Design of multi-layered building structures using BIM method

D Szalai and T Horváth
Széchenyi István University, Egyetem tér 1. Győr, H-9026, Hungary

szalaidory@gmail.com

Abstract. Today BIM is an inevitable concept in construction design and while the workflow of consultant designers is mostly influenced to a small extent, new methods require a new kind of communication between them. This research focuses on the workflows of construction designers because their design works have a big impact on many other disciplines. This paper presents an examination about the processing methods of the building structure designers and the use of BIM with a questionnaire survey. In this research, a new way was also introduced to integrate definitions of multi-layered structures (created by construction designers) into the BIM/CAD model itself. The goal was to allow the data in the layer structure documents to be automatically linked to the model, and make it possible for all collaborators to continue working with the data separately. This paper proofs that this automated workflow greatly increases efficiency, accuracy and reduces human errors. ArchiCAD and Excel were used as our development framework: former one to create CAD/BIM models, latter one to handle the database of multi-layered structures. Individual codes were used to identify each unit of the layer structure and link them to the model itself. This way, it is not necessary to manually add the data to the elements, but the material properties can be read automatically into the model and the quantities can be measured. Similar scale, size, and complexity buildings were selected as a test environment where the ordinary and the new method were used in parallel throughout the design process. This provided a good comparison and demonstrated the effectiveness of database-based design. With the new approach, time required for first-round quantification was reduced by 41% and the time of a repeated quantification due to modifications was reduced by 56%, in average.

1. Introduction
Construction design, although 2D-based design is a long way off, in many places uses outdated technologies. This lag can be felt especially in the workflows of discipline designers. The main tool for digitalization in construction is the BIM workflow. The BIM (Building Information Modelling) is a model-based design method, which basically means 3D elements with extended information content [1]. In the construction industry, the use of BIM is becoming more widespread [2] [3]. At the same time, the spread of BIM processing towards discipline designers has not yet started or has started to just a small extent. The aim of this article is to present a developed workflow which can integrate the method of writing multi-layered structure documentation into model-based design. This database-based way can increase efficiency and extend BIM systems to disciplines.

As a first step, current building construction design methods and work processes should be studied. The Hungarian construction designers’ habits were surveyed through a questionnaire. Then based on the results, a solution system was developed to integrate their tasks into the BIM workflow.
2. Working methods of building construction designers
The building construction designer is usually a specialized architect who deals with the design of building structures and / or the preparation of construction plans and has gained extensive experience. It is important to note, that such a specialist building construction designer is not involved in all projects. For smaller ones, this task is usually performed by the architect team. However, for larger projects, the building construction designer may not be a single person, but a team with different competences such as energetics, building insulation, acoustics, fire protection and so on.

Building construction designers’ responsibility is to determine the most appropriate structural designs taking into account the complex effects and uses on building structures, and
- in the case of layered structures, they prepare layer documentation with a list of the planned materials, the expected performance characteristics, material thicknesses and construction technology instructions;
- in the case of problematic section or floor plan details, they draw up detailed plans to determine the correct design of the appropriate structural connections;
- and they prepare performance specifications about the properties of materials, structures and about the expected properties (performance characteristics) to determine the range of interchangeable products that can be used for a specific purpose.

3. Survey about building structural design methods
In the form of an online questionnaire [4], a survey was conducted on the working methods of building construction designers in Hungary. The questionnaire was available online for a month, the survey was posted on several professional forums to reach the designers. The aim of the survey was to map the processing strategies used by the construction designers in connection with the performance of each subtask, as well as the impact of BIM systems on their work. The following questions were included:
1. How many years of experience do you have in the field of building structure design?
2. What scale of projects do you usually work on?
3. In which program do you make the construction details?
4. What program do you use to create multi-layered structure documentation?
5. What program do you use to create performance specifications?
6. Does the spread of BIM-based design affect on your working methods at present?
7. Will the spread of BIM-based design have an impact on your working methods in the future?

The questionnaire was completed by a total of 35 designers engaged in building construction design. 60% of the respondents work only in this field, and the rest are architects who do this part of the work themselves within the whole design task, so they have gained a lot of experience in it. 50% of the respondents have more than 10 years of experience and 23% have 3-5 years of experience. Mainly highly experienced designers took part in the survey, so conclusions can certainly be drawn from the collected data on the conditions in Hungary.

The examination of software use shows that digitization has advanced in the field of architectural design. The results of the programs used for the three characteristic tasks of building construction design (detail drawing, layering and performance characterization) are shown in Figures 1-2-3. Detail designs are almost always created with the help of a program capable for vector graphic designs, which also facilitates editing and collaboration with related disciplines, as the software is able to link the drawings to the model elements by sending the given detail drawings back and forth on a .dwg basis. Thus, for example, detail drawings of branch designers can be linked to architect plans, where the location of the recording can also be accurately indicated.

50% of the respondents use Word and 39% use ArchiCAD to create and maintain multi-layered structures. These two programs are fully suitable for flowing text editing, but data can only be further processed manually, making it impossible to connect them to BIM systems. 82% of respondents also use Word software to create performance statements. This data is remarkably high, from which two conclusions can be drawn. On the one hand, experts do not solve administrative tasks in a way that can be further developed and effectively combined with other software, but they concentrate on the given
task in the most convenient way. On the other hand, they do not currently have a software solution that can help the task with sufficient efficiency along the lines of BIM.

Figure 4-5 show the current and future impact of BIM-based architectural design and design processing on the work of building construction designers based on the opinions of the respondents. The difference between the work processes that can be envisioned according to the current and the BIM principles shows well that this area has so far been only marginally affected by the new approach. At the same time, it is also clear that most construction designers expect significant change in this area.

4. Dynamic Information Raise method for multi-layered structures

The examination of the construction designers’ workflows make obvious that flowing text data writing is essential in building design, as many other disciplines use this data, and they have an important role in the final design documentation of the building. The results of the survey reported above also show that there is a need to increase digitization and BIM integration in the field of building construction design [5] [6].

One obvious IT solution for big data management is the application of databases. A database can be almost anything that can manage recorded values in a structured way, organize them into tables, and create relationships between them, and so on. Creating multi-layered structure documentation in a systematic form would provide an opportunity to automate certain work processes. One such process is the quantification of the designed materials, as the BIM model provides the correct geometry, so the quantities, and the exact material definition would be provided by the database-based multi-layered structure documentation [7].

Figure 6 Database based material quantity logic
The concept of Dynamic Information Raise (DIR) has to be introduced, which means this process. Systematic, structured processing of data created by construction designs in a database-like environment and then automated loading into the BIM model and further use by related disciplines.

4.1. New method of making multi-layered structures documentation

A new method has been developed to create multi-layered structure documentation on a database basis, so it is possible to link it to models created in 3D CAD software, which also operate as databases. Interconnection allows automation of quantification and loading of material properties.

Excel was used as the framework for the development because it is available on all colleagues’ computers, it is easy to manage, and it is also suitable for programming with the help of the VBA (Visual Basic for Applications) development environment. The goal was to create a solution that is easy to use but stores all the necessary information in a form suitable for further processing. Therefore, a structured system was created, the logic of the system is shown in Figure 7. A hierarchical, extensible system has been defined that more accurately describes the properties of the products designed into each structure.

![Figure 7 Positioning layer documentation in project hierarchy](image)

The Excel-based module is divided into three main groups, into three worksheet groups: building materials (orange), multi-layered structure documentation interface (blue), assistant sheets (green) (figure 8). The designer can group the construction products thematically and collect all the product properties on the orange worksheets. The assistant sheets contain the background settings necessary for the operation of the program, the designer has nothing to do on these tabs. The main function is available on the blue tab, where construction designers can create the layer sequence of the multi-layered building structures. In the upper right corner are buttons required for operation, which are programmed in VBA, for example a button for the creation of a new multi-layered structure unit.

![Figure 8 Excel development for multi-layered structure documentation](image)

The operation of these buttons is ensured by VBA programming. The principle is that the blue background cells can be edited freely, while the modification of other cells need an administrator permission. Excel’s non-editable cells and code are also password-protected to prevent accidental errors and ensure the proper work of the file.
4.2. Connection with the model file
An important feature of the new method is the ability to connect to a 3D BIM model. The main advantage of its application is that Excel data can be linked to the information of the model elements. The model must be prepared for the integration of the subsystem, since automated operation can only be ensured if the following conditions are met:

- geometrically correct model elements are created;
- layer unit codes are defined, assigned to model elements, either in the name of the composites or fixed as a property value, etc.

An architectural design software usually has a function that can sort its information content into a list according to a filter condition system. This function can be used to extract the required data, so the multi-layered structure layer unit code and the quantity value. A BIM manager is needed to supervise the building of the right model and ensure the right operation.

Excel files that contain the documentation of multi-layered structures must be linked to the BIM files that contain quantities. Along the principle of database-based data linking, with the help of Excel's Power Query add-on, the two amounts of data can be linked using a layer unit code and converted into a large table (figure 9). The completed table is containing all the data, and the required data can be queried and formatted. It is quick to filter and summarize data, but other operations can be also performed on the data. The main advantage of the above method is manifested when the source files are modified, the queries can be updated, thus the documents can be generated quickly.

![Figure 9 Merge of quantity and material data](image)

4.3. Project testing
The developed method and program have been tested on real projects. Ongoing design tasks provided a good opportunity to compare the ordinary and the developed method. The development was tested on three living design projects, so that the building material quantity take off (QTO) was also completed using the ordinary, manual calculations and the new method. An efficiency comparison was made by measuring the time spent on these processes. The basic data of the test projects and the results of the comparison are summarized in Table 1.

| Project | Project2 | Project3 |
|---------|----------|----------|
| Design function | bookstore | office building | military base |
| Designed floor area (circa) | 11 000 m² | 25 000 m² | 40 000 m² |
| Design task status | new | renovation | new |
| Design task complexity | average | complex | simple |
| QTO with ordinary method | 28,0 h | 31,5 h | 24,5 h |
| QTO with new method | 15,5 h | 13,5 h | 19,0 h |
| QTO due to modifications with ordinary method | 3,0 h | 4,0 h | 3,5 h |
| QTO due to modifications with new method | 1,5 h | 1,0 h | 2,0 h |

Testing three projects with different functions and scales, the comparison of quantification with the ordinary and the new method showed significant saving of working time. Although this test procedure is not suitable for exact comparison, as small number of different projects were observed. The timing of quantification depends on many factors (e. g. building complexity, easy understanding of drawings,
colleague practice, etc.). However, the positive effect can still be stated, and it is likely that this method will increase the accuracy and reduce the planning time. The test showed reduction in the quantification time by an average of 41%, and the re-quantification was also achieved in an average of 56% less time due to some modification.

5. Conclusion
The aim of the research was to create a development that can actively channel construction designers into BIM workflows. A survey was used to assess the BIM impact of the area. The results clearly show that this sector of the industry still uses ordinary design methods, using a word processing program (mostly Word) to create written documents. In the digital design environment, the rapid flow of information and its connection to a model is playing an increasingly important role.

A unique programmed solution was created in Excel framework, thus, the multi-layered structure information can be connected to the model and the information can be further processed. The quantity take off method was examined primarily. Using the suggested solution the quantities can be calculated from the building material and the geometric data of the BIM. This developed method is called Dynamic Information Raise.

The developed new solution was tested on three design projects. The results clearly show a significant reduction in time requirements in the case of QTO tasks. In addition to the time saving, the loss of information content can also be minimized, as the document prepared by the building construction designer is connected directly to the BIM.

Multi-layered-structure data generated using the DIR method also allows for additional automated processes, it can provide connected and updatable data for energy calculation about the building structures, or the layered weight data can be used during structural dimensioning. There are many more connection possibilities, which would be worth to be examined in a later research.

6. Acknowledgement
Special thanks to the TSPC Group for the opportunity and the support of the development, for the testing opportunity, and for the comments helping the research. Thanks to Épszerinfó Kft. for the application of the development, for providing useful ideas and for the support in the implementation.

References
[1] C. Eastman, P. Teicholz, R. Sacks, K. Liston, BIM Handbook: A guide to building information modeling for owners, managers, designers, engineers, contractors. John Wiley, Hoboken, 2008, 490 p.
[2] K. Zima, E. Plebankiewicz, D. Wieczorek, “A SWOT analysis of the use of BIM Technology in the Polish construction industry” Buildings, tom 10, nr 1, https://doi.org/10.3390/buildings10010016
[3] A.J. Garcia, S. Mollaoglu, M. Syal, “Implementation of BIM in Small Home-Building Businesses” Practice Periodical on Structural Design and Construction, tom 23, nr 2, doi: https://doi.org/10.1061/(ASCE)SC.1943-5576.0000362
[4] Y.M. Brenda, S. Arash, Z. Li Hao, W. Mark, C. Yuan, University of Toronto: 2nd Annual BIM Report 2019; Canada
[5] C. Sun, S. Jiang, M.J. Skibniewski, Q. Man, L. Shen, “A literature review of the factors limiting the application of BIM in the construction industry” Technological and development of economy, tom 23, nr 5, pp. 764–779, https://doi.org/10.3846/20294913.2015.1087071
[6] H. Kim, Z. Shen, I. Kim, K. Kim, A. Stumpf, J. Yu, “BIM IFC information mapping to building energy analysis (BEA) model with manually extended material information” Automation in Construction, tom 68, nr 8, pp. 183–193, http://dx.doi.org/10.1016/j.autcon.2016.04.002
[7] M. Cheng, N. Chang, “Dynamic construction material layout planning optimization model by integrating 4D BIM” Engineering with Computers, tom 35, pp. 703–720, doi: https://doi.org/10.1007/s00366-018-0628-0