Information Modelling of Historical Buildings of Selected Culture Heritage Objects in Moravia Region

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Abstract

Due to current legislation, a local public body is obliged to preserve as-built documentation of its buildings. A form of as-built documentation has been currently transforming according to building information modelling methodology. As-built documentation of listed buildings is an important step in preserving cultural heritage and allows preserving as much information as possible about immovable cultural monuments for future generations. Currently, building information models (BIM) of the real estate cultural heritage objects are being produced due to digitizing and conserving entire buildings with all the construction details with respect to culture heritage needs. Land surveyors are responsible for data acquisition at the building site to deliver geometrically accurate and precise 3D spatial data for the following modelling process as well as georeferencing data to appropriate datum and reference coordinate system. The 3D spatial data is primarily represented by a point cloud acquired by laser scanning technology. Historic buildings typically contain unique construction elements of very different and often more complex geometric shapes, such as arches, columns, statues, attics, etc. Such elements need to be individually modelled from the point cloud with respect to the precision of the model. The modelling process of existing historic building elements becomes far more demanding than the design of the future building. Building elements for new buildings are available in the construction products BIM database for information modelling. n the other hand, a certain degree of generalisation must always be considered when modelling historical buildings. The building elements are more of an aesthetic nature. Hence, the modelling process needs to cover the geometrical shape of the element, construction assembly as well as material definition. The resulting model of the element is geometrically and visually affected by a generalization of spatial information. Nowadays, game development environment tools are increasingly used outside the video game industry, especially in architecture/construction/engineering, automotive, virtual production, etc. Thus, the information model can be delivered to a broader audience of stakeholders without vendor-locked software restrictions. Simultaneously, culture heritage value can be provided to the public in an immersive way. This paper discusses in which cases generalization in the sense of the level of information needed (LOIN) is involved and when it is already a geometric error of modelling regarding the needs of the public body and specification of public procurement. In this paper, the matters mentioned above are described using several case studies of the creation of an information model of listed buildings, namely the Maxmilian's Court in Kroměříž and the Parish office in Cetkovice.

Keywords: information modelling, historical buildings, laser scanning, as-built documentation, video game development environment

Introduction

Every construction work should have its own documentation, especially monuments. As a rule, the documentation phase of a listed building must be preceded by a surveying phase. In addition to the actual layout of the building and its size, the choice of the appropriate measurement method is influenced by unstoppable technical progress, which involves the use of new measurement methods that are considerably more productive/efficient than those of the past. The requirements for the use of one of the mandatory reference systems in our national territory, which are always governed by the applicable government regulation, should not be overlooked. The choice of the data collection method is of course also related to the form and method of graphical processing of the acquired data. From the surveyor's point of view, the form is currently unambiguous, namely digital. The method is chosen according to the client's requirements; it can be a 2D documentation, which is represented by drawings of floor plans, sections and views, or a 3D documentation, which results in a spatial model of the surveyed object. In recent years, it has become more and more common for the client to request the production of an information model of the specified object. In this case, the model itself is also enriched with non-geometric properties of the elements of which it is composed, and these properties can express a certain, predefined, level of detail. From the spatial model, it is relatively easy to produce a 2D documentation at any time, which can be supplemented with lists of any elements contained in the model, exactly according to the client's requirements. In this paper, this topic is presented on the example of two selected culture heritage objects.

History Of Selected Culture Heritage Objects

Maximilian's Court was built in 1844 and 1845 by Archbishop Maximilian Sommerau Beck according to the design of the architect Antonín Arche as a model farm building for the needs of the archbishopric. The construction took place in two phases. The main building with the adjacent walled courtyard was eventually extended by two pavilions at the corners of the courtyard, creating a cour d'honneur and giving the building a more noble character. The main building has a rectangular plan and can be divided lengthwise into three parts in a roughly 1:3:1 ratio, with the stables in the central longest part. The ground-floor corner pavilions are L-shaped with equally long wings and are mirrored. The facades of the whole complex are uniform in style. The stable building from 1844 and 1845 has retained its historical appearance to the present day. During the socialist era, the yard served as a veterinary hospital, today it serves as a teaching facility called the Hubertcenter (Fig. 1a) [1].

The one-storey Baroque chateau in Cetkovice dates back to 1762. It was originally built as a summer residence of the abbots of the Hradisko monastery near Olomouc with the coat of arms of the last abbot of Hradisko above the main entrance. After the dissolution of the Hradisko monastery in 1784, the building of the chateau was placed under the administration of the Religious Fund, which established a parsonage. The enclosed area of the parish office consists of a ground-floor L-shaped outbuilding next to the main building, adjacent to the parish office, while the rest of the grounds are enclosed by a low wall. The facade of the main building is decorated with lozenges, finished with a cordoned moulded cornice and topped with an attic gable. The building is listed (Fig. 1b) [2], [3].


Fig. 1a. Hubertcentrum building


Fig. 1b. Building of Cetkovice parish office

Legislation

A new law on Building Information Modelling (BIM) is in the legislative process. The comment procedure is currently closed. This law will make the use of BIM mandatory for public works contracts financed from public budgets. This obligation is expected to come into force in July 2023.

As it is already common, legislation usually fails to predict the development of modern technologies, so in this case new technologies provide us with a number of possible variants of spatial models, products and other specific outputs that can be used to quantitatively and qualitatively describe given objects. In order to be able to use these products practically, it is necessary to standardize their data formats, attribute structure, parameter values and many other properties. This is necessary in view of the need to transfer data between the various professions and actors in the process of constructing new buildings or documenting the condition of existing buildings. Currently, these data standards requirements are only partially met. There is still no clear structure of the information model that should describe the object. In the Czech Republic, this issue is addressed, among others, by the Czech Agency for Standardization (ČAS), which is trying to define a uniform data structure for building information models. Currently, a set of such definitions is being developed separately for civil engineering structures and for transport structures. The data structure is defined in a document called the Data Standard for Structures (DSS), while emphasis is also placed on another important aspect, namely uniform terminology, which is a necessity for the practical use of the data standard. Uniform terminology will be ensured through the CCI (Construction Classification Internatinal) classification system, which, in simple terms, will ensure that the same things are named in the same way. This will be achieved through unique codes that will be assigned to individual elements or objects. These elements will therefore be uniquely interpretable even though they may be called or referred to differently in different countries, professions or sectors.

Creation Of Drawing Documentation

The creation of construction drawing documentation is mainly carried out in two cases. Firstly, in the context of designing a new building and secondly, in the context of drawing up the documentation of an existing building for the purpose of reconstruction, additional approval, etc. All CAD/BIM concepts are developed primarily for the first purpose, namely building design. In this case, all building elements are clearly specified mathematically, technically and in general parametric terms. It is therefore possible to simply represent, describe or model them using these technologies. In the second case, when we create documentation for an existing building, we have to deal with a number of geometric inaccuracies, where real masonry is never ideally flat or vertical, the thickness of the plaster is not the same throughout, each building opening is to some extent individual. Given the precision with which individual building elements and structures are created, it is not practically realistic to document their dimensions to the millimetre, even though the standards for the production of construction drawings require it. Similarly, it is not possible to find an object in BIM object libraries that accurately represents a given real building element. In view of this fact, it is always necessary to work with a certain degree of generalization, namely rounding the dimensions of building elements according to the accuracy that corresponds to their production method, state of wear and tear, or the method of measuring the actual condition.

The documentation of existing buildings is not specified in the current legislation; the procedure is based on standards intended for the documentation of new buildings, i.e. for the purposes of building design. This creates unrealistic requirements for the documentation of the existing state of the historical buildings. In practice, this problem is solved by specifying the level of detail that the resulting model should meet. These are specific values of predetermined deviations of the BIM model from reality that will not be considered as a processing error. This level of detail is referred to as LOD or LOIN.

Previously, documentation of historical buildings, was documented according to the Guidelines for Surveying of Monuments and Protected Areas of Nature from 1966 [4] and the Guidelines for Surveying of Immovable Cultural Monuments from 1976 [5], which specified the accuracy of geodetic measurements, the modification of measurement sketches and the appearance of construction drawings. Unlike drawings produced in the context of building design, these drawings were dimensioned to centimeter accuracy. This made it clear at a glance that this was not a design for a new building. The other details are almost identical to those of the design of new buildings, in view of their unambiguous interpretability. These guidelines for the alignment of existing buildings have not been translated into binding standards, unlike the requirements for the creation of construction drawings in the process of designing buildings, which are currently specified in the standard ČSN 01 3420 Drawings of civil engineering structures - Drawing of construction drawings [6]. This standard is often required for the documentation of existing buildings, even though it was not created for this purpose. For the purposes of documentation of heritage buildings, the directive [7] is intended, which specifies the requirements for drawing documentation. A similar analogy can be seen in the requirements for creating BIM models of existing buildings, where individual BIM formats and BIM libraries are created for the purpose of designing new buildings. Fortunately, the various software in which BIM models are created allow for user modification of a range of elements, objects and their parameters, so that it is possible to produce construction documentation that depicts a given building with the required level of detail. In fact, individual building elements can be modelled with any level of detail, including that which corresponds to the accuracy of the data collection technology.

Binding Reference Systems

The BIM model is stored in computer memory in the model coordinate system. The position of objects on the earth's surface is expressed in a geodetic coordinate system. Georeferencing is the process of determining the relationship between the position of data in the model coordinate system and the geographic or map position expressed in the geodetic coordinate system. The problem is the non-identity of the mathematical definition of the model and geodetic coordinate system, which becomes apparent as the size of the structure increases. The model coordinate system is a Cartesian right-handed 3D system, and the model position is near the origin. In contrast, the geodetic coordinate system is left-handed and, in addition, does not form a 3D system; the heights are not perpendicular to the plane of the cartographic representation used. The use of a cartographic representation is necessary because otherwise it is not possible to represent a 3D world (in simplification, an ellipsoid) in a 2D plane. A slightly annoying feature is the distortion of the horizontal dimensions, the dimension in the terrain is different from the one calculated from the coordinates in the plane of the cartographic representation. Direct use of 3D geodetic geocentric reference systems (WGS84, ETRS-89) without mapping them to a plane is impractical because the Z-axis does not point upwards and for modelling purposes it is essential that we understand the horizontal as flat.

Georeferencing is therefore of far greater importance for large-scale structures (whether linear or plan). However, it is also important for smaller structures, especially for easier, more accurate and faster coordination of BIM models of individual structures.

In the Czech Republic, the binding geodetic reference systems are defined by Government Regulation No. 430/2006 Coll., namely the (planar) coordinate system of the Unified trigonometric cadastral network (S-JTSK) and the Baltic height system - after levelling (Bpv). Surveyors understand and are ready to help with all these issues.

Case Study

The surveyor's view on information modelling of buildings is presented in the article by means of a case studies of the creation of an information model of the building of the Hubertcentrum in Kroměříž, which was created within the pilot project for the Zlín Region, and of the building of Parish office in Cetkovice, in which the authors participated. The process itself can be divided into several stages, which build on each other.

Measurements in the field

The beginning of the process of creating construction drawing documentation of an existing building is its geodetic survey. Nowadays, a range of measurement technologies are available. Total stations for simultaneous measurement of angles, lengths and elevation, satellite apparatus for determining the spatial position of points or laser scanners for obtaining point clouds. These technologies allow accurate and detailed mapping of the entire building, connection to binding reference systems. [8] The outputs of these measurements are not only construction drawings but also spatial models of the given building including information on the properties of specific elements. The result is the so-called information model of the building. Drawings of floor plans, sections and views can be generated from this model using appropriate software, and any change in the model is automatically reflected in the corresponding drawings. It is also possible to automatically process statements of any group of elements present in the model. Examples include lists of rooms, windows, doors, etc.

The following modern technologies were used to survey both the historic building of the Maximilian Court and Parish office in Cetkovice. A network of auxiliary measuring points was established around the building, the coordinates of which in the JTSK coordinate system and the Bpv height system were determined by GNSS technology, specifically by the RTK method. Using a total station, the coordinates of the so-called ground control points were determined from these auxiliary points, which were signalled using checkerboard targets directly on the walls of the documented building. This ensured that the targets were also captured during subsequent laser scanning of all interior and exterior areas of the structure. Using the known coordinates of the ground control points, the point cloud from the laser scanning could be placed in a binding coordinate and elevation system. In this way the point cloud is so-called georeferenced, i.e. each point of the cloud has defined global coordinates. This point cloud was used as the basis for the building information model. It is a spatial model that describes both the geometric shape and layout of the building in question (walls, floors, windows, doors, staircases, etc.) and the individual elements of the technical equipment of the building (lighting fixtures, heating, fire extinguishers, etc.).

Information modelling

The creation of an information model starts with the definition of a coordinate and elevation system. This step can only be defined by entering coordinates as well as height of project base point with respect to survey point. There is no possibility of defining the direction of axes in the software, or assigning the EPSG code of coordinate system and datum. It is also necessary to define the height levels of the floors that will be in the model. The next step is to import the point cloud. Since it is georeferenced, it is imported according to the set coordinate and height system to the corresponding location.

The first elements that are usually inserted into the model are the walls. When creating models of existing buildings, it is necessary to expect that the walls will not be perfectly rectangular (Fig. 4b). Any slight deviations from the horizontal or vertical direction of the drawing in the floor plan are not supported in Revit, leading to the need to generalize or refine and distort the actual shape.

Another problem is the inconsistent thickness of the wall throughout its course (Fig. 4a). Again, generalization and idealization are necessary. Therefore, modelling of the as-built state is a) difficult to implement and b) impractical (with respect to time spent).

Windows and doors are designed in the software using so-called Revit Families, which can be thought of as a library of similar components. These families are parametric, for example a certain type of window is produced in different dimensions. Since the entire dimensional range has the same appearance, it is advantageous to create a family so that by simply changing a parameter (e.g. width), automatic adaptation occurs. For historic buildings, however, it is necessary to create a window family essentially to measure (e.g. Fig. 6a).

Of the geometric elements, the beams can definitely be considered the most challenging to create (Fig. 2a and Fig. 5b). Again, the rafter roof model should be idealized because it is unthinkable to model individual beams bent.

For historic buildings, modelling of the vaults can be equally challenging. Finally, building services such as lighting and heating were added to the model (Fig. 5a). These elements are again treated as parametric families. A huge benefit will be when the manufacturers of the HVAC objects provide BIM families and they will be available for download and implementation into the building model. This also assumes perfect standardization.

The advantage of working in BIM is that it is an object-oriented database creation. So, if we change something in the 3D view, it will automatically change in the drawing documentation. Of course, there will also be a change in the meshing according to reality.

When creating the information model of the Parish office in Cetkovice, it has been proven to be the most difficult to model the vaults (Fig. 2b). It is not possible to create a family for such intricately shaped irregular vaults, so each had to be modelled individually as a so-called component in situ.

Fig. 2a. View of the roof of a building in Cetkovice

Fig. 2b. Corridor in Cetkovice

There are a large number of specific and historically interesting building details within the historical building. One of these is the cow statues by the arcade on the south east elevation of the building, which reference the original purpose of the building of the Hubertcenter. These statues, although not preserved in their original state, represent a significant architectural detail throughout the building. In creating the model of the building, we have tried to incorporate these sculptures so that the historic value, including the details, is preserved. Any sculptures (spatially and geometrically complex objects) are quite challenging to model in Autodesk Revit. Therefore, we decided to create a detailed mesh model (triangular mesh) for each statue from the point cloud, which we added to the BIM model via Autodesk NavisWorks as a coordination model, i.e., referenced in S-JTSK coordinates and elevation in Bpv. This approach reassures us of the need to use binding reference systems.

Similar approach was applied for the coat of arms in Cetkovice. Detailed orthophoto was done from a photography (Fig. 3a). The outline was made in Revit and then the orthophoto was placed on the outline as a material (Fig. 3b).

Fig. 3a. Coat of arms in Cetkovice

Fig. 3b. The model of coat of arms in Cetkovice

Comparison of model and point cloud

Spatial data obtained by geodetic methods are subject to requirements concerning their geometric accuracy. Current data acquisition technologies, in particular laser scanning, make it possible to acquire point clouds with an internal accuracy of the order of millimetres. A point cloud is therefore a highly accurate representation of a real object. The problem arises when creating a 3D model or building information model. During the modelling process, the actual shape of the building must be captured through mathematically definable solids. In the first place, we encounter the real irregularities of the actual structural elements, namely, the actual walls or floors are not ideally plane, the arches are not ideally circular, the rooms may not be ideally rectangular, etc., as mentioned in the previous chapter. Secondly, we always have to deal with the economic aspect in creating a spatial model, namely we cannot usually model a building including all the details, be it architectural shapes, artistic additions or simple irregularities and imperfections of the materials used. The above factors cause that the resulting spatial model no longer corresponds to the source point cloud with millimetre accuracy, because it is always necessary to approach the modelling of individual building elements with a certain degree of generalisation of details, which is referred to as LOIN.

The following figures show that the spatial model does not always copy the point cloud exactly. The deviations are on average about 0.05 m, at the maximum 0.08 m.

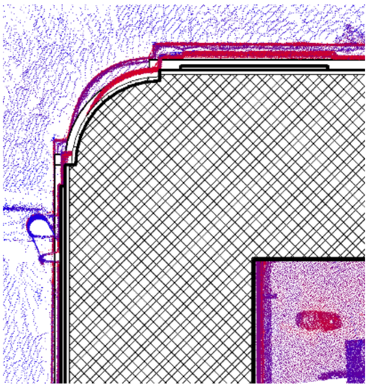

Fig. 4a. Deviation of the point cloud from the model (floor plan)

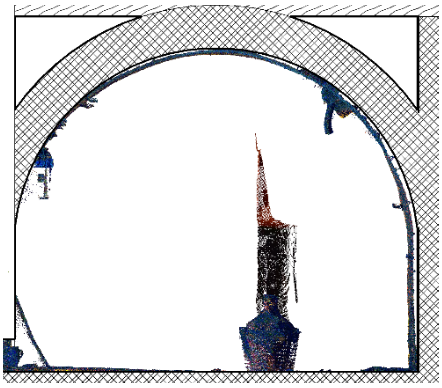

Fig. 4b. Deviation of the point cloud from the model (section)

Fig. 4c. Deviation of the point cloud from the model (view)

Modelling in a video game development environment

Immersive deliverables of the model can be provided using a variety of software. Nevertheless, video game development environment have been increasingly used for these purposes. These tools (e.g. Unity or Unreal Engine), originally designed for video game development, are being applied in other sectors such as the film industry, architecture and construction, and automotive manufacturing. At the same time, they allow significantly higher interaction with the digital world (in our case, the BIM model), e.g. fly-through/passage through a building, display of information about elements, addition of realistic materials or artificial lighting. The output from the video game development is meant to be in the form of static image visualization as well as video sequence or a desktop application, or an application for virtual reality glasses [9], [10]. All of these options, familiar from AAA video game titles, are available to the general professional community thanks to freely available video game development environments. Examples of the application of BIM and video game environments in specific tasks are given by e.g.

The as-built documentation of the actual construction is followed by the visualization of the model, which makes the historical value of the Hubertcenter building stand out (Fig. 5a). The Unreal Engine game development environment was used in a pilot project to document this building. In this environment, a scene was created with a custom BIM model and surroundings including surfaces and vegetation. In addition, realistic materials and impressions of defects on the facades and columns were added to ensure that the final appearance matched the actual condition of the building.

Fig. 5a. Example of modelling of defects on the facade

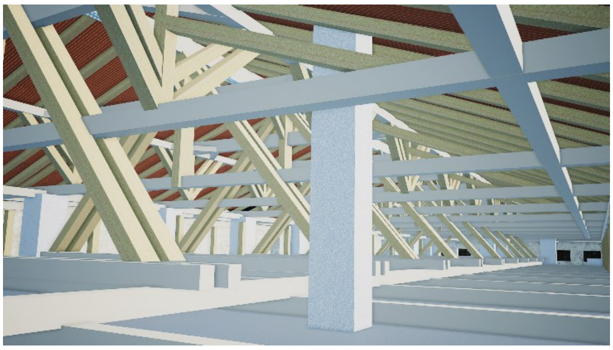

Fig. 5b. Example of modelling of roof

In addition to the visualizations, the game environment was used in our project to run through the BIM model and iteratively check the building structures and elements for correctness of modeling (e.g. Fig. 6b). With interactive controls, it is possible to walk through the building model room by room and detect errors and incompletions. This process revealed, for example, an incorrect floor-to-wall connection at the basement entrance (Fig. 6a).

Fig. 6a. Window and door in Cetkovice

Fig. 6b. Corridor in Cetkovice

At each stage of the BIM modelling in Revit software, it has been proven advantageous to check the quality of the model in an application from the game development environment, which allowed for a walk-through of the model and a visual check of the quality of the model.

Conclusion

The creation of plan, section and elevation drawings has long been a standard in the documentation of building structures. Whether we are referring to documentation in the design phase or during the construction life cycle. With the development of modern technology, this area is also evolving, and it is possible to create spatial models that represent the original object in digital format or physically as a scale model. Current technologies allow us to create spatial models that are dimensionally, in shape, in colour and overall optically faithful to the original object, thus allowing us to preserve a faithful description of it in some way. In the case of buildings, transport structures and other immovable objects, these spatial models can be used to generate drawings in the form of horizontal and vertical sections through the object. After adding the relevant details, it is therefore possible to provide construction drawings in a standard format.

The definition of the above-mentioned standards (DSS, CCI) is still not definitively established at the moment, many professions are involved in their definition, which is not a simple situation. It cannot be expected that in the foreseeable future a single standard will emerge that would cover the entire breadth of construction issues and at the same time be universally accepted by the professional community. The situation is such that each participant in this process will somehow create or adapt the structure of the information model to their own image, and gradually individual definitions of data structures will be established to suit the widest possible range of users and gradually become the standard in the construction industry.

With the use of building information models, the requirements for the visualization of finished models for the general public are increasing. To this end, game development environment tools have recently been increasingly applied to allow, for example, building walkthrough/passage, display of element information, addition of realistic materials or artificial lighting. The output can be a video file, a web application, or other standardized output that is viewable by ordinary users. The Unreal Engine environment was used for the visualization of Hubertcenter and Parish office of Cetkovice. It can be said that by linking these game environments in the context of BIM, a new sector is emerging that will enable a paradigm shift in the way information is handled in the construction industry.

Finally, it is important to mention that the surveyor's qualifications are involved in capturing the object and creating the geometry of the 3D model. Fulfilling the non-geometric properties of each object is done by other professional professions. Collaboration between the different professionals and stakeholders on the BIM model is desirable throughout the entire life cycle of the building.

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