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PARAMETRIC MODELLING FOR HBIM: DESIGN OF WINDOW LIBRARY FOR RURAL BUILDING

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ABSTRACT

This article deals with parametric modelling of three types of windows from the 19th and 20th century. All three types of windows are fitted in the same set of buildings – a coaching inn. The article describes the design and creation process of library for Historic Building Information Modelling (HBIM). The design and development of the window-library are based on the analyses of available metric survey documentation - photo documentation, point cloud, drawings of ground plan. The characteristics of the final Building Information Model (BIModel) are derived from the nature of the case study, respectively type of historical building, Level of Details (LoD) of surveys, purpose of modelling and required Level of Development (LOD). Based on these specifications, it is possible to realize three different types of BIModel - simplified, detailed and shape-faithful. The aim of this modelling was to design a library usable for detailed BIModel.

KEYWORDS

19th and 20th century, Cultural heritage, Historic Building Information Modelling (HBIM), Metric survey documentation, Parametric modelling, Rural architecture

INTRODUCTION

The concept of Building Information Modelling (BIM) began to develop in the 1970s. In current sense of BIM, the term *“Building Model”* first appeared in scholarly articles in late 1980s. The term *“Building Information Model”* first appeared in a scholarly article in 1992, see [1]. However, the terms *“Building Model”* and *“Building Information Model”*, including BIM abbreviations, have been widely used since 2002. Currently, Building Information Modelling (BIM) can be defined as *“a set of technologies, processes and policies enabling multiple stakeholders to collaboratively design, construct and operate a Facility in virtual space. As a term, BIM has grown tremendously over the years and is now the 'current expression of digital innovation' across the construction industry”* [2]. Building Information Modelling thus allows building the Building Information Model (BIModel), which is the object-based, data-rich, 3D digital model generated by using a BIM Software Tool [2]. BIModel can represent two basic types of buildings:

1. New – BIModel is a part of the project of construction, especially in the field of AEC industry.
2. Existing – BIModel is created on the basis of metric survey documentation and surveys of buildings of interest, especially in the field of cultural heritage term HBIM is used.

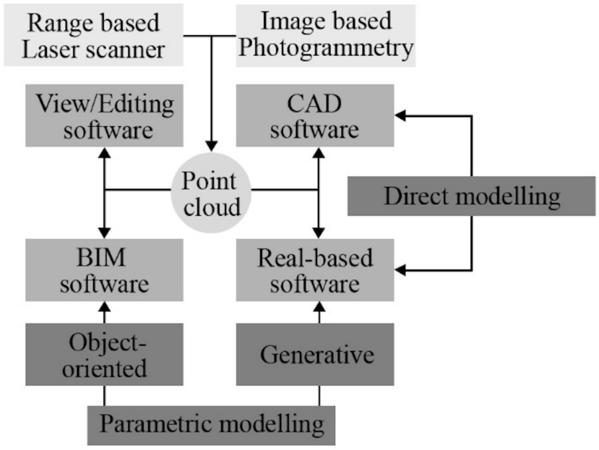

Fig. 1 –Point cloud management workflow: from dense survey data to various processing of 3D modelling [3]

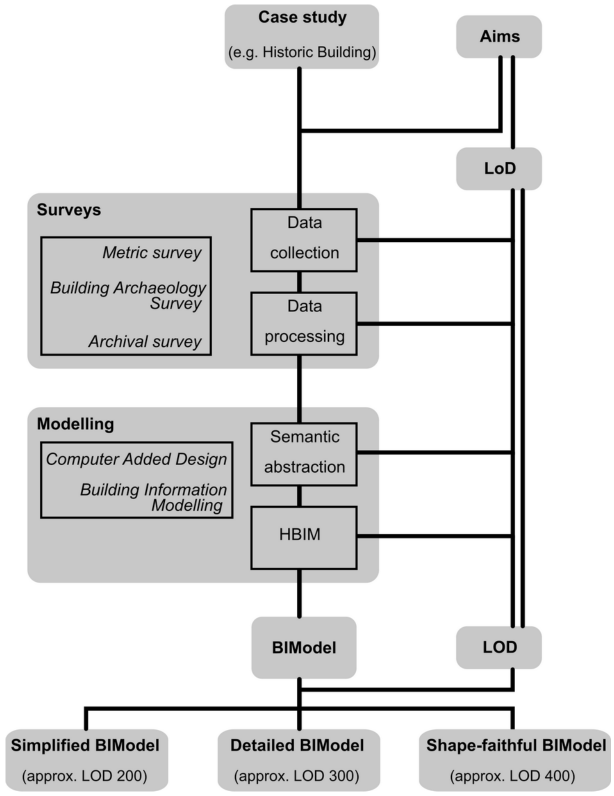

Fig. 2 – Proposed HBIM framework for architectural heritage, according to [4–6]

The concept of HBIM, i.e. Historic Building Information Modelling, was born in Dublin Institute of Technology [7–9]. Currently, this concept is being developed at various scientific workplaces in the world. In the context of HBIM, it is quite common to find the phrase *“From point cloud to HBIM”* [3, 4, 10] and the term *parametric modeling* [3, 4, 8] in the literature. Their relationship is illustrated in Figure 1.

HBIM-based workflows and methodologies are undergoing gradual development. In recent years, several professional publications have been published dealing with the use of BIM in the field of cultural heritage management, e.g. [3–6, 10–12], etc. The summary and synthesis of these aims are illustrated in Figure 2.

Currently, surveying technologies are popular for data collection if allow to create spatial point clouds. Therefore, terrestrial laser scanning (TLS) or close range photogrammetry, using Image Based Modelling and Rendering (IBMR) technology, are often used for detailed metric surveys, e.g. [3–6, 10–12]. On-site, detailed surveys should be complemented by observations of GNSS and total stations [10].

Building Archaeology Survey examines building objects and their structural elements, their mutual position and orientation in space, their development during the existence of the object and collects further descriptive information about the object, e.g. about used materials, technical condition of structures etc. [13]

A detailed analysis of modelling techniques used in the field of cultural heritage is described in [3]. It seems the best to use parametric object-oriented modelling to exploit the potential of HBIM. This technique is based on the use of pre-designed libraries of basic architectural and structural elements, so-called "smart objects" [6]. Whereas the BIM approach is made to design new buildings, its application to architectural cultural heritage is complicated. Most often, it is the absence of relevant libraries. In recent years, several professional publications have been published dealing with the creation of libraries for HBIM. They describe several possible approaches:

1. Analyses of archival sources
2. Analyses of metric survey documentation
3. Combination of archival sources and metric survey documentation

The first approach involves outputs based on the analyses of historical literature that is well known or found in archival research. Subsequently, literary sources, most often architectural samplers, serve as a basis for the design and creation of libraries of parametric objects [8, 14].

The second approach involves outputs based on analyses of metric survey documentation – drawings, point clouds, orthophoto, etc. This approach creates ad-hoc architectural samplers. Subsequently, these serve as a basis for designing and building parametric object libraries. In recent years, several specialized publications have been published describing library modelling for vaulting systems [4–6, 15–18] – irregular walls, vaults, atriums, columns and pillars; a particular type of architectural element – Falconatura [3], Roshan [12, 19], portals from the Etnean region [20]; architectural style [12, 21, 22] etc.

The third approach combines the two previous ones, i.e. libraries are created in both approaches that complement each other [11].

In the context of metric survey documentation, several terms are needed that relate to the definition of detail – *Level of Detail* (LoD), *Level of Development* (LOD) and *reference scale*. *Level of Detail* is a parameter that gives geometric detail and accuracy according to the current CityGML standard [23]. *Level of Development* is a parameter typically used in connection with BIM. The LOD is described not only in terms of detail of geometry, but also in terms of detail, accuracy and scope of information about individual objects [24]. Both parameters are primarily intended for applications in current construction, which works mostly with regular geometric shapes, therefore they are not entirely suitable for models of historical buildings. A historical building consists of a complex of structural elements, mostly of irregular shape, e.g. statues and elevated structures, which have to be modelled too. Therefore, it is necessary to appropriately adapt the application of LOD to models of historical buildings, for examples see [5, 25]. For metric drawings, a reference scale of 1 : 50 is used by default [3, 26, 27].

The characteristics of BIModel are derived from the nature of the case study, respectively type of historical building, details of surveys, i.e. LoD, purpose of modelling and required LOD, see Figure 2. Following these specifications, according to [24, 27], three different types of BIModel [5] can be implemented:

1. *Simplified BIModel*, approx. LOD 200 – simplified building model with low geometric detail and minimal information.
2. *Detailed BIModel*, approx. LOD 300 – detailed building model where the quantity, size, shape, location and orientation of the designed element can be measured directly from BIModel; modelling is done by creating parametrized and simplified families to obtain the model.
3. *Shape-faithful BIModel*, approx. LOD 400 – elements are modelled with sufficient detail and precision to produce the represented component, their quantity, size, shape, location and orientation can be measured directly from BIModel. BIModel copies as much as possible the geometric irregularities of the building and is enriched with the maximum amount of information.

This article describes the process of parametric modelling of three types of windows from the 19th and 20th century. All three types of windows are fitted in the same set of buildings – a coaching inn in Kostelec nad Vltavou (Písek District, Czech Republic). This building has been the subject of Artistic and Historical Research over the past few years [28]. The article describes the process of creating a library for HBIM, which is based on the analysis of available metric survey documentation. The aim of the modelling was to design a library usable for a detailed BIModel.

METHODS

In relation to Figure 1 and [6], the HBIM library creation process can be divided into several stages:

1. Data collection
   a. Terrestrial laser scanning
   b. Close range photogrammetry
   c. Detailed survey
2. Data processing
   a. Registration and georeferencing of point clouds
   b. Filtration and decimation of point clouds
   c. Elaboration of drawings – edge identification
3. Semantic abstraction
   a. Typological identification of building structures in metric survey documentation
   b. Selection and classification of building structures in metric survey documentation
   c. Abstraction of building components
4. Historic Building Information Modelling (HBIM)
   a. Geometric modelling – main BIModel and HBIM libraries
   b. Data enrichment of IFC metadata – main BIModel and HBIM libraries
   c. Application of smart objects into main BIModel

Surveys – data collection and data processing

Metric survey, i.e. data collection and subsequent data processing, was carried out in the form and scope according to [28]. The final outputs of the metric survey documentation, that are used for creation of the HBIM library, are:

- Photo documentation, see Figure 3 – Figure 5
- Point cloud, see Figure 6 – Figure 8
- Drawings of ground plan at the reference scale of 1 : 50, see Figure 9 – Figure 11

Fig. 3 – Example of the first window type - section from the photo

Fig. 4 – Example of the second window type - section from the photo

Fig. 5 – Example of the third window type - section from the photo

Fig. 6 – Example of the first window type - section from the point cloud

Fig. 7 – Example of the second window type - section from point cloud

Fig. 8 – Example of third window type - section from point cloud

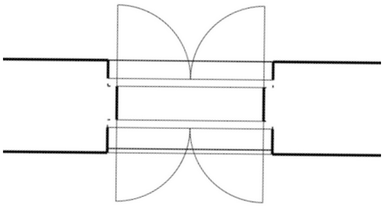

Fig. 9 – Example of the first window type - section from ground plan

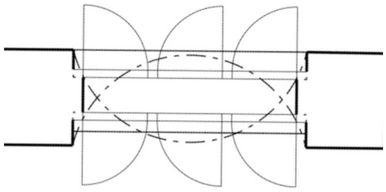

Fig. 10 – Example of the second window type - section from ground plan

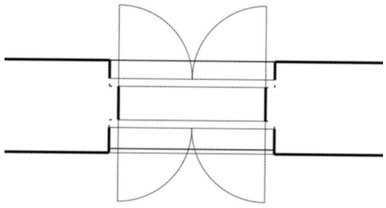

Fig. 11 – Example of third window type - section from ground plan

Modelling – Semantic abstraction and HBIM

Based on the analysis of existing metric survey documentation, it is possible to identify, select and typify building structures that are represented in the mass of a historical building. For HBIM, it is advantageous that the metric survey documentation enables the implementation of a digital 3D reconstruction of the building construction. Furthermore, it is advantageous that is possible to extend the created 3D model with additional descriptive information based on other surveys. Typologies of historical building structures can be divided as follows [29]:

1. Masonry
2. Wooden walls
3. Clay and cardboard
4. Ceilings
5. Vaults
6. Floors and paving
7. Stairs
8. Railings and grilles
9. Roof trusses
10. Roofing
11. Heating
12. Ventilation, water regime and waste
13. Doors and gates
14. Windows
15. Surface treatment

Autodesk Revit software [30] was used for HBIM. According to the terminology of this software, these structures can be divided into families of the same name. Different elements belonging to a family, called components, may have different values for some or all of the parameters, but their names and meanings are the same. Revit software uses two types of parameters:

1. *Type* – it defines parameters that are common to components of the given type. For example, you can change the "Height" parameter for all components in the window family.
2. *Instance* – it defines the component-specific parameters. For example, you can change the "Height of sill" parameter for every component in a window family.

The parameterization of architectural and structural elements must also be a part of HBIM. Unlike BIM, freely available libraries of building components are not commonplace. Therefore, they usually need to be modelled according to the available background and the purpose they are intended to serve. During parameterization and subsequent modelling of this library, it was found that the parameters can be divided into several basic groups:

1. *Basic parameters* – Length, Width, Height – form the basic dimensions, so-called "bounding box", of a parametric object. For nested objects, typically doors and windows, some of the parameters can be labelled like Depth.
2. *Location parameters* – facilitate placement in BIModel. For example, for nested objects, it is useful to define the offset from the face of wall (horizontal plane) and floor (vertical plane).

3. *Architectural parameters* – define the architectural morphology of a parametric object. These are sets of architectural rules and shape grammars [6, 8, 9, 11, 15, 25] that characterize a modelled building element.
4. *Additional parameters* – extend the variability of a parametric object, e.g. in the fields of graphic representation, material composition and surface finishes, descriptive information, etc.

To ensure the interoperability between parameters of a component, such as dimensions, graphic representation or material composition, it is necessary to design logical links with its components. Revit software allows importing existing components in the design of new components. To ensure interoperability between sub-elements within a component, the new component must take over the parameters of the imported component. The interoperability of components is affected by the choice of types of parameters – *type* or *instance*. Very often, it is advantageous to define *localization parameters* and *extended parameters* as *instances*. The localization of individual components can be variable in BIModel. In the case of composite components, that contain imported components, the material compositions and surface finishes of the sub-components may vary, for example, for double windows - exterior vs. window colors, types and treatment of glass panes etc. The design and subsequent testing of component interoperability is an iterative process that can be time consuming in some cases.

RESULTS

The final results of parametric library modelling and examples of their application in BIModel are presented in Figure 12 – Figure 17. An example of parametric object variability is presented in Figure 18.

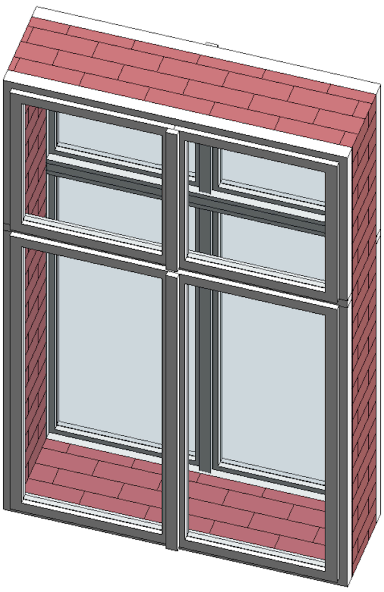

Fig. 12 – Example of the component of the first window type

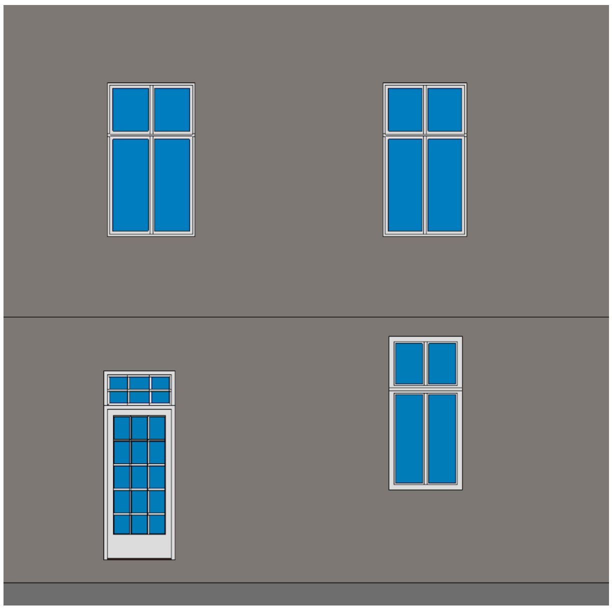

Fig. 13 – Example of the use of the first window type in BIModel – the location of the perimeter wall

Fig. 14 – Example of the component of the second window type

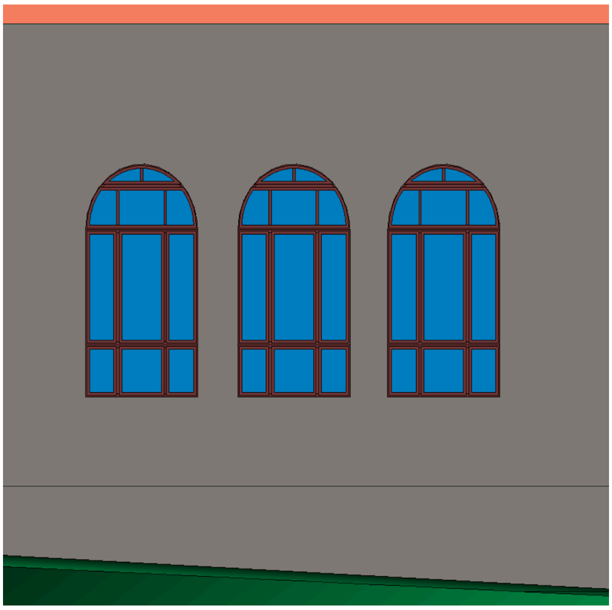

Fig. 15 – Example of the use of the second window type in BIModel – the location of the perimeter wall

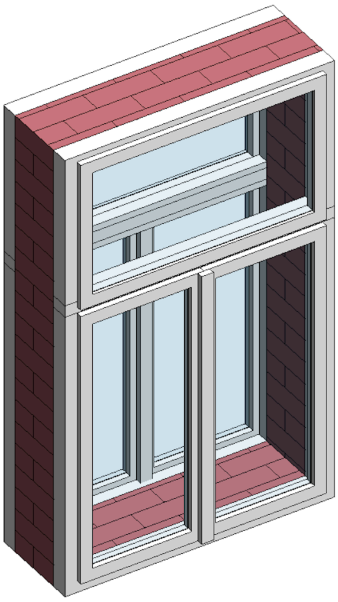

Fig. 16 – Example of the component of the third window type

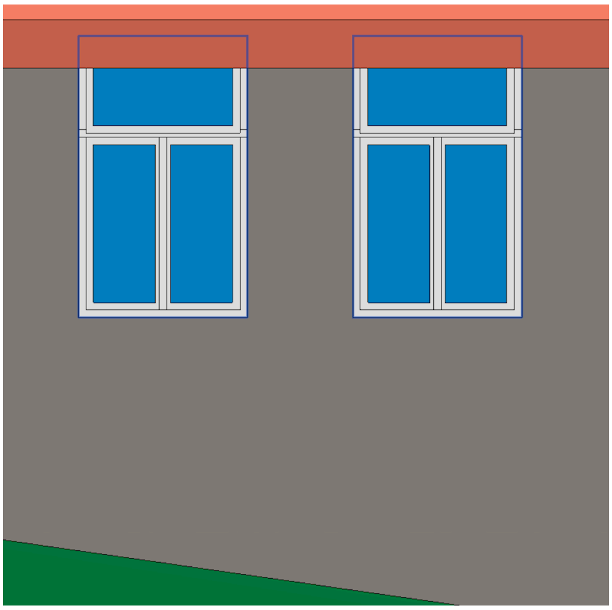

Fig. 17 – Example of the use of the third window type in BIModel – the location of the perimeter wall

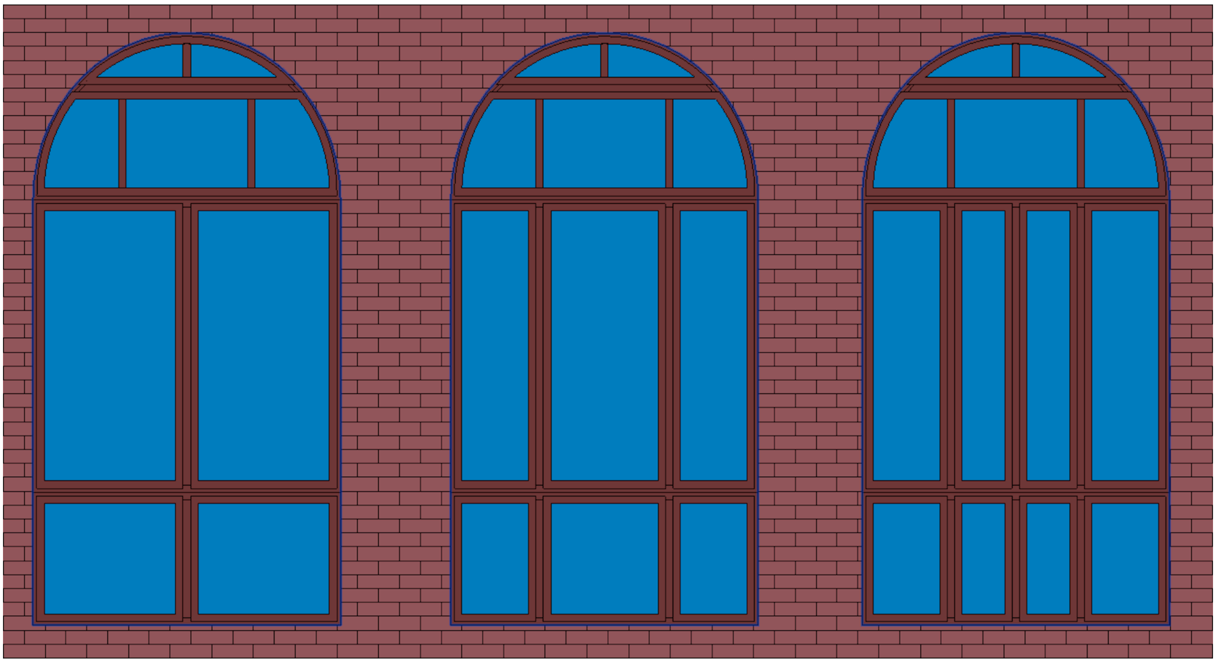

Fig. 18 – Example of the variability of component of the second window type – count of centre columns

CONCLUSION

This article deals with parametric modelling of three types of windows from the 19th and 20th century. All three types of windows are fitted in the same set of buildings – a coaching inn. This building has been the subject of Artistic and Historical Research over the past few years [28].

The article describes design and creation of library for HBIM. These processes were preceded by the study of the current state-of-art in this field. The results of the literature review are presented in the Introduction. Furthermore, the design and creation of the window library are based on the analysis of available metric survey documentation, which consists of photo documentation, point cloud, ground plan drawing, see Figure 3 – Figure 11. Based on the analysis of existing metric survey documentation, three types of window constructions were identified, selected and typified, which are represented in the historical building. These constructions were parameterized to sub-structural elements, from which new components were subsequently modelled, see Figure 12 – Figure 18. Generally, the characteristics of the final BIModel are derived from the nature of the case study, respectively historical building type, Level of Details of surveys, modelling purpose and required LOD, see Figure 2. The result of this modelling is the component library usable for a detailed BIModel.

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