, and a system for mapping the objects onto point clouds and/or imaging systems. The proposed HBIM library would include remote collection of survey data using a terrestrial laser scanner, combined with digital photo modelling [4]. The design and construction of HBIM objects were based on the historical manuscripts, such as Vitruvius or 18th century architectural pattern books. The mapping process from BIM objects to the components of point-cloud models could create or form the entire building in a reverse engineering process, to create full 3D models including details of methods of
construction and material make-up [4]. The advantage of HBIM object library is that the end result provided automated documentation with engineering drawings for precise conservation of historic buildings for architectural heritage [4]. But the highly sophisticated visualization products depended on the existence of manuscripts and records. For the situations when the only obtainable records are photos of a building or when accurate information about a historic building is unavailable, HBIM object library would not be able to create reliable BIM objects; hence fail to generate the BIM model for the building.

Case Study

The authors performed a case study on the project of recording a historical building using 3d information modeling. The project helped the Town of Normal to establish the detailed information record for the historical preservation and future renovation of an ancient building called “Van Leer Mansion” at 1301 S. Fell St., Normal, IL. The project was also for the students at Illinois State University (ISU) to gain experience on BIM modeling using most up-to-date, innovative technology. The Van Leer project impacted the following groups of people:

1) ISU students went through the data collection, data modeling, and project analysis process to learn how a historical preservation and renovation project will impact the local community.
2) The Town of Normal received a set of detail information for the current situation of the historical mansion to submit for a National Register application. The mansion was built in 1906 and reached it 110 years of age in 2016. It has been the local landmark designation since 2015.
3) Normal/Bloomington community received preservation and renovation suggestions in graphical and 3-dimensional format. The project helped the community to build the understanding of the kind of context the technology can be used in order to give new life to tradition.
4) This project offered ISU a chance to gain public exposure when the faculty and students collect data at the site, and present their work to Town of Normal, the local community, and general public. The experience gained through the project process was shared through the Facebook pages of the Construction Management program and the Department of Technology of ISU.

The entire process of Van Leer project is described below: on 3/28/2016, the student group started the data collection of the building. From 3/28/2016 to 4/8/2016, the group performed site survey, scanned the building using a 3D scanner, and took pictures for record-keeping purpose. From 4/9/2016 to 5/5/2016, the group created 3-dimensional, digital, and integrated building information model for the historical mansion. They generated detailed floor plans, elevations, section views, and interior and exterior rendering images. They also discussed the possible uses of the BIM model for heat distribution and preservation solutions. From 5/5/2016 to 5/12/2016, the group presented the model, drawings, images, data, and research findings to the city planner and the community.

Object Levels

The different products of the Van Leer project are shown in Figure 1. The pictures and figures in Figure 1 show the 3D scanning process using a Leica 3D scanner and BIM modeling process, including:

1) 3D scanning of each room and hallway on 1st, 2nd, and 3rd Floors
2) 3D scanning of all the outside surfaces of the building
3) Scans combined in Cyclone
4) Imported using Autodesk Recap
5) Floor plans and model created in Autodesk Revit
Data Structure

In this research, the data structure is developed with Open-BIM based, object-oriented, parametric Revit Families (RFA). RFAs are components used to build BIM models in Autodesk Revit software environment. The components include walls, windows, stairs, doors, etc. Each RFA can have multiple types, such as different sizes, materials, parameters or variables, etc. The data structure provides both the construction of the building architectural elements, and the extension of open portals to BIM structural model, comprehensive design models, and mechanical/electrical/plumbing (MEP) models of the selected historic building. Figure 2 shows the data structure of this research. Revit software divides parametric objects into architectural, structural, and system elements. This research further complements the data structure of the parametric objects with comprehensive design elements, such as furniture, interior and exterior architectural details (trims, moldings, railings, etc.),
and interior design features (wall papers, paint colors, etc.). The comprehensive design elements provide access to modeling of objects through the definitions of parametric rules. These objects are specifically constructed for one or many uses and carry the required parametric information for the objects’ functions. All Revit objects are created within a 3D space, measured by the x, y, and z-axes, with the global origin of (0, 0, 0). The local coordinate system of an object can be moved and provides a reference to the global origin. Simple shapes are scripted, based on primitives that represent the simplest solid objects and Boolean operations, such as conjunction, disjunction and negation. Common objects are composed of the primitives, which have all the vertices of the object’s components, all the edges linking the vertices and all the surface polygons within the edges. For complicated objects and transformations, additional values are required in their definitions. For those objects, Revit imports the shapes of the objects from other modeling software.

![Data structure of the Open-BIM system for historic buildings.](image)

**Analysis**

In this research, a P20 scanner was used to pick up high precision of point clouds and create an accurate replica of the real building with digital points. All the building objects in the Revit model were measured in the 3D model generated from Autodesk Recap software. The level of each floor was also created based on the measurement from the 3D point clouds data. Once the model was completed, all floor plans, sections, elevations, isometric views, etc. were generated from the BIM model. The basic building design was modeled and visualized from the scanned data for documentation purpose. All the comprehensive design of the historic building was with visual importance and modeled separately through the Open-BIM connection. The controls between the different BIM models were exercised through RFA definitions and parametric rules.

The modeling results and analysis of the selected historic building were presented to the related stakeholders. The audience gave the evaluation of the project as environmental friendly, organized design, psychologically pleasing, and cost effective. Based on the analysis of the material selection of the historic building, the building was environmentally friendly, considering that preservation and restoration is the ultimate form of recycling. In addition, preservation of historic buildings helps to reduce construction waste and save the energy that is usually spent on manufacturing and transporting building materials and tools. This research differs from other approaches, as the open-BIM historic preservation system includes the creation of full 3D models including structural, system and comprehensive details behind the object’s surface. The resulted 3D BIM documentation includes orthographic projections, sections, details and schedules (floor areas, energy consumptions, cost projections, etc.), adding intelligence to facility management.
Conclusion

The economic impact of the project is the 3D digital model for the building and the associate value of using it for future design, analysis, and simulation. The social impact of the project is its value of Building Information Modeling for Historical Heritage and opportunity for the renovation market in traditional markets. The environmental impact of the project is to understand the heat distribution of the building and make the future renovation more efficient.

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References


