International Conference on Sustainable Materials, Systems and Structures (SMSS 2019)
Energy Efficient Building Design and Legislation
20-22 March 2019 – Rovinj, Croatia

POSSIBILITIES OF USING BIM FOR DEEP ENERGY RENOVATION ANALYSES

Sanjin Gumbarević (1), Bojan Milovanović (1), Marina Bagarić (1) and Mergim Gaši (1)

(1) Faculty of Civil Engineering, University of Zagreb, Croatia

Abstract

With unsustainable greenhouse gas emission and irrational energy consumption, building sector have big impact on environment pollution and climate change. In order to reduce the building sector impact, the majority of current buildings need to be renovated and new buildings built as Nearly Zero-Energy Buildings (NZEB). Since for building renovation and new NZEB, together with integrated design, management of relevant information is crucial, the use of Building Information Modelling (BIM) becomes evident. BIM is a concept which promotes integrated design process in a way that connects all key stakeholders by collaborating on the same information model. In order to assess energy demands of renovated building and therefore perform an optimization process, BIM must be transformed in Building Energy Model (BEM). Today, BIM-to-BEM Information Process (BBIP) is still not fully developed which results with some information being lost during BBIP. Those lost information must be re-entered to create correct BEM. This paper proposes a procedure for tackling this BBIP information loss. This procedure is summarized in the workflow steps needed to acquire correct information about the building as an input for optimization of envelope design in deep energy renovations and exploitation of the building during its lifecycle by using BIM tools and processes. Moreover, to increase the use of BIM for energy efficiency purposes, competences of all building stakeholders must be enhanced.

Keywords: BIM, Deep Energy Renovation, Building Performance Simulation, Envelope Design, Net-UBIEP, BIMzeED

1. INTRODUCTION

Contribution of building sector in the energy consumption and greenhouse gases emission is unsustainably large. Energy consumption in the building sector mostly manifests through energy demands for heating and cooling, so the influence of the building envelope cannot be underestimated [1]. Therefore, European Union made political decision (with Directive 2010/31/EU) to increase the number of Nearly Zero-Energy Buildings (NZEB), but society in general should also recognize the impact of each and every individua as well. As large portion of current building stock do not have the NZEB performance (especially residential buildings), extensive retrofit of those energy poor-performing buildings should be carried out in order to meet the performance goals set by EU 2020, 2030 and 2050 targets. Additionally, new NZEBs must be built from 2021. Those NZEB buildings, due to their complexity need to be designed following the integrated design principles, i.e. all engineering professionals should be involved from the start, all in order to achieve cost optimality. Building Information Modelling (BIM) is a solution to gather all the engineering professionals and architects to develop a project altogether by working on the same building model which contains the relevant information (integrated design approach). BIM is changing design process according to the MacLeamy Curve introduced in [2] and shown in Figure 1 (curve marked with *4 – preferred design process* is integrated process design), so it is considered to be a good tool for designing the NZEB because more time and effort is invested upfront in the early design phases and therefore a better solution could be provided, i.e. cost optimal solution of the NZEB. Not only more variant solutions could be examined but also they could all be checked by preliminary energy simulation as BIM model can be, reasonably quickly, transformed into the Building Energy Model (BEM).

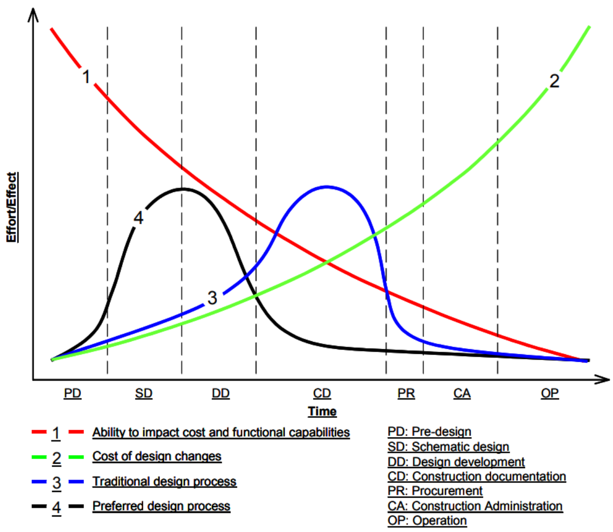

Figure 1: MacLeamy Curve [2]. Curve 4 (preferred design process) describes BIM design process.

Many BIM software have add-ins for creating BEM, and energy simulation can be carried out in the same BIM interface, but since they are often not in line with national standards or calculation algorithms and lack the possibility of defining all the necessary inputs, those simulations could be performed just for variant checking. This variant analysis in early design (schematic) phase can significantly contribute to cost savings and functional capabilities. It is very important to create as-built model to ensure that all the correct information are collated in BIM model, which can then be prepared not only for possible future retrofit designing process but also for storing all the information about the building for future processes as well (refurbishment, maintenance, facility management, demolition…). BIM as-built model is prerequisite for creating more reliable BEM from trustworthy input data. More reliable simulations are needed to ensure compliance of the NZEB with regulatory requirements as well as to develop building mock-up model which reflects the real building. Reliable simulations could then be used for a whole range of applications intended to manage the energy consumption in buildings. Accurate geometry of the BIM as-built model could be achieved through the inspection strategies as described in [3] or with laser scanning through the importing point-cloud into BIM [4] and by comparing model created by 2D drawing inputs with one of proposed methods. In order to create more reliable BEM, it is important to accurately determine the hygrothermal properties of building elements and building in general. Destructive and/or nondestructive methods could be used to determine the thermal properties of building elements, i.e. thermal transmittance. It might be trivial to say that accurate input data will result with more reliable energy simulation, but regarding the energy consumption simulation to collate and manage this different data which is influencing the simulation results. When reliable as-built BIM and BEM are created and tested, design phase could proceed. To ensure the optimal energy balance, optimization of the building envelope and technical systems (HVAC, MVHR, RES) should be carried out in the design phase and it could be performed in BIM software because of quick transition between BIM and BEM so every variant could be checked in a reasonably short time. After the optimal global solution check it is important to perform detail solution check, i.e. including Thermal Bridges (TB) in energy simulation, and other detail design solutions by all professions involved. Impact of TB can be included by comparing numerical models of TB details (multidimensional heat flow equation) with 1D heat flow which can be included in energy simulation by adding exact thermal properties on TB area to copy heat flow of multidimensional model. A helpful method for determine TB when construction is finished is through the Infrared Thermography (IRT) [6-8] and numerical simulations which could then combined help to determine real linear (or point) thermal transmittance.

There is one more important property of the building envelope to be included in the energy simulations – it is airtightness, which could be predicted or measured [8]. For optimization process, predicted value should be used as construction phase has not started yet, while for final energy simulation (and BIM as-built model), measured value should be used in order to get BEM as close as possible to the real building consumption.

This paper is divided into three parts, except section 1 (Introduction). Section 2 shows recent research review papers concerning BIM – BEM connection and BIM usage for renovation and retrofit design. Section 3 describes model for BIM usage in deep energy renovation and BIM as input for required energy simulations. Last section represents some guidelines for the model testing and provides general conclusion of this research.

2. REVIEW OF CURRENT RESEARCH

Analyzed papers are literature and case study reviews from which a general conclusions are presented in order to explore possibility of proposed model's (section 3) feasibility. For BIM based energy simulation, information transfer between BIM software and energy simulation software is crucial. Gao, Koch and Wo [9] made studious research in the connection between BIM and BEM models as they named it BIM-based-BEM. That connection is in view of the information transfer between BIM modeling software and energy simulation software. They described information transfer through Industry Foundation Classes (IFC) and green building XML (gbXML). In this paper information transfer is examined and divided in 6 steps: geometry (step 1), material (step 2), space type (step 3), thermal zone (step 4), space load (step 5) and HVAC (step 6). With exploring transfer between large cup of software (BIM to energy simulation BEM) they concluded that the IFC schema transfer is at step 1 as only geometry characteristics can be transferred correctly and the gbXML schema is at step 3 as, apart from geometry information, material properties and space type can be transferred too. The same group of authors [9] conclude that correct information transfer is not user friendly as there are many steps between BIM and BEM. On the other hand it can be concluded that even if there is no BIM to BEM connection at all, BIM should be used for the building renovation design as Sanhudo et al. [10] found BIM's finest benefit is in storing and organizing data. They see BIM as a connection between data acquisition and data management as shown in Figure 2. Sanhudo et al. [10] have analyzed BIM-to-BEM connection and, like in [9], they found information loss to be the main problem in BIM-to-BEM workflow, which means a lot of stored information must be re-entered to BEM.

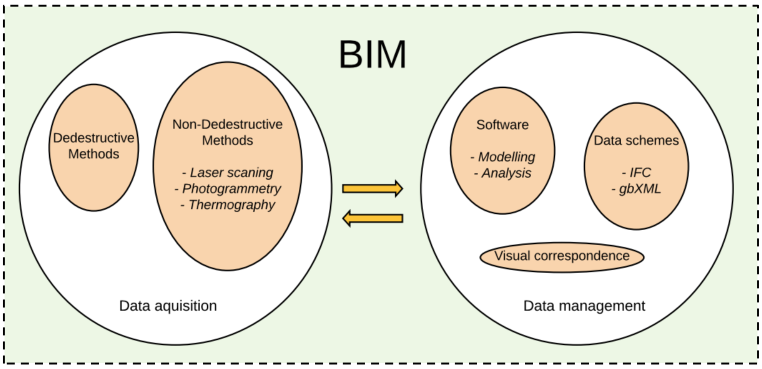

Figure 2: As-built BIM methodologies for retrofitting. [10]

Kamal and Memari [11] also analyzed the connection between BIM and BEM and the process of information exchange between them which they called BIM-to-BEM interoperability process (BBIP). Similar as in [10], they found the main contribution of BIM in energy modeling as the "*ease of handling data, which can lead to automation in energy modeling, better presentation of output, capability of storing and organizing new building data especially the real-time information to have an up-to-date energy model, and enhancing existing libraries by adding new attributes to the normal energy simulation process*." [11]. As main problems, they see the lack of standards and the lack of easy solutions which is, probably, the main reason why energy simulations are not performed more often in BIM tools. On the other hand, Habibi [12] sees lack of reliable data sources as one of the biggest barrier to retrofit and renovation design so he concludes that it is important to consider integrated steps which could be also managed using BIM. BIM can be a key factor to optimize energy consumption in the existing buildings by providing a good input for a deep energy renovation in view of stored and organized building information database, i.e. as-built BIM. Energy simulation is playing a significant role in decision making where in design phase, especially in the early design phases where, with optimization methods, large energy savings could be achieved [12]. Habibi [12] also reports that in order to ensure reliable BEM for energy simulation, lost information in BIM-to-BEM information transfer must be re-entered manually from BIM.

Several conclusions could be drawn from the analyzed research papers. Firstly, the BIM and BEM information transfer is not yet fully developed, but as concerning geometry, material properties and space type information transfer (gbXML) the connection could be realized. Some data should be re-entered, and other needed data should be added (e.g. climate data). Even if there is no connection between BIM and BEM, BIM is useful for managing the building information data and for controlling quantities needed in energy simulations.

3. PROPOSED MODEL

Taking into account existing BIM to BEM issues identified from the literature review and experience in BIM and BEM modelling, a procedure for deep energy renovation using BIM is proposed in this paper. The Model consists of three phases: input phase, design phase and output phase; and they are focused only on building envelope. Figure 3 shows flow chart of all required steps in each defined phase.

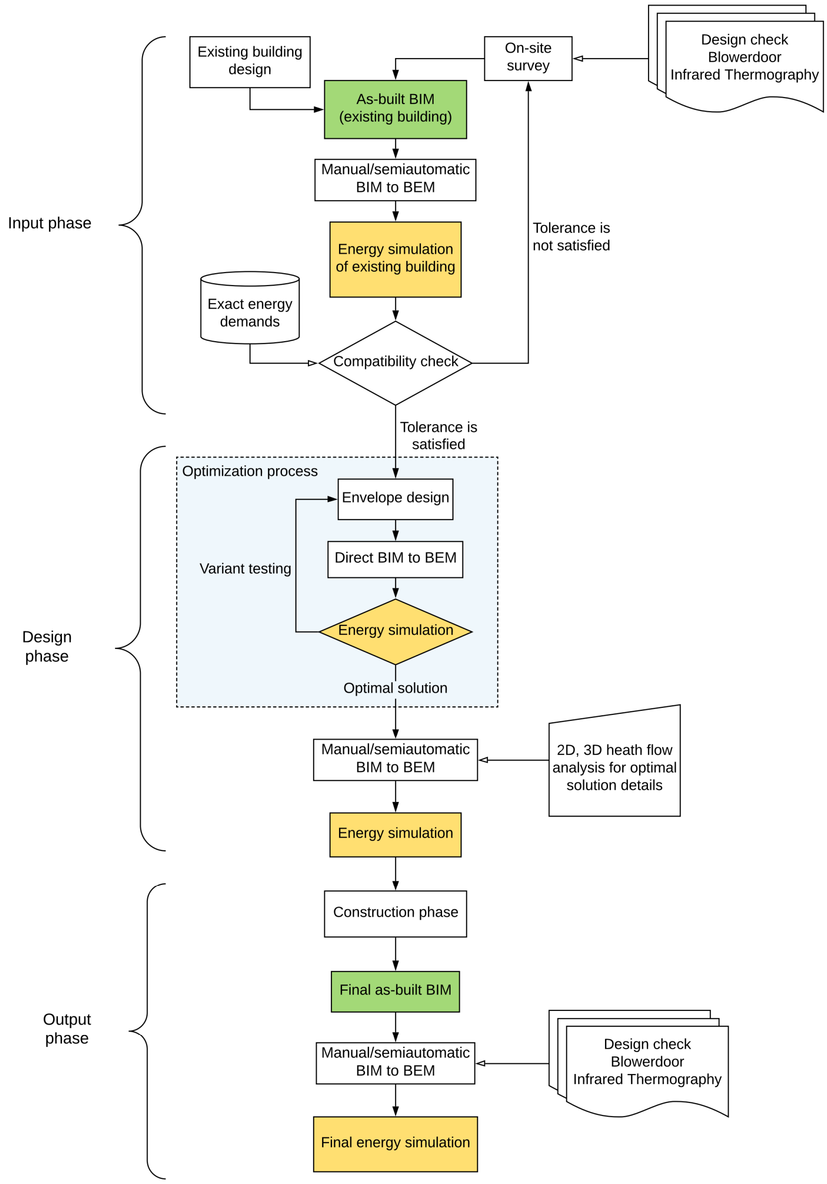

Figure 3: Proposed procedure for deep energy renovation using BIM.

Each phase is equally important and should not be left out. In the start of the project, as-built BIM model needs to be created regarding existing building design and on-site survey. As the goal is to perform a reliable energy simulation, thermal properties of building elements should be explored during the on-site survey using nondestructive or destructive methods, e.g. heat flux measurements (U-value), IRT for TB exploration and BlowerDoor (BD) for airtightness of existing envelope, etc. It is very important to create correct as-built BIM as possible, because energy model (which is input to renovation design) needs to have as close energy consumption as real building in order to be used in future energy related analyses. After as-built BIM is created it has to be transformed into BEM. BEM is created combining information which could be transferred through gbXML or IFC schema with re-entering lost information in BBIP, this step is called Manual/semiautomatic BIM to BEM. After energy simulation is performed, the results should be compared to real energy consumption of the building. If satisfied with the results, input phase is completed, if not, differences of the BEM and real building must be explored.

Finishing input phase, correct as-built BIM and BEM are created which means reliable input for the design phase is provided. BIM design software (e.g. Revit, ArchiCAD, Allplan) often have solutions for preliminary energy modelling in the same BIM environment. Lacking some harmonization with specific country legislation, standards and input data for energy simulation and building performance analyses, these solutions should be viewed only as a general assessment and could be used during the optimization process of envelope and building systems design. Loses through building envelope is one of three main factors which influence energy demands. Other two are building systems and schedule of building usage which would not be explored for optimization in this model, but analogous principles can be applied. With described solutions for direct BIM to BEM in BIM environments, variant checking is quickly done, and optimal solution should be chosen for further steps of the design phase. Numerically modeled TBs are another manual/semiautomatic BIM to BEM which needs to be performed. Thus, after general optimization process is finished, detail numerical analyses is to be carried out (i.e. 2D/3D heat flow (TB) analysis for details of chosen optimal solution). This would result with more reliable design phase energy simulation while on the other hand would save resources of numerous and tedious analyses of all possible variations. Output of this step is BIM of planed deep energy renovation design with BEM including TB analysis.

The final phase is called an output phase because the final as-built BIM is created after construction process has finished and handed over to be exploited during the building's life cycle and end of life stage. Since BIM model of a building should be used through all the building's lifecycles – from early planning and designing stages [13, 14] through facility management and (possible) renovations to deconstruction [15, 16], in the output phase, final energy simulation must be carried out after as-built BIM is finished, so that investor and users have a reliable information on building's energy performance. Therefore, as an input in the final energy simulation there should be as-built BIM containing information from the tests performed and on-site survey of the newly constructed building. Those information (TB and airtightness) must be determined with IRT and BD test and included in energy simulation through Manual/semiautomatic BIM to BEM.

The proposed procedure was checked on the case study on deep energy renovation design of an abandoned exhibition hall building into a NZEB museum. Input and design phases with all their parts were completely tested while the output phase is to be tested after the building renovation is completed. Input phase with as-built BIM shown in Figure 4 is created from design drawings and on-site checking while BD and IRT testing was not performed since the whole building envelope was in a condition which requires complete replacement (Figure 4: a - c) and both tests would thus be futile. While in design phase, variations of roof, curtain wall and shading were examined, and optimal solution was chosen with demand to fulfill Croatian NZEB standards. In this case study, structural stability and load bearing capacity check were also explored using SAP2000 and as-built BIM as an input (Figure 4: d). The result was that current building does not satisfy the Eurocode 1998 requirements, i.e. building is weak under the action of horizontal forces. This resulted with strengthening the building's structure together with the energy renovation.

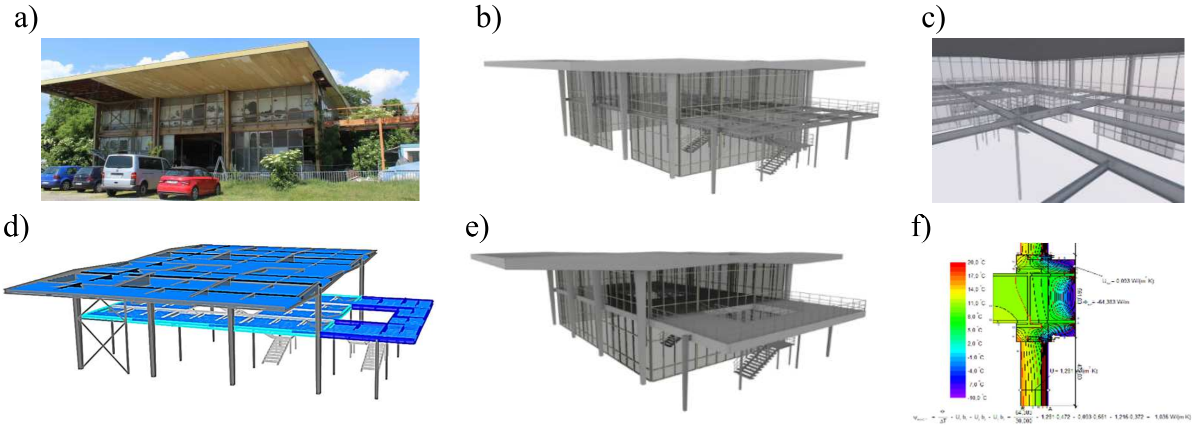

Figure 4: Deep renovation project for model testing [17]. a) Analyzed building, b) as-built BIM input - exterior, c) as-built BIM input - interior, d) numerical model for structural bearing analysis, e) BIM of renovation design and f) numerical thermal bridge analysis.

4. CONCLUSION AND FURTHER RESEARCH

This paper describes the procedure of BIM usage for deep energy renovation projects (concerning optimal envelope design). It describes phases and steps for providing more accurate as-built BIM and BEM through three predefined phases. The model should be used to enhance the BIM use for fulfilment of ever-increasing building performance demands. Proposed steps of described phases are logically deduced from the authors' experience with energy renovation and BIM. Further research is needed on direct BIM to BEM connection which should be explored by comparing it with widely accepted building performance simulations to approve its usability. Described possibility of including impact of numerically determined TB in energy simulations is plausible, but to better exploit advantages of BIM should be fully automated. Airtightness can be included in BEM as the number of air changes per hour for pressure difference of 50 Pa between interior and exterior environment (n_{50}). The n_{50} is the output of BD test and should be included in energy simulations because of its impact on the energy balance. The proposed process can be analogously used not only for building envelope aspects of the energy performance simulation but also for technical systems design and performance, including HVAC, MVHR, RES, automation. In other words, analogous process using BIM can ensure integrated design approach in building's deep energy renovation resulting with the solution which will be cost optimal during the building's lifecycle. In order to increase the use of BIM for energy efficiency purposes, BIM competences of all professionals must be enhanced. EU projects Net-UBIEP and BIMzeED are working on developing training programs and training materials to tackle this issue.

ACKNOWLEDGEMENTS

Authors would like to thank Zagreb Fair for providing all necessary inputs for deep energy renovation design project, so testing of design phase from proposed model was carried out.

They would also like to thank students and mentors who have worked on described project as part of joint final work for master thesis. Also, authors would like to acknowledge Horizon 2020 project Net-UBIEP for support. One of authors (Sanjin Gumbarević) would like to acknowledge the Croatian Science Foundation and European Social Fund for the support under project ESF DOK-01-2018.

REFERENCES

[1] K. Loukaidou, A. Michopoulos, and T. Zachariadis, "Nearly-zero Energy Buildings: Cost-optimal Analysis of Building Envelope Characteristics," *Procedia Environ Sci*, vol. 38, pp. 20–27, 2017.

[2] "Collaboration, Integrated Information, and the Project Lifecycle in Building Design and Construction and Operation." https://kcuc.org/wp-content/uploads/2013/11/Collaboration-Integrated-Information-and-the-Project-Lifecycle.pdf (accesed: 10. of December, 2018), 2004.

[3] Y. C. Lin, C. P. Lin, H. T. Hu, and Y. C. Su, "Developing final as-built BIM model management system for owners during project closeout: A case study," *Adv Eng Inform*, vol. 36, pp. 178–193, 2018.

[4] J. Jung, C. Stachniss, S. Ju, and J. Heo, "Automated 3D volumetric reconstruction of multiple-room building interiors for as-built BIM," *Adv Eng Inform*, vol. 38, pp. 811–825, 2018.

[5] M. O'Grady, A. A. Lechowska, and A. M. Harte, "Infrared thermography technique as an in-situ method of assessing heat loss through thermal bridging," *Energy and Buildings*, vol. 135, pp. 20–32, 2017.

[6] M. O'Grady, A. A. Lechowska, and A. M. Harte, "Application of infrared thermography technique to the thermal assessment of multiple thermal bridges and windows," *Energy and Buildings*, vol. 168, pp. 347–362, Jun. 2018.

[7] G. Baldinelli *et al.*, "A model for the improvement of thermal bridges quantitative assessment by infrared thermography," *Applied Energy*, vol. 211, pp. 854–864, Feb. 2018.

[8] M. Prignon and G. Van Moeseke, "Factors influencing airtightness and airtightness predictive models: A literature review," *Energy and Buildings*, vol. 146, pp. 87–97, Jul. 2017.

[9] H. Gao, C. Koch, and Y. Wu, "Building information modelling based building energy modelling: A review," *Applied Energy*, vol. 238, pp. 320–343, 2019.

[10] L. Sanhudo *et al.*, "Building information modeling for energy retrofitting – A review," *Renewable and Sustainable Energy Reviews*, vol. 89, no. March, pp. 249–260, 2018.

[11] E. Kamel and A. M. Memari, "Review of BIM's application in energy simulation: Tools, issues, and solutions," *Automation in Construction*, vol. 97, no. October 2018, pp. 164–180, 2019.

[12] S. Habibi, "The promise of BIM for improving building performance," *Energy and Buildings*, vol. 153, pp. 525–548, 2017.

[13] I. Kovacic and V. Zoller, "Building life cycle optimization tools for early design phases," *Energy*, vol. 92, pp. 409–419, 2015.

[14] C. Langenhan, M. Weber, M. Liwicki, F. Petzold, and A. Dengel, "Graph-based retrieval of building information models for supporting the early design stages," *Advanced Engineering Informatics*, vol. 27, no. 4, pp. 413–426, 2013.

[15] J. C. P. Cheng and L. Y. H. Ma, "A BIM-based system for demolition and renovation waste estimation and planning," *Waste Management*, vol. 33, no. 6, pp. 1539–1551, 2013.

[16] A. Akbarnezhad, K. C. G. Ong, and L. R. Chandra, "Economic and environmental assessment of deconstruction strategies using building information modeling," *Automation in Construction*, vol. 37, pp. 131–144, 2014.

[17] B. Barić *et al.*, "PROJEKT SANACIJE PAVILJONA „ĐURO ĐAKOVIĆ" – ZAJEDNIČKI DIPLOMSKI RAD –," in *14. INDIS Conference*, 2018, pp. 935–942.

BIM-BASED WORKFLOWS FOR BUILDING ENERGY MODELLING – A VARIANT STUDY

Julia Reisinger (1), Leonard Donkor (1), Stephan Loncsek (1) and Iva Kovacic (1)

(1) Department for Industrial Building and Interdisciplinary Planning, Faculty of Civil Engineering, Vienna University of Technology, Vienna, Austria

Abstract

The AEC (Architecture, Engineering & Construction) industry counts to the most wasteful ones, thereby urgently needing improvement for achievement of sustainable built environment. Early design stages, where project is conceptualized, are of great importance for the future energy performance of buildings. Tools such as the Energy Performance Certificate (EPC) - a rating scheme to express the energy efficiency of a building during operation - are used for the rating of building performance. Building Information Modelling (BIM - as emerging digital design tool) coupled to EPC has the potential to serve as an early decision-making tool for building performance optimization. However, the interoperability of the software tools is still a challenging task, causing problems with data exchange, thus resulting in information losses.

This paper presents a comparative study of different BIM to EPC workflow-variants, generated by applying three different BIM tools (ArchiCad, Revit and Allplan) for the same case study; thereby comparing the variation of the obtained EPC (ArchiPhysik) results. The process design, interoperability and the validation of the EPC results of the three variants were evaluated. Varying requirements regarding the Level of Detail between the BIM and the Building Energy Modelling (BEM) and the discrepancies in the EPC results were identified as main problems. Finally, through comparison of the various exchange combinations and identification of the potentials and deficits, suggestions for improving BIM-based workflows for energy modelling are proposed.

Keywords: Building information modelling (BIM), Building Energy modelling (BEM), Energy performance certificate (EPC), Interoperability, Design process

1. INTRODUCTION

The building sector is one of the biggest contributors to global environmental influences and consumes up to 40% of all raw materials extracted from the lithosphere. Furthermore, it is responsible for about 50% of global greenhouse gas emissions [1]. The early planning phase is crucial for defining important sustainable variables, relevant throughout a building´s lifecycle;