BIM-Based Timber Structures Refurbishment of the Immovable Heritage Listed Buildings

To cite this article: Vladan Henek and Václav Venkrbec 2017 *IOP Conf. Ser.: Earth Environ. Sci.* **95** 062002

IOP Conf. Series: Earth and Environmental Science **95** (2017) 062002 doi:10.1088/1755-1315/95/6/062002

BIM-Based Timber Structures Refurbishment of the Immovable Heritage Listed Buildings

Vladan Henek [1], Václav Venkrbec [1]

[1] Brno University of Technology, Faculty of Civil Engineering, Veveří 331/95, 602 00 Brno, Czech Republic

venkrbec.v@fce.vutbr.cz

Abstract. The use of Building information model (BIM) design tools is no longer an exception, but a common issue. When designing new buildings or complex renovations using BIM, the benefits have already been repeatedly published. The essence of BIM is to create a multi-dimensional geometric model of a planned building electronically on a computer, supplemented with the necessary information in advance of the construction process. Refurbishment is a specific process that combines both - new structures and demolished structures, or structures that need to be dismantled, repaired, and then returned to the original position. Often it can be historically valuable part of the building. BIM-based repairs and refurbishments of the constructions, especially complicated repairs of the structures of roof trusses of immovable heritage listed buildings, have not yet been credibly presented. However, the use of BIM tools may be advantageous in this area, because user can quickly response to the necessary changes that may be needed during refurbishments, but also in connection with the quick assessment and cost estimation of any unexpected additional works. The paper deals with the use of BIM in the field of repairs and refurbishment of the buildings in general. The emphasis on monumentally protected elements was priority. Advantage of the proposal research is demonstrated on case study of the refurbishment of the immovable heritage listed truss roof. According to this study, this construction was realized in the Czech Republic. Case study consists of 3D modelled truss parts and the connected technological workflow base. The project work was carried out in one common model environment.

1. Introduction

Building information modelling (BIM) can be perceived as a natural technological development of AEC, as a part of the technological revolution "Industry 4.0", particularly "Construction Industry 4.0".

On the theoretical level this topic is well covered in details, regularly there are plenty of conferences and lecture. There have also been some case studies on the application of BIM [1] [2]. It is a true evolution in construction industry. Currently the implementation of BIM is especially visible in the phase of building design, but there are also studies about the effectivity of this technology in other phases of the construction life cycle like deconstruction projects [3].

The beginning of BIM development comes in 1970s when Professor Charles Eastman stated the fundamental questions if it would be possible to use computers to build models of buildings and architectural designs including their properties, and thus he defined the revolutionary idea of BIM [4]. Consequently, there were presented many studies about BIM. The authors [5] presented an article about the sustainability of BIM which concluded that in the field of BIM and refurbishment it is necessary to

IOP Conf. Series: Earth and Environmental Science **95** (2017) 062002 doi:10.1088/1755-1315/95/6/062002

establish a methodology and standards for manipulation with waste in this phase. In another article the authors [6] defined the development of the research in the field of refurbishment and maintenance, and concluded that refurbishment as a part of Facility Management (FM) is not efficiently implemented in the BIM process. Based on the mentioned literature and their own designing practice the authors, this article focuses solely on the designing phase in construction industry and especially on the renovation of listed monuments; it aims to identify to what level is the use of BIM efficient.

2. Paradigm of BIM effectiveness?

2.1. Advantages of BIM

Generally acknowledged advantages of BIM include:

- make designing faster
- more efficient cooperation with designers of tradework and specialist subcontractors
- mutual interconnection of all design phases documentation from a study to the completion
- easier way how to detect collisions, elimination of errors
- better quality of work, better arrangement of drawings
- the project covers more disciplines in one entity, e.g. the energy class certificate, insolation study, budget/bill of quantities, etc.
- possibility to quickly compare various options/alternatives of the solution, in connection to the price of the construction

2.2. Disadvantages of BIM

- the first phase of project requires much more time, especially the development of study
- the preparation and setting of the building software takes a lot of time, so BIM model becomes efficient when this or similar projects are repeated. Specific/one-off or non-standard projects are not cost effective.
- at the present/to date/provisionally a poor cooperation with the designers of tradeworks and consultant subcontractors for who working with BIM is not efficient, e.g. electricity installations, fire safety solutions, etc.
- it is complicated to export the 3D data onto a drawing as the current Czech Standards for drawings are outdated
- the software does not allow export in the form corresponding to the Czech regulations, e.g. the energy consumption certificate, so the utilization of these small “bonuses” is now very limited
- BIM is not widely known among investors, councils and governments, but this situation is slowly improving.
- a necessity to develop a 3D model without which BIM cannot be used; and it is not always possible to create a model, or it could be very complicated and time demanding.

3. The influences on the efficiency of BIM

As described above, the efficiency is depending on the workload of the project and on the number of subcontractors, the extent of the brief, etc. Here follows the efficiency of the project in correlation with other criteria of construction process.

3.1. The types of structures (according to the investor)

When using BIM it is suitable to take into consideration the type of structure. For the solved case we selected following classification of structures:

- newly-built structures,
- alteration of structures (extensions, remodelling),
- special partial projects (design of refurbishment, roof truss refurbishment,…).

It is obvious that for newly-built structures the use of BIM is the easiest, and to a certain level and by certain criteria it is cost effective. For refurbishing or special/specific projects is not unequivocal. It is caused primarily by the demanding development of the as-built documentation into 3D model and also the necessity to set more layers of the project according to the individual phases of construction (from existing state, through demolition, to the new state).

Before we start working with BIM it is necessary to estimate the workload of the project and accordingly use BIM only partially or not at all. The workload depends mainly on developing the 3D model; the more is the structure complex and rich in non-standard details, the less it is worth to use BIM.

3.2. Subcontractors

They are mainly designer of tradeworks as electricity installations, heating, air conditioning, and then the specialist/consultants: fire safety solution, energy class certification, insolation study, etc.

To make BIM completed, all subcontractors have to use this technology. It is possible to develop VIM only for a part of the project but then it loses the advantages, especially in the following phases, i.e. during construction and eventually in use of completed structure where BIM has its justification as well.

This means that using BIM in construction without subcontractors certainly is cost effective, while the more subcontractors who do not use BIM are included, the more the efficiency decreases. This becomes obvious when transferring data: time-consuming conversion (there and back) into other formats not supporting BIM, and manual check of collisions, etc.

3.3. Contractors

A considerable disadvantage of BIM is that the workers on the construction site require standard 2D drawings with standard amount of information and appropriate symbols and colours. Whatever is slightly different is taken as unclear, and may lead them to omit some information, which is given in the project and it leads to misunderstanding.

If there is only 3D model, the situation is opposite, especially for prefab timber structures (roof truss, roof slabs, etc.), they use 3D figures more often and they use 2D drawings only to specify the dimensions for a given structure.

3.4. Relevant building authorities

For the authorities the BIM projects are not relevant, some authorities may appreciate the 3D presentation, e.g. conservators, which may facilitate and fasten the permission process of the given designs but in general BIM has no particular use for them.

3.5. Investors

Many investors already demand to see a 3D design. They appreciate the efficiency of BIM especially when calculating the price and to be able to see direct difference in price in case of alternations. Then it needs to be used advanced version of BIM which nowadays cannot compete with standard designing.

So far there is a high pressure on the price, so for example with complex refurbishments BIM technology is not efficient while with serial or technologically similar new buildings it is more and more cost effective with every new building.

3.6. Extent of project

Not every project goes through all phases from a study to realization documentation. As stated above the more phases, the more BIM becomes able to compete to the traditional designing.

How to proceed, when to use BIM partially or completely or when to use it at all? The following example presents new methodology for refurbishment of roof truss and roof in BIM where some of these questions are answered.

4. Methodology for using BIM in refurbishment

The basic idea of BIM is, apart from 3D model of the building, to interconnect all information and data into one model which is enabled only by some software.

It is necessary to set various renovation filters, combination of layers and display setting so that it would be possible to generate any floorplan, section, elevation or 3D figure (not a static photo), but as an interactive model where any alteration is demonstrated/revealed immediately. Furthermore, it is necessary to set relevant interactive charts with bill of quantities without a need to complete and adapt it manually. Before processing it is necessary to define:

- selection of software
- content of drawings
- extent of documentation

4.1. Selection of software

The market offers specialized programs which are defined for specific structures, e.g. timber structures, air conditioning, etc. and complex programs that cover all but with certain limitations. Thus it is necessary to consider if for the project of roof truss is worth to use specialized software which is capable to design all types of connectors, etc. or to be satisfied with general program which cannot design these details, or only in a limited way. For the current task it was used Archicad.

4.2. Content of drawings

The content is intended as the drawings for individual phases of construction. BIM consists of one modelling environment where through setting different layers it is possible to modify a drawing by one click. The way how individual drawings are prepared is individual, in this case the following way was chosen.

4.2.1. Existing state. Standard drawings completed with description of elements and dimensions + bill of timber and flashing elements. Existing timber is marked brown and replacement (green), non-load bearing elements (light blue) and damaged elements (pink), flashing and other elements (purple), brickwork (black).

4.2.2. Demolished structures. The existing elements in black, all demolished elements in yellow; change of elements marking. The list will contain only the demolished elements.

4.2.3. Works after demolishing. Drawings only black and white, the demolished elements invisible including the labels.

4.2.4. Newly designed structures. Designed structures: again the unchanged elements are in black + red elements of newly designed ones including new dimensions and labels. The lists contain only the newly designed elements.

4.2.5. Refurbishment. It is a combination of demolished and designed structures. In this case the drawing is not suitable; the large amount of elements overlap and the drawing becomes unclear.

4.2.6. New state of building. The colours are the same as for existing state, labels and dimensions reflect all modifications, bills include existing and new elements.

4.3. The extent of project documentation

Apart from the compulsory parts as site analysis and reports that are created independently on the 3D model, the content of the documentation is a series of drawings as floor plans for individual phases of construction, cross-sections, elevations, and general bird's eye view visualization for corresponding phases. Each drawing should contain 2D and 3D form including floor plans and cross-sections.

Separated chapter is for bills of quantities that are listed in interactive charts. The given software enables to state anything about all elements; for given purpose the basic dimensions were given: quantity and number of elements. Apart from entering any data, these charts are able to link information and drawings (change in labelling in the chart is immediately revealed automatically in all other relevant drawings.)

For the purpose of the task, there may be set bills of roof truss elements, roof elements, flashing and locksmith elements, small-scale walling, or e.g. set the calculation of roof areas.

The project itself is processed in 3D model; each element has its ID which corresponds automatically with bills of quantities in the interactive charts and its phase is indicated (element for demolition, or new element). Dimensions and notes are completed that are associated with a certain level (and on which drawing it will appear and where not).

Any changes after the completion of the project should be automatically presented on all relevant drawings including 3D figures, suitable e.g. for incorporation of modification during construction and then for as-built documentation after the completion of the building.

5. Case study - BIM and refurbishment

The topic of this article focuses on renovation of heritage buildings. In order to answer the question if it is cost effective to use BIM, we will take a heritage building of primary school in Brno where the task of the project documentation was to refurbish the roof truss, the roof, and adjoining gables with balustrades in the extent of 1 000 m2. It is a multi-storey building from 19th century located on the corner of the crossroad (in the form of asymmetric U). The building is divided into 3, at the level of loft, connected wings that are attached to buildings of same height on West and South.

The floor plan of the loft is irregular; it does not contain any right angle. The roof is saddle (apart from the smallest wing where the roof is single-pitched), contains 5 ornamental gables oriented to the street which considerably divide the roof. The ridges of individual parts and the rim wall near the gutter are at different levels; also the inclinations of roofs are different. There are many ornamental chimneys of irregular shapes penetrating the roof. The ornamental gables are interconnected by balustrades. The access is through inner staircase, and through several roof windows onto the roof.

The loft is open without internal walls but at several levels. The roof truss is traditionally timber, made of massive strutted purlins; the roof is made of clay tiles, to the courtyard there is tin sheet, and in the connection of two wings with smaller inclination angle, there is walkable membrane for flat roofs.

Although the roof truss is original, there are several unprofessional interventions forming replacements and other supporting elements of the truss. The roofing was newer but long after the service life period and also provisionally repaired; the chimneys, gables and rim walls are damaged, the most damaged are the balustrades which were inclined to collapse. The flashing was also damaged to considerable level and completely dysfunctional.

The brief covered the following phases:

- preparation of project
- obtaining of documentation and measuring the as-built state
- constructional-technical and historic survey
- design of repairs, consultation with investor (Statutory City of Brno)
- project for building permission, consultation with relevant authorities
- construction documentation and following cooperation with the contractor of the construction.

5.1. Preparation of project

As a part of the project it was necessary to identify the extent of the project, way of presentation, colour labelling, and the composition of drawings; and above all to select appropriate software which could cover all the elements.

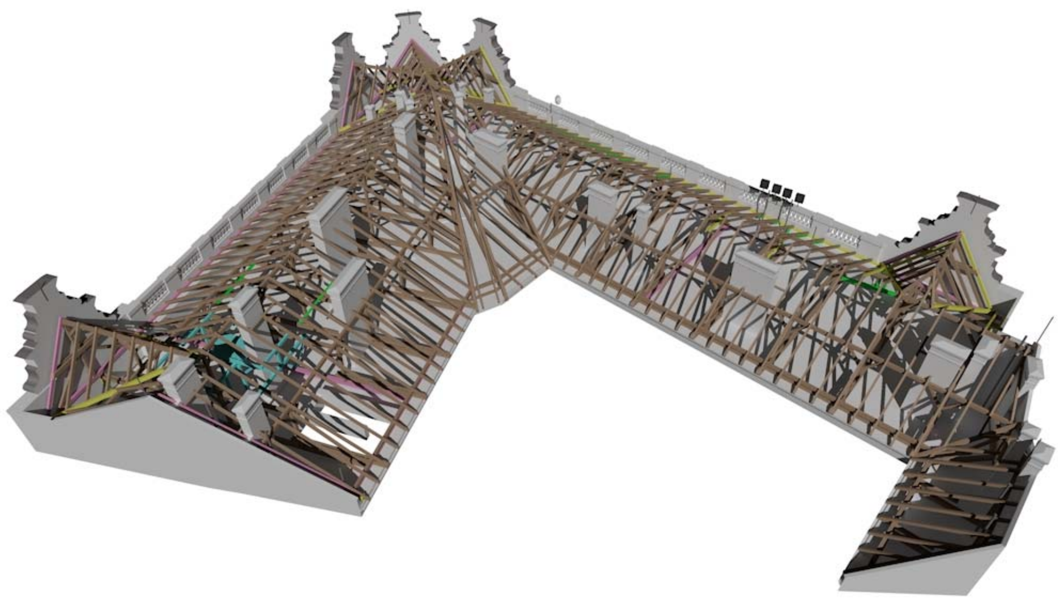

Figure 1. As-built state - 3D modelled truss (more than 750 timber pieces)

5.2. Measurement of as-built state

The measurement of as-built state was performed manually (with laser and measuring tape). The works were performed in 2014 when using laser scanning of interiors and exteriors was, and especially using drones was not so common in the Czech Republic as today.

Consequently, a complete 3D model of roof and truss was created as shown figure 1 and figure 2. It is obvious that without the 3D scan the creation of 3D model would be very laborious and time-consuming as it was necessary to model each connection and beam separately. There were more than 750 timber pieces. For the inspection of all connections it was used detailed photo documentation but there were several inaccessible places where it was necessary to improvise slightly. Also the gable walls and balustrades along the roof were modelled.

Figure 2. As-built state - 3D model with highlighted damaged elements of truss

5.3. Constructional-technical and historic survey

In the following phase there was a constructional-technical and historic survey performed by a specialist who does not need BIM for his work. The output was presented only in printed form. The notes on the degree of damage of individual elements were entered into the prepared floor plans as shown on figure 3 and cross-sections in 3D model of as-built state.

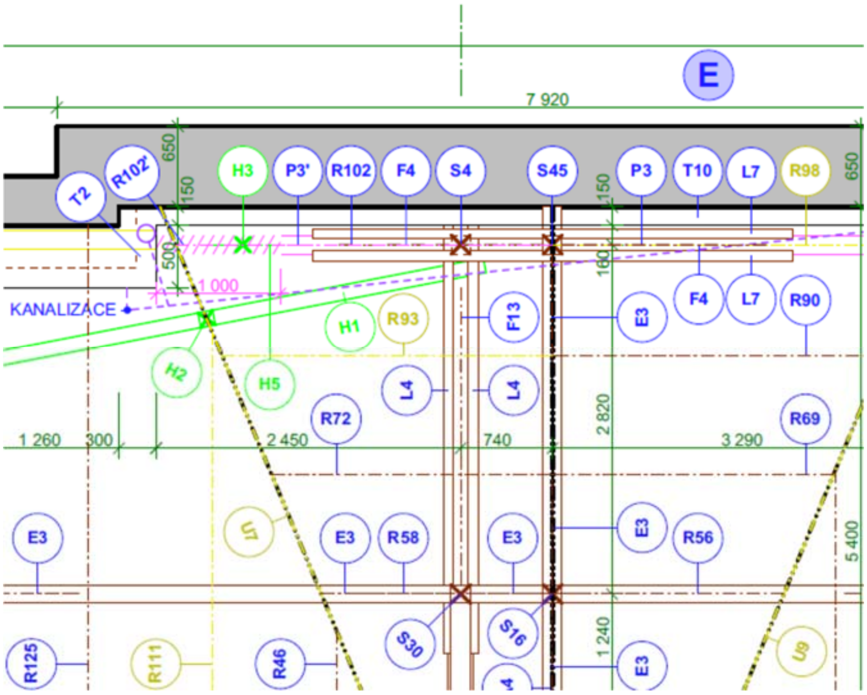

Figure 3. Floor plan with highlighted damaged elements of truss

5.4. Proposal of reparations

Now it was possible to develop the design including proposed modifications and to estimate the price and workload, and to consult this with the investor. This phase is usually developed in 3D model as shown figure 4, for this case it was completely inefficient and thus the consultations were based on drawings for building permission.

Figure 4. 3D model with highlighted new parts of truss

5.5. Project for building permission
Consequently, the project was developed for building permission in BIM. The 3D model with marked alternations was consulted with the Conservation Department. Here was the advantage of 3D model striking when the approach of the relevant authority was much warmer and faster than in case of 2D drawings.

The partial projects as fire safety solution were developed only in text and the requirements were included in the in the construction project.

3D model was developed only for the loft, other irrelevant storeys and adjoining buildings were not plotted. For this purpose, it would be completely useless.

5.6. Project for construction completion
A considerable advantage of BIM is that the following phases are very fast, and completion of project for building permission and realization was very fast.

6. Conclusions
From the above mentioned it is obvious that to develop the project of refurbishment in BIM cannot compete with standard projects; nevertheless, the efficiency of work is considerably higher (the cooperation with conservation authorities, with investor, with contractor) and it helped to avoid several complications and misunderstandings.

The development of roof structure in BIM standards is meanwhile highly laborious and time-demanding. Also it was necessary to simplify some elements as it would take inappropriate time to develop; e.g. the details on balustrades, gables (pilasters), cornices, etc. By using the latest technologies of measurement for as-built state (laser scanning) with direct transfer of data into 3D this state will considerably improve. Still there are drawbacks, especially for carpenter's connections which have influence on the overall dimensions of elements stated in the bills. Thus it is not a complete utilization of BIM and in current situation it is not within the reach of the author, only partially.

Acknowledgement
The outcome has been achieved with the financial support of Standard Internal Grant No. FAST-S-17-4148 provided by Brno University of Technology.

References
[1] Ghaffarianhoseini, J. Tookey, A. Ghaffarianhoseini, N. Naismith, S. Azhar, O. Efimova and K. Raahemifar, "Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges," Renewable and Sustainable Energy Reviews, vol. 75, pp. 1046-1053, 2017.
[2] Sun, C., Jiang, S., Skibniewski, M.J., Man, Q., Shen, L. "A literature review of the factors limiting the application of BIM in the construction industry", Technological and Economic Development of Economy, pp.14, 2015.
[3] M. Galić, Z. Dolacek-Alduk, A. Cerovecki, D. Glick and M. Abramovic, "BIM in planning deconstruction projects," eWork and eBusiness in Architecture, Engineering and Construction - Proceedings of the 10th European Conference on Product and Process Modelling, ECPPM 2014, pp. 81-85, 2015.
[4] M. Eastman, "BIM handbook: a guide to building information modeling for owners, managers, designers, engineers and contractors," Hoboken, NJ: Wiley, 2nd ed., 2011.
[5] H.-Y. Chong, C.-Y. Lee and X. Wang, "A mixed review of the adoption of Building Information Modelling (BIM) for sustainability," Journal of Cleaner Production, 142, pp. 4114-4126, 2017
[6] Ilter, and E. Ergen, "BIM for building refurbishment and maintenance: current status and research directions," Structural Survey, 33 (3), pp. 228-256, 2015.