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Automating Parametric Modelling From Reality-Based Data by Revit Api Development

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Abstract: The main objective of the project that is presented in this chapter is to explore the application of Building Information Modelling (BIM) on parametric modelling of beam frame system in the field of cultural heritage. Reality-based data has been widely accepted to realize the heritage geometric modelling, and the current challenge comes to the element segmentation and information management aiming at heritage conservation. The recently developed as-built BIM technique is increasingly utilized to parametrically describe the entity and its elements with attribute and spatial relationship information. This project exploits the typical BIM software, *Autodesk Revit*, to transfer the measured total station points and recorded terrestrial laser scanning data to the parametric beam model. Two parametric models from total station points and point cloud are manually built. A plugin tool dedicated to automating the modelling process is in preparation by *Revit Application Programming Interface (API)*.

Keywords: Cultural Heritage; Building Information Modelling; Parametric Modelling; Point Cloud; Autodesk Revit

1. Introduction

Built heritage is our unique and irreplaceable treasure from the past. The recording medium of cultural built heritage has changed from paper materials to digital materials, from two-dimensional (2D) drawings to three-dimensional (3D) models, and it is changing from geometric model to information model. ICOMOS (2003) has recommended the need of further structural analysis and management of the architectural heritage on the basis of geometric documentation. That is, a complete documentation of architectural heritage requires a unified information platform with 3D geometric model and additional semantic, materials, and relationship information. It not only records the graphic and non-graphic aspects of the structure, but it also provides the base for further analysis and management.

However, current heritage projects are still struggling with such data management and information exchange, especially for the complex structures. For example, 3D geometric information is acquired by photogrammetry and laser scanning equipment, algorithms, and software; the attributes, material, and relationship information can be added and managed in Building Information Modelling and Geographic Information System environment; and, further structural analysis is conducted in civil engineering software. The separate processing, the software incompatibility (not interoperable), and data exchange increase the difficulty about heritage conservation analysis among multi-field specialists.

1.1. Documentation of Beam Frame Structure

The above mentioned problem is particularly true for timber roof structures (Yang et al., 2017). Timber roof structure is the typical architectural style in mostly Asian historic buildings, and it is generally supported by a beam frame system. The connected and joint beams are organized as a structural system to sustain the load bearing of the roofs. However, for the wooden beam frame supporting the building roofs, the bearing mechanisms still have not received the due attention and consideration that they certainly deserve. Semplici and Tampone (2006) explored the widely existing historic timber architectures and load bearing structures in the UNESCO World Heritage List. They reported that timber beam structures were not the object of conservation and appropriate repair in many countries and were suffering from neglect and alteration.

Structural analysis is the only way to assess the structural condition and load-bearing capacity of the beam structure (Chapman et al., 2006; Sanchez-Aparicio et al., 2015; Sanchez-Aparicio et al., 2016), which is extremely important to the building roof conservation. The structural analysis depends highly on how the as-built model is close to the real situation, including various aspects of input parameters (geometry, materials, and joint relationship). That is, both reality-based geometry modelling and structural analysis of the beam frame system need to be addressed for the conservation of historic timber roof. On the one hand, the reality-based remote sensing data can model the accurate geometry model of the current condition of the heritage and monitor the subsequent changes. The typical beam frames have been geometrically modelled from reality-based data, such as the roof of historical castle (Koehl et al., 2015; Bertolini-Cestari et al., 2016) and towers (Leonov et al. 2015). On the other hand, Finite Element Method (FEM) based computational software can conduct structural analysis by introducing 3D geometry files that are obtained by reality-based modelling (Armesto et al., 2009, 2015), provided that the beam connection has been built.

Currently, it is no longer a problem to obtain an accurate 3D geometric model, either by terrestrial laser scanning or dense image matching approaches, focusing

on the outline structures and measurement information for the real object. However, it is still highly anticipated to realize semantic segmentation of sub-elements and to build their connection information (Díaz-Vilariño et al., 2015). When it comes to timber beam frame structure, a detailed model of the beam frame should provide the material information and spatial relationships as joints, which is important for further analysis and heritage conservation. Therefore, the gap (shown in Figure 1) between the geometry modelling and structural analysis needs a 3D information model with segmented beam elements and their connection information.

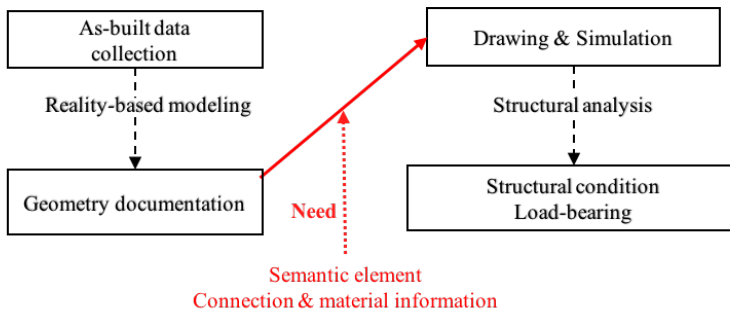


Figure 1. The separation between remote sensing reality-based modelling and civil engineering structural analysis dealing with timber beam frame.

1.2. As-Built Building Information Modelling/Management

The recently developed Building Information Modelling (BIM) technique is in accordance with the above mentioned need (Park, 2011; Chi et al., 2015) about the uniform platform for geometric and parametric modelling, connection information management, and structural analysis of the beam framed roof structure. BIM contributes to the creation of a digital representation having all of the physical and functional building characteristics in several dimensions, as e.g., XYZ (3D), time and non-architectural information that are necessary for construction and management of building and its elements. BIM technique can help to segment and parameterize the entity-based geometric reconstruction to element-based model enriched with measurement, semantic, attribute, relationship, and dynamic information (Yang et al. 2016).

With recent developments in “as-built” BIM techniques, the well-known traditional geometry model is increasingly developing to information model. Some BIM software have provided a platform for manual semantic modelling on reference of reality-based data. Once the elements have been parametrically created, they are simultaneously linked together with strict spatial relationships. The spatial relationships are fixed, even if the sizes or shapes of the elements change. The new model offers us a uniform platform for the whole information

representing the heritage and further structural and material analysis (Barazzetti et al. 2015; Murphy et al. 2013; Saygi and Remondino, 2013).

1.3. Autodesk Revit

Autodesk Revit, a widely used software in most practices, was one of the BIM-related computer program to pay attention on the reverse engineering based as-built parametric modelling. *Revit structure*, as one of its typical workspaces, is also specialized software with the necessary theoretical model to analyse the global structure of the frame. Thus it combines the geometric modelling, element parameterization, connection information management, and structural analysis together, which avoids the transformation among diverse platforms and data formats.

Autodesk Revit has been well supportive of point cloud to aid the reality-based parametric modelling process, by direct manual family creation (Garagnani and Manferdini, 2013) or commercial plugins (Klein et al., 2015) such as *Scan-to-BIM* and *Leica CloudWorx*. However, the manual elements segmentation and parameterization process is time-consuming, especially when addressing complex structures. The plugins are expensive and address to regular buildings and the manual creation becomes time-consuming with the complex 3D space distribution of the elements.

Fortunately, *Revit* provides a rich and powerful *.Net Application Program Interface (API)*, with some free and friendly tools to the development process, such as *Revit SDK*¹, *RevitLookup*², and *AddinManager*. *Revit SDK* is the *Revit API* document, which provides the *API* class name and function methods. *RevitLookup* interactively and visually look up the built-in information in *Revit*. The digitalized parameters link the *Revit* and developed plugins together to interactively process the elements. *AddinManager* provide the totally interactive processing between *Revit* and *API* program in real-time.

The *Revit API* combines the BIM parametric modelling and programming functions (Table 1). The interacting programming methods offer designers the ability to interactively design and manipulate *Revit* elements using algorithms and computational logic. *Revit* can provide the UI platform, serves as the basic view platform and database, and parametrically represents the element and builds the relationship automatically. The program can reduce the manual operation, and realize automatic and batch processing aiming at specific functions. Besides, the existing algorithms and libraries can be combined and called directly in the developed program to improve the point cloud processing. Therefore, they can

¹ <http://www.autodesk.com/revit-sdk>

² <https://github.com/jeremytammik/RevitLookup>

simultaneously automate the element segmentation and parametric representation procedure in BIM environment by specific functions.

Table 1. Revit Application Program Interface (API) development.

	<i>Revit Software</i>	<i>API Programming Functions</i>
Merits	UI platform	Reduced manual operation
	Viewing platform	Automatic and batch processing
	Information storage and management	Specific functions
	Three-dimensional (3D) block representation	Calling existing algorithms
	Automatic relationship building	External library (PCL, OpenCV, NumPy.)
Limits	Low efficiency	Information storage
	Accurate position information	Relationship management
	Reality-based segmentation	Parametric modification

1.4. Research Aims

Bassier et al. (2016) noted the important role of BIM from scan data to structural analysis model for heritage timber roof structures. They utilized the BIM technique to connect the geometry model (*SolidWorks ScanTO3D*) and structural analysis (*ANSYS*) (Figure 1). That is, *Revit* is utilized to store the parametric information about the beams and build their relationship, while the geometric modelling and analysis needed to be conducted in other environments.

The goal of our research is to explore the potential of such uniform platform for heritage documentation and management (Figure 2). Total station and terrestrial laser scanning data is utilized in situ to create the parametric models in *Revit* environment. The *Revit* platform serves as the visualization platform, spatial database, and the base for structural analysis. A *Revit* plug-in is in preparation to automate the semantic segmentation and parametric modelling process.

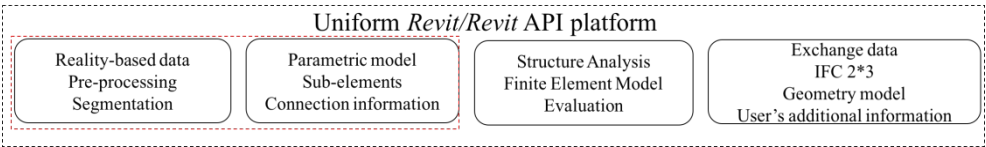


Figure 2. Uniform Building Information Modelling (BIM) environment for beam frame structure construction and analysis.

2. Case Study and Data Source

2.1. Study Area

The case study is a historical building roof with wooden beam framed structure, the so-called “Castle of Haut-Kœnigsbourg”, Alsace, France (Figure 3). It is a medieval castle and has been restored (from 1900–1908) following a close study of the remaining walls, archives, and other fortified castles that were built at the same period. It reflects the romantic nationalist ideas of the past and has been officially designated as a national historic site by the French Ministry of Culture.

The timber roof is supported by a beam frame and truss structure (Figure 3). The beams are normally leaning and oblique distributed in the 3D space. The beams are of very regular shape and are not broken, which makes a total station based approach feasible.



Figure 3. Castle of Haut-Kœnigsbourg (top left) and details of its truss structure (top right and bottom).

2.2. Total Station Data Source

In this project, conventional manual measurement surveying data was utilized. The beams were identified through a total station recording (Leica TS02), taking measurements on the edges of them. The project was georeferenced using GNSS reference points around the site in order to define a consolidated geodetic network (Figure 4). For this manual survey, we needed 18 surveying stations. The field operation lasted six days. Totally, 1,710 XYZ points (Figure 5) were collected

in order to obtain the 3D model. At least six points were acquired on each beam, located in the three or four parallel edges of this beam.

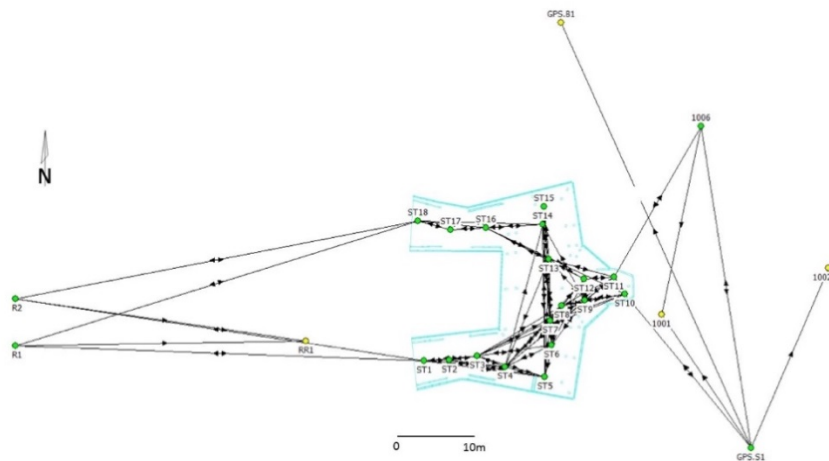


Figure 4. Geodetic network of the total station recording.

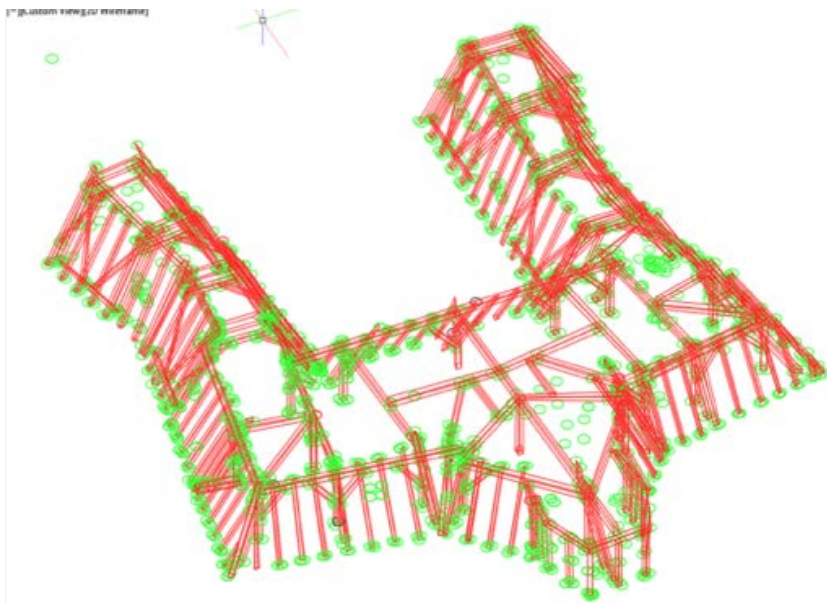


Figure 5. The total station data recording of the beams (AutoCAD). Each beam collects at least six total station points, and the green circles (left) show the distribution of the original total station points.

For the detail, the position recorded whether the collected point was the corner of the beam. In horizontal beams, the points are labelled with "n" (north), "s" (south), "e" (east) or "o" (ouest, means "west" in French) to display its position in

the cardinal oriented beam edge. For vertical beams, the points are labelled with "h" (haut means top) or "b" (bottom). The oblique beams are labelled with the combination of "h" or "b" and "n", "s", "e", "o". Some typical points are also marked with additional "p" to identify it as points that were to be prolonged on the edge (Figure 6). Anyway, when collecting the total station points, it is difficult for the operator to identify correctly the end of the beams, which can be a source of error, therefore a strict codification has been used during the recording. The collected data such as point IDs and XYZ coordinates were saved in ASCII text formats. The ID indicates the selected beam, the point position, and edge number.

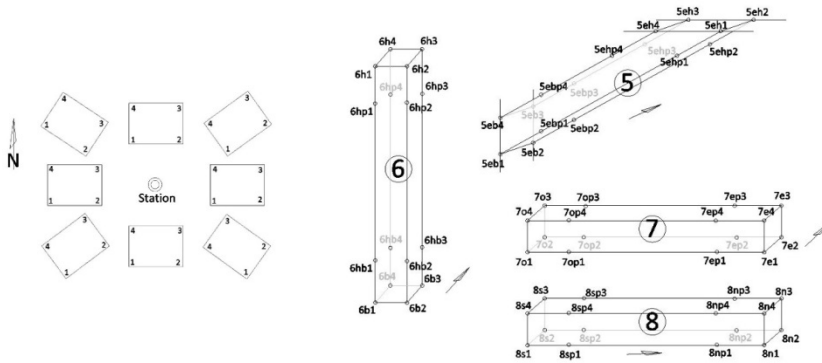


Figure 6. Point numbering and codification used by total station survey.

2.3. Terrestrial Laser Scanning

The laser scanning directly captures the 3D geometric information of the object, which provides a highly detailed and accurate representation of the shapes. Laser scanning is one of the intense developments in geomatics, and has been established as a standard tool for built heritage reconstruction. The pipeline of accurate geometric modelling derived from laser scanning generally consists of data acquisition, point cloud registration, segmentation, mesh generation, and texture mapping. In this project, point clouds are the data source for further parametric modelling in *Revit*. So, just point cloud registration and segmentation is needed for the acquired data. The obtained point cloud is shown in Figure 7.

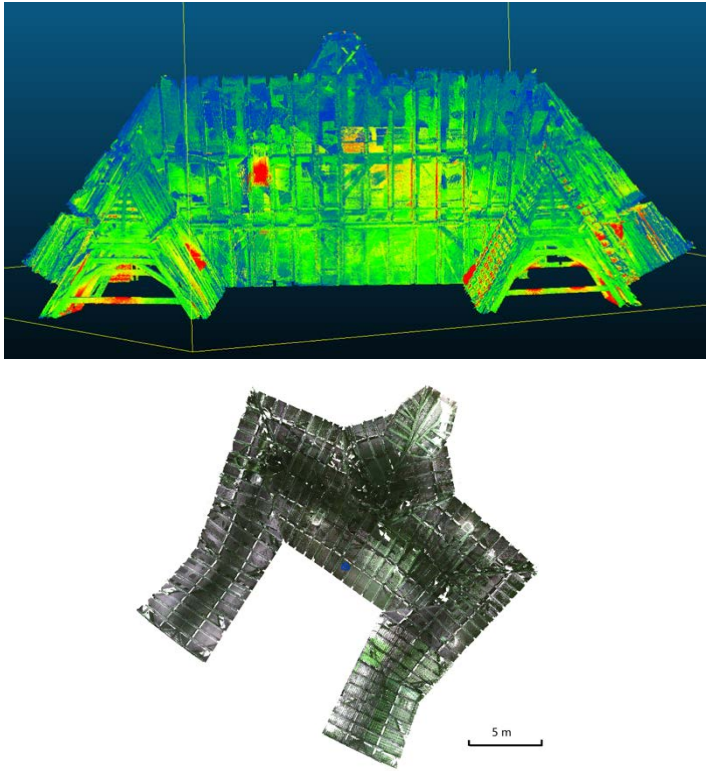


Figure 7. Terrestrial laser scanning data (left) serves as spatial reference in *Revit* (right).

3. Manual Parametric Modelling

BIM has been widely employed to obtain the parametric solid model by manual element creation. Based on the different data sources made of total station points and terrestrial laser scanning point clouds, two parametric models are created.

3.1. Wireframe Model from Total Station Points

When compared to datasets that are based on point clouds acquired by terrestrial laser scanning, the number of points that are recorded by total station is very low but each point is significant. Total stations deliver highly accurate single-points, often used as 3D surface reconstruction reference points or control points for other techniques. Although a limited number of measured points do not allow for a detailed study of the structure, it is still easy to rebuild wireframe rectangular beams.



Figure 8. Wireframe model in *AutoCAD*.

Despite the increasing supporting of reality-based as-built data, *Revit* cannot directly support the ASCII format file with total station points. Thus, *AutoCAD* is employed to build the parametric model by manually connecting the beam edges. This modelling was very time consuming. About 400 beams were reconstructed (Figure 9). The obtained beam system is a linear wire-frame model (Figure 8). The wireframe model cannot define relationship and variable parameters that are describing the beam elements. The obtained wireframe model is supported for further BIM application and structural analysis in *Revit* and computational software.

3.2. Manual Scan-To-BIM Process

Laser scanning and photogrammetry can rapidly capture the most accurate documentation of reality, serving as the data source of as-built BIM. Currently, the geometric model can be accurately created from the surface point cloud, even for the irregular built heritage. Yet, the problem is how to convert the geometric model to a semantic model on which additional attribute information can be attached. As-built BIM software provides such a platform to manually create this kind of parametric model with the reference of point cloud. The friendly support for 3D point clouds has currently made *Revit* the main reality-based parametric modelling environment.

The point cloud can be directly loaded in *Revit* environment and three reference levels are created to confirm the location (Figure 9). The final parametric model is created based on the *Revit* beam family on the reference of point cloud (Figure 10 and Figure 11). Compared to the wire-frame model (Figure 6), the BIM solid model provides not only a definite relationship and variable parameters describing the beam elements, but also more reality results in terms of geometry and structure behavior (Bassier, 2016).

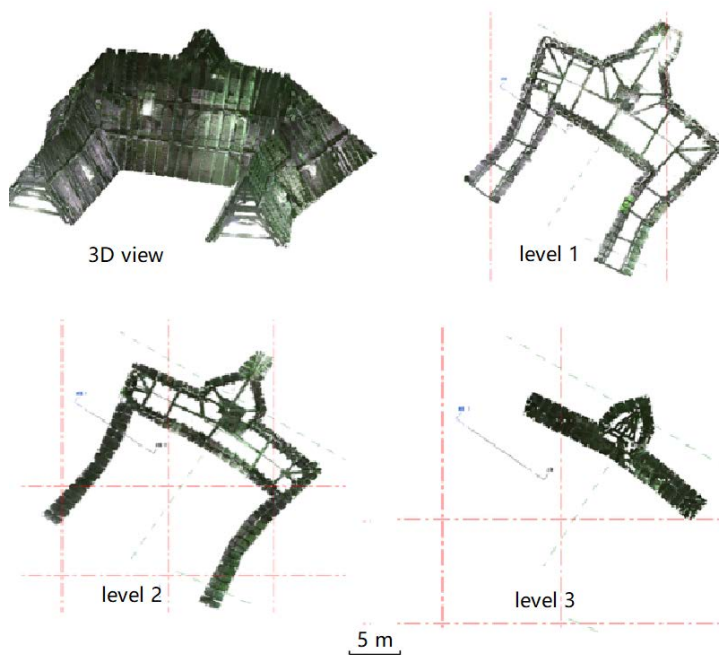


Figure 9. Different reference levels to model the beams.

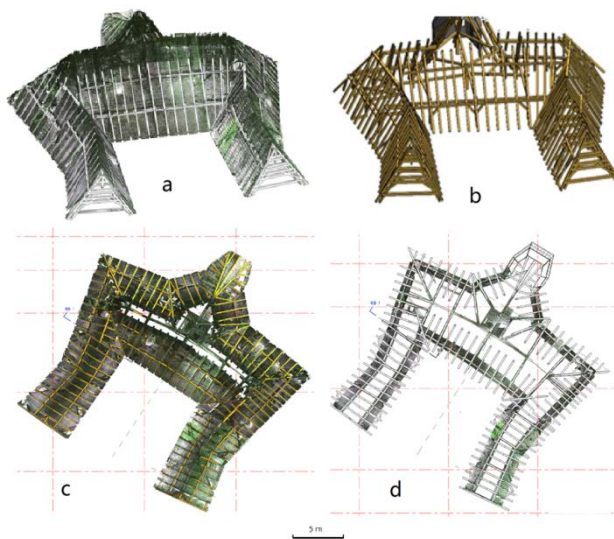


Figure 10. Parametric beam frame model from point cloud. (a) 3D viewer with reference point cloud (b) 3D frame (c) two-dimensional (2D) viewer with reference point cloud (d) 2D frame.

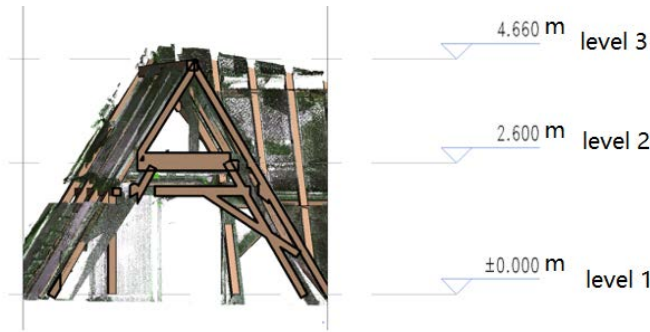


Figure 11. Local detailed information.

The complexity of the historic timber beam frame lies in the sloped and crossing distribution, instead of the geometry that tends to be rectangular based regular shape. However, most BIM software (including *Revit*) is not a 3D-centric and free-form geometry modeller. They mostly create the 3D model based on the stretch of prior defined position in 2D plane. It is feasible for the modern steel truss system, the beams are basically in horizontal and vertical distribution, and are perpendicularly connected. As for the sloped timber beam frame, the parametric model is created by alternating 2D plane positioning and 3D space drawing with prior defined angle value.

4. Revit API Implementation

Currently, Scan-to-BIM is widely accepted for constructing the parametric model directly, thus avoiding the transfer from geometry model and element segmentation to parametric and semantic model. However, the process is mostly finished manually in time-consuming ways, as described in Section 3.

In our project, the “Beam Frame Modelling” package is setup in order to characterize the geometry of timber roof structures from total station surveying and TLS-based point cloud. This plugin consists in a *Microsoft Windows .Net 4.5* Dynamic Link Library (DLL), developed in C# by means of *Revit API 2017*. It is a *Revit API* plugin that can run automatically in *Revit* interface and conducts further processing with *Revit* functions. The plugin consists of two parts, dealing with the two kinds of datasets from total station points and laser scanning point cloud. The obtained model is defined and managed in the unique BIM environment with the framework of geometry, attribute and spatial relationship knowledge.

The current package focuses on the total station data processing and the next version, including point cloud processing parts is in preparation. The current version realizes the total station related functions: displaying total station data, cleaning point data, parameter and corner calculation, and parametric beam generation. If a timber roof structure is studied, then the plugin allows for the

geometry reconstruction of the beam frame from ASCII text files, and outputs the IFC format data.

4.1. Rectangular Beam Geometry Construction

Although the field work that was based on the total station points was time consuming, the beam construction process could be finished fast with a limited number of accurate points. It is expected to transfer the disordered points to parameters describing the cuboid beams. A cuboid beam can be described by a central point, three directions and extensions (Figure 12d), which is the basis to create the beam element in *Revit*. As the points are not always the corners, two parameters of the beam are not totally confirmed: one is the circle point and another is the height.

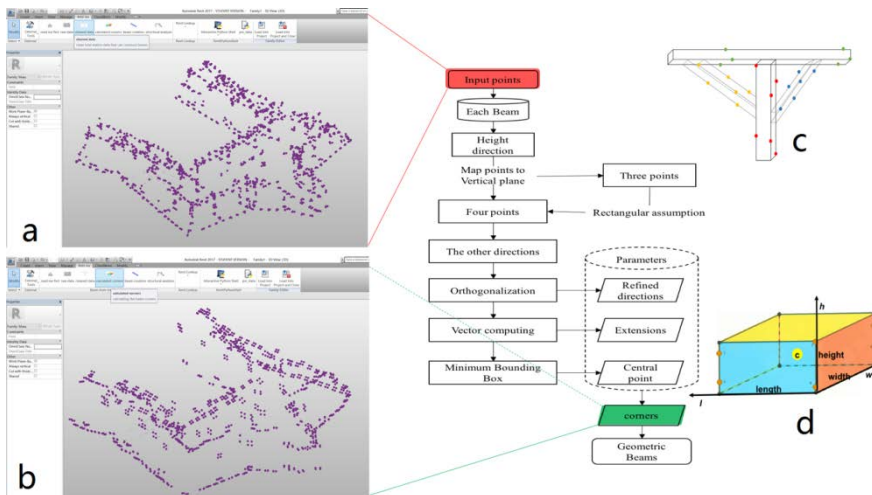


Figure 12. Beam reconstruction workflow (a) Initial total station points displayed in Revit after data cleaning; (b) Beam corners calculated by the algorithm in workflow; (c) Simplified description of the distribution of the initial points; and, (d) Rectangular beam description by central point, extensions, and directions.

A *Python* program has been developed to calculate the beam parameters based on the following algorithm workflow (Figure 12). Firstly, we can obtain the direction of height (h), considering that collected total station points are located in a set of parallel edges. Then, mapping the points to the vertical plane along with the height direction, we can obtain three (if the points are located in the three out of four edges) or four corners (if the points are situated in the whole four edges). In the former case, we can calculate the fourth point under the rectangular assumption of the beam shape. The other two directions (l & w) are thus confirmed. The three obtained directions are further refined because they may be not vertical to each other, owing to the error of total station points. Finally, the

extension can be calculated by vector computing. The circle point is confirmed by the minimum bounding box of the total station points. After constructing the blocks, the relationship and additional information need to be added and managed, which is the advantage of BIM technique.

Displaying total station data. This plugin is able to conveniently parse ASCII text files containing XYZ coordinates derived from real beam frame total station data capture, translating them into native reference points Revit's mass modelling environment.

Cleaning point data. Some total station data are redundant and mistaken, which then need to be eliminated before the beam parameter calculating. Inputting total station points is shown in Figure 12a, which are disordered and difficult to transfer to Revit beam structure directly.

Parameter and corner calculation. The parameters and corners are calculated by the proposed workflow in Figure 12. The algorithm is also a built-in function in the developed plugin. It can automatically transfer all of the disordered points to the corners of beam structures (Figure 12b).

Parametric beam generation. A Revit "Beam family" is created firstly, which is in the regular rectangular shape and basic wooden materials. Then, the family instances can be created in the central position (based on the calculated parameters) along the direction confirmed by the corners. The beam elements (Figure 13) are in standard BIM parametric type, which can be modified and exchanged either by the API or users.

The results show the potential of automating the parametric modelling by interactive API development in BIM environment. It also integrates the separate data processing and different platforms into the uniform *Revit* software. *Revit* BIM environment provides the attributional material and construction information management and structural analysis based on the obtained model.

The parametric model from total station is the pseudo solid model from wireframe model. Although the total station points provide the highest single point positioning accuracy, it is difficult to accurately describe the surface and geometry of the beam element. It can hardly monitor the dynamic change of the beam frame when considering the huge time cost.

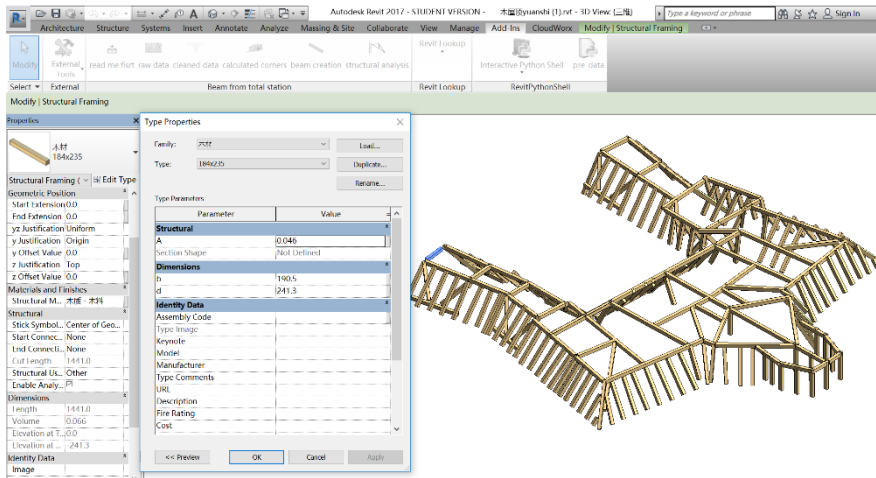


Figure 13. Display of the Parametric Beam frame system in Revit.

4.2. Scan-To-BIM Plugin

Revit 3D modelling tools focus primarily on delivering 2D documents with the added 3D capability. When creating complicated geometry and handling large amounts of data in 3D space directly, the user's freeform design is limited. This dramatically reduces project productivity and the accuracy of arbitrary tip-tilted distribution of beam frame.

The manual elements (Section 3.2) segmentation and parameterization process is time-consuming, especially for the historic timber truss system with sloped and crossing beams. The scan-to-BIM plugin for timber beam frame parametric modelling from point cloud is expected and is currently in preparation. The *API* development really maintains the need of beam construction in two ways: the first one is obviously the automation, and the other is the possible improvement of accuracy. The *API* directly calculate the parameters of parametric beam and then manipulate the Revit beam family with obtained parameters, which can return more accurate spatial location than manual drawing. Moreover, the regular geometric shape of the beam element makes the automatic segmentation feasible.

Some point cloud segmentation algorithms have been proposed for regular steel beam frame (Laefer et al., 2017) and columns (Díaz-Vilariño et al., 2015). Our developing plugin is expected to realize the semantic segmentation and parametric modelling in the BIM environment for sloped timber beam frame. Currently, we are trying to obtain the total station like-wise wire-framed model by feature points choosing from dense point cloud. The developed plugin addressed total station points, which are the sparse point cloud with specific spatial position. That is, the plugin can be utilized for dense point cloud if a certain number of points can be selected and define the edges. The workflow consists of following steps: (1) straight line detection by 3D Hough transformation to obtain the candidate edges

in point cloud space; (2) nearest neighbourhood matching to merge the wire-frame semantic model and point cloud together; and, (3) beam edge selection among the candidate straight lines based on the distance judgment between the straight lines and the obtained model. (4) the developed plugin can be utilized once the three or four edges for each beam have been selected.

5. Conclusions

The main objective of the project presented in this chapter is to explore the potential of a parametric modelling tool in as-built BIM environment for a timber roof structure whose elements are leaning and crossing beam frame. The tool does not only automate the semantic and parametric modelling, but also integrates together the traditionally separate geometric modelling, parametric elements management, and structural analysis.

BIM software, typically as *Autodesk Revit*, is increasingly supportive of reality-based data, normally called *Scan-to-BIM* process. Aiming at the timber beam frame, different parametric models are built from traditional total station points and terrestrial laser scanning data. The current element parametric procedure is generally manual, as the obtained model in Section 3.

The manual process ignores the existing semantic modelling and point cloud processing algorithms and libraries. The *Revit API* provides an interactive environment to utilize *Revit* functions and to develop specific algorithms simultaneously. The API development can manipulate the geometric/semantic modelling and structural analysis directly in BIM environment as well. For example, beam elements are traditionally constructed first, and their joint and interconnected relationship need to be judged and analyzed further, while the relationship is the core for BIM technique and the related functions are available within API development. Thus, the integrated environment not only avoids the data exchange, but also reduces some inefficient and repetitive work.

In conclusion, current reality-based modelling and structural analysis techniques and platforms are important for verifying the actual load-bearing capacity and structural safety of historic timber roof structures. The BIM provides the possibility to combine the separate processing, the software incompatibility, and data homogeneity to the uniform platform. The BIM based parametric modelling of a timber roof structure can provide: (i) an accurate complete survey on the geometry aspect; (ii) attribute, material, and relationship information of the sub-elements; (iii) possible deformations and changes over time; and, (iv) load-bearing and structural analysis. Generally, it provides the conservation professionals decision support with spatial, temporal, and multi-criteria analysis.

The Plugin is still in preparation. The current version is just supportive of total station data. Ongoing development focuses on the laser scanning data to obtain accurate modelling by combining *Revit API* with *PCL* functions.

The automatic path from a point cloud to a BIM structure is certainly an interesting goal, but remains very complex. Nevertheless, the implementation of an automatic process allowing for the use of a reduced set of significant points (from topographic measures) allows the user to foresee an intermediate stage using the 3D TLS point clouds. By using the TLS point cloud as reference recording, a digitization following the principles of the codification developed for the total station survey allows the user to extract the reduced significant point cloud, which will afterwards allow an automatic reconstruction of the beams and the beam structure in a BIM environment.

The intersection and crossing relationship among the beam frame are there still being addressed. The final frame consists of parametric beam elements, which can be applied to structural analysis.

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