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

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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;

these variables can minimize the environmental impact of construction projects [2]. BIM can contribute to a more consistent decision-making process and can therefore serve as a support for sustainable assessment of building projects in early phases [3]. The BIM model itself serves as a joint knowledge database and offers the possibility of data transfer between multiple models [4]. BIM has been recognized as a useful tool for collaboration of professionals to manage complex communication and information processes, thus in practice, there are still difficulties with the implementation and actual performance. [5] Energy simulation programs used in the early design stage can assist the decision-making tools, progression of optimization methods, calculating and indicate the building energy performance [6]. The EPC certificate provides reliable information about the building's energy performance. It gives information about the heating and end energy demand, CO_2 emissions or the energy performance factor [7]. "…architectural design tools have poor connections to thermal and environmental analysis software, which is exacerbated by a lack of knowledge of the data requirements of other disciplines both upstream, and downstream [8]." In order to import, export, adapt or modify information with BIM, a continuous cooperation between all project participants over the entire lifecycle is necessary. In practice, the planning process participants working with BIM and BEM still need to manual re-enter numerous data, make additions and set new parameters in the energy performance tools in addition to the input data obtained from BIM.

The main aim of this study is examining three BIM-based workflows for energy modelling within one case study. It investigates the quality of data exchange between the discipline models (the 3D-Models with the EPC tool) within a Variant Study. It identifies the problems of the BIM to BEM design process and validates the EPC results. The focus is on the modelling process and the interoperability between the BIM models and the EPC tool and provides an assessment for the integration of energy efficiency aspects into the overall BIM workflow.

2. LITERATURE REVIEW

Interoperability has been identified as a challenging task due to the multiple heterogeneous applications and systems applied by diverse planning process participants. In practice, the vision of a seamless global interoperability has not turned into reality yet [9]. Gourlis and Kovacic [4] state that the most common information exchange format from BIM to BEM is the open non-proprietary interface IFC (Industry Foundation Class), developed and supported by buildingSMART [10] and the gbXML (green building extensible markup language) [11] data format. Arayici et al. [12] developed an interoperability specification for an effective and efficient data and process integration in BIM-practice for collaboration and information exchange for performance based design.

Currently the most common way of sustainable planning in practice is modelling the building with traditional CAD (computer-aided design) tools first and entering the design data into an energy simulation tool to analyze the performance afterwards. Salguerio and Ferries [13] pointed out that there are still limitations in the interoperability capabilities, which make iterative interventions of the designer inevitable. The problem is that although BIM has the capability to allow designers to compare project variants and generate important quantitative data volumes, there is still no interface or software to organize and classify this data for enabling an easy multiple criteria assessment. Beazley et al. [8] claim that the main problem is the integration of different tools, the multiple data entry and the data flow between BIM models and energy analysis tools. Pinheiro et al. [14] claim that preparing BEPS (Building Energy

Performance Simulation) models require multiple manual operations and this fact is connected with data fragmentation and poor quality of data.

Literature review has identified numerous problems with BIM to BEM workflows such as data exchange and iterative manual design process loops. This paper is addressing these issues and identifies within a Variant Study remaining bottlenecks in BIM-based workflows for EPC.

3. VARIANT STUDY

In order to evaluate the potentials of BIM for EPC, a comparative study was carried out. Based upon a design brief of a real industrial facility (dwg. and pdf. files), BIM Models of the same production hall were created. The building is located in Völs in Tyrol, Austria. The building envelope characteristics are displayed in Table 1 and the facility's basic data such as gross floor area, volume and the energy supply in Table 2.

Table 1: Construction and u-values of the building envelope

Roof	Facade and walls	Bottom Plate
30 mm OSB plate (650 kg/m³) 260mm timber (475kg/m³) with 260mm mineral wool insulation 15 mm OSB plate 30 mm plasterboard **U-value: 0,170 W/m²K**	<u>*Post and beam facade*</u> **U-value: 1,30 W/m²K** <u>*Outer wall massive*</u> 60 mm aluminum sheet 200 mm thermal insulation 200mm reinforced concrete wall **U-value: 0,187 W/m²K** <u>*Outer wall lightweight*</u> 60 mm aluminum sheet 20 mm OSB plate 260 mm timber(475kg/m³) 260 mm thermal insulation 20 mm OSB plate **U-value: 0,171 W/m²K**	200 mm XPS 300mm reinforced concrete 60 mm cement composite screed **U-value: 0,186 W/m²K**

Table 2: Basic data and energy characteristics of the production hall

Climate	-1,4°C – 18,6°C (outside); 17°C – 20°C (inside)
Gross floor area	10.023 m²
Volume	120.648 m³
Energy supply	District heating
Electricity supply	Electricity mix Austria 85%, 15% photovoltaics
Window ventilation	1,5 1/h (with night ventilation)
HVAC (heating, ventilation, and air conditioning)	No mechanical ventilation; no cooling

The EPC calculations were generated using ArchiPhysik, a statistical analysis software for building physics and energy performance assessment, authorized by the Austrian regulative.

The tool is linked to baubook [15], a building material eco-data repository, including data on thermal conductivity, density and specific heat capacity of construction layers, which is directly available as default data. It does not offer IFC import/export. The software provides two proprietary interfaces; for ArchiCad, an architectural BIM CAD software by Graphisoft and for SketchUp, a 3D modelling software by Trimble.

For the comparative Variant Study four Variants of the same case study were generated: A Referential Variant – EPC only; Variant A – ArchiCad to EPC; Variant B – Revit to EPC, Variant C – Allplan to EPC.

For the referential variant, a reference EPC was created manually with ArchiPhysik; based on the dwg. and pdf. files provided by the design brief of the industrial facility.

The BIM Model for Variant A was created with ArchiCad based on the provided documentation. For data exchange the ArchiCad - ArchiPhysik Add-On was applied.

To obtain the model for Variant B, the architectural ArchiCad Model was imported via IFC into Autodesk Revit. Some further re-modelling steps regarding geometry adaption were necessary to obtain the architectural model in Revit. As Revit lacks interface to ArchiPhysik, the model was transferred via IFC into SketchUp and for the EPC the SketchUp-ArchiPhysik Add-On was used.

Variant C was created based on the provided documentation with Allplan, a Nemetschek software. The geometry data was exported via Excel and transferred manually into ArchiPhysik, as there is neither available interlink to Allplan nor an IFC. Interface.

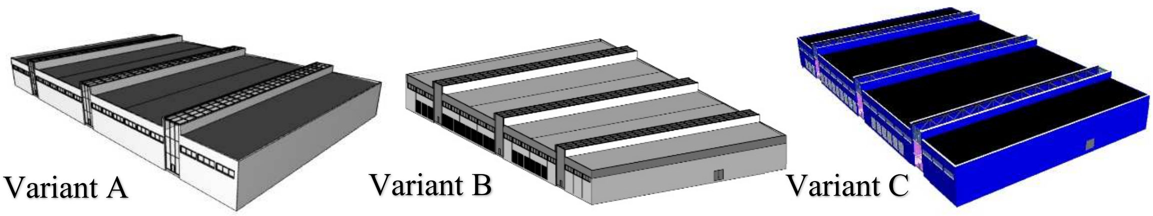

Figure 1: BIM models: Variant A in ArchiCAD; Variant B in Revit; Variant C in Allplan

4 RESULTS

4.1 Workflows

The comparative analysis of the Referential Variant and Variant A workflows are displayed in Figure 2. Based on the original planning documentation the data entry for the EPC was carried out manually in the Referential Variant. In the Variant A, the software used in the modelling process included on the BIM side ArchiCad for architecture and ArchiPhysik via the ArchiCad Add-On for BEM. However, to transfer the BIM model to the energy calculation software without receiving error messages, it was necessary to re-model the architectural model to a more simplified model (BEM Model) regarding geometry and setting specific layer combinations. With the Add-On and the simplified BIM Model, it was possible to transfer geometry, construction and the building envelope to ArchiPhysik. In ArchiPhysik, it was necessary to apply the project data, the construction and component list and the facility properties for HVAC manually to create the EPC. The Add-On recognized constructions consisting of several drawing elements as a common structure from ArchiCad and grouped them accordingly in the ArchiPhysik component list to assign the material properties such as thermal conductivity, density and specific heat capacity. An error occurred by importing the post and beam façade. It was imported from ArchiCad as a wall and had to be changed to a window in ArchiPhysik. Further manual corrections were the change or delete of room stamps (gross floor area and volume adaption).

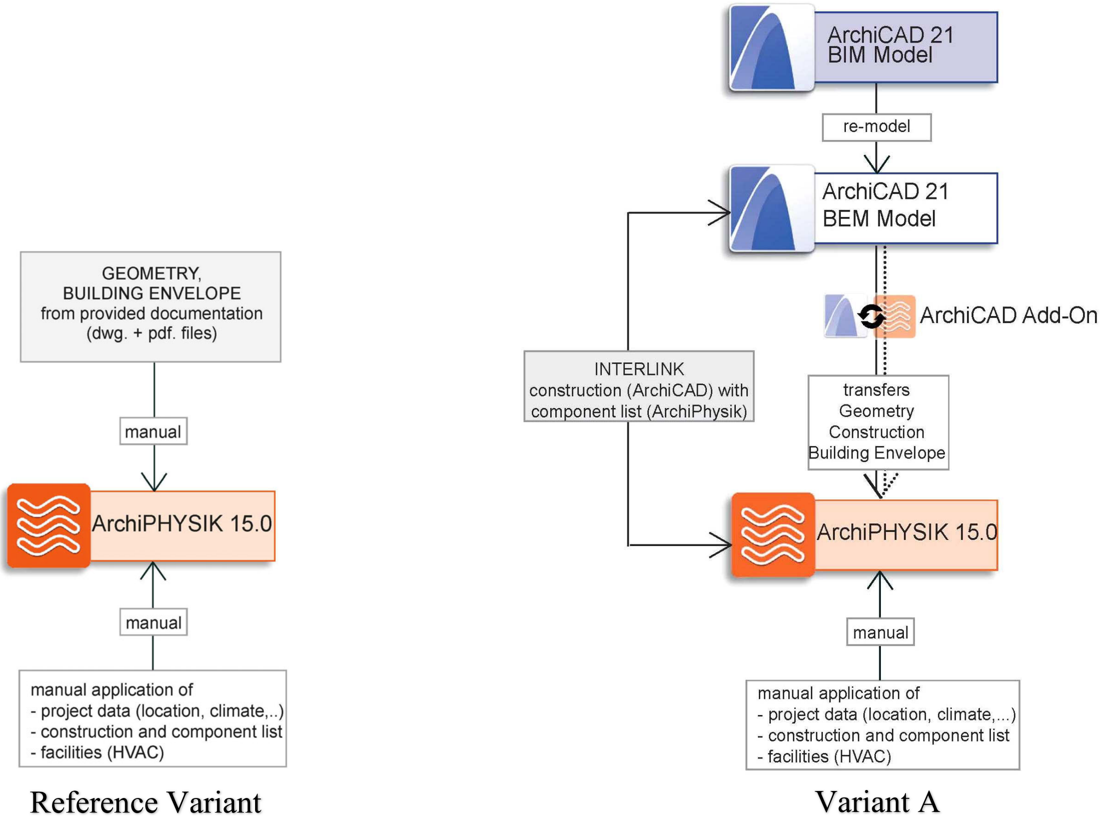

Figure 2: Workflows with software constellations – Reference Variant and Variant A

The workflows with software constellations in the modelling process for Variant B and C are displayed in Figure 3. In the Variant B the ArchiCad BIM Model was transferred via IFC to Revit, with additional geometry re-modelling necessary. The Revit BIM Model was converted via IFC in SketchUp. By making use of the SketchUp Add-On the geometry of the building could be imported to ArchiPhysik. As SketchUp is not a BIM software, only the geometry could be transferred. As in Variant A, the project data, component lists and HVAC properties had to be applied manually in ArchiPhysik. The geometry from SketchUp was interlinked with the component list in ArchiPhysik and the building envelope was defined. Manual Corrections in ArchiPhysik were required as the change or delete of room stamps (gross floor area and volume adaption) and the change or reproduction of the building envelope. For Variant C the BIM Model was created with Allplan and the geometry and building envelope data was exported into Excel. As ArchiPhysik offers no IFC. interface, the EPC in Variant C was carried out by applying the data manually in ArchiPhysik.

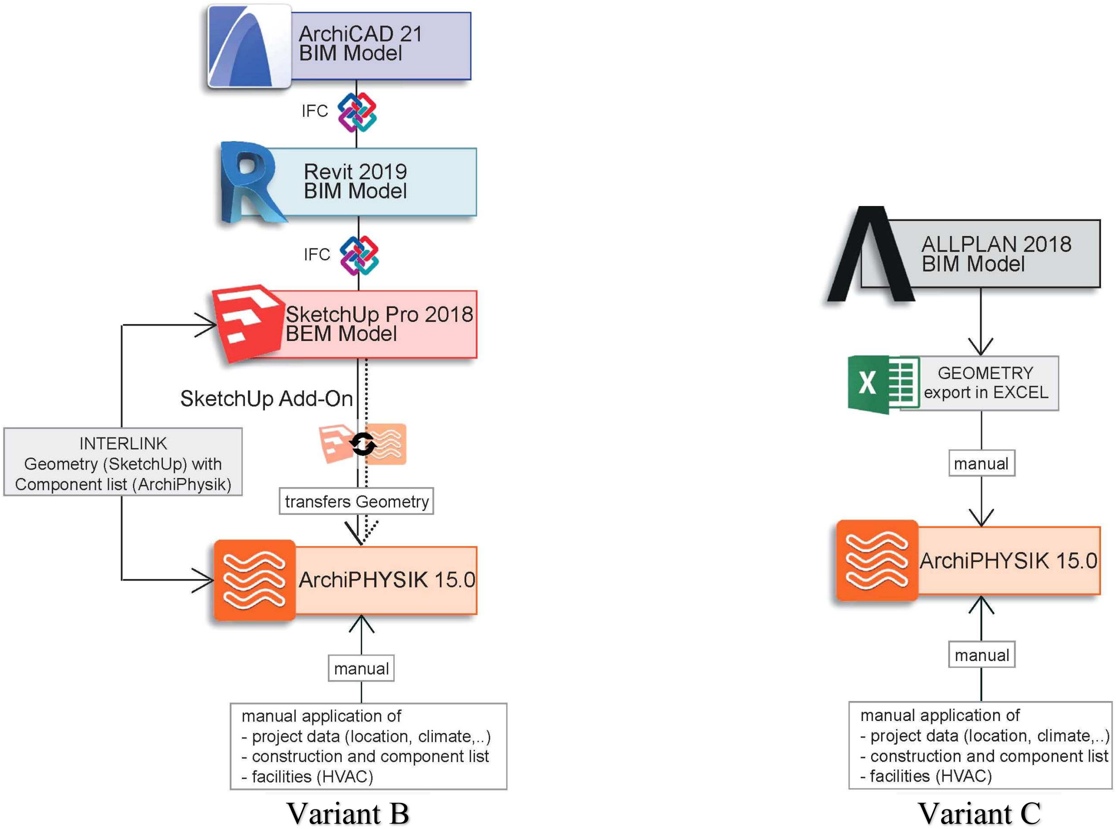

Figure 3: Workflows with software constellations – Variant B and Variant C

4.2 Validation

The results of the quantities such as gross floor area and volume obtained from the three different Variants based on three different BIM Models are presented in Table 3 and validated by comparison to the Reference Variant.

Variant A shows a negligible deviation of the gross floor area and volume and Variant B and C both differ by 0,29% from the Reference Variant. The heating and final energy demand results of the EPC differ by 12%. Variant A has a 6% higher and Variant B a 6% lower heating demand than the Reference Variant. The ArchiCad and Revit Model display a difference of 12,38% for the heating demand. Variant C's heating demand is around 3% lower than the Reference. The final energy demand ranges from +1,95% in Variant A to -1,59% for Variant B (total difference 3,5%). The final energy demand of Variant C is 0,9% lower than the referential values.

Table 3: Geometry outcomes and EPC results

	REFERENCE	VARIANT A	VARIANT B	VARIANT C
Gross floor area (m^2)	**10.023** 100%	10.019 -0,045%	10.052 +0,29%	10.052 +0,29%
Volume (m^3)	**120.648** 100%	117.547 -2,57%	121.879 +1,02%	119.213 -1,19%
Heating energy demand (HED) (kWh/m²a)	**44,01** 100%	46,66 +6,02%	41,21 -6,36%	42,64 -3,11%
End energy demand (EED) (kWh/m²a)	**194,67** 100%	198,46 +1,95%	191,57 -1,59%	192,92 -0,90%

5. DISCUSSION AND CONCLUSION

A comparative study of three different BIM-based workflows for energy modelling investigated the modelling process, the interoperability and the EPC results.

Thereby, following observations of the **modelling process and interoperability** were captured: The BIM Models were created for architectural purposes. Thereby, the modelling did not consider specific modelling requirements of energy analyzing software; resulting in displaying too many room stamps, geometrical errors and requiring re-modelling efforts on the building physics side. In Variant A, despite the fact that the BIM model required re-modelling to a simplified BEM Model, the inconsistencies were kept to a minimum level as ArchiCad has a direct Add-On to ArchiPhysik. Variant B in Revit made use of the SketchUp Add-On; which imports only geometry to ArchiPhysik, therefore requiring revisions of gross floor area and volume. As Variant C does not have an interface with ArchiPhysik, problems with data transfer did not occur, but the workflow resulted in more manual, time affording work, making the process error-prone. Although all BIM models would have contained very detailed construction and HVAC information, these had to be applied manually in ArchiPhysik.

Regarding the **validation of the EPC results**, following discrepancies were identified: Variant A displays a HED of 46,66 kWh/m²a and Variant B 41,21 kWh/m²a; the difference of 12% results from the varying gross floor area and Volume data from the BIM model.

This test implies that BIM for EPC calculation is possible with a semi-automated workflow but still requires re-modelling and adaption, which can be time consuming, disruptive and error-prone. In AEC practice, many different stakeholders with different mindsets are involved in a building project, using a heterogeneous software landscape. This leads to problems in data exchange and information losses. Even though in this study the BIM and BEM modelling was carried out by "one hand", problems in the design process and discrepancies in the results occurred. The architectural model is very detailed and has a large number of room stamps and product information, whereas the energy model needs simplified information. Due to the oversimplification of the BIM models to BEM, they are not for architectural purposes anymore.

The comparative study identified the advantages of semi-automated BIM-based workflows for EPC calculations as time saving in order to obtain precise geometry for the purposes of building performance analysis. In order to enable full benefits of BIM, the focus on further development of open interfaces between interdisciplinary software tools is needed. Recommendations for an improved BIM-based workflow for energy modelling are:

- Establishing a modelling standard at the very beginning of the design process; determining the required Level of Detail.
- BIM Model shows high Level of Detail - setting own layer definitions for BEM in BIM
- Setting own BEM room stamps and hiding BIM room stamps when transferring
- Seamless modelling of components is important for exchange

In our future research, we aim to develop an optimized semi-automated BIM to EPC workflow based on the results of this study; As well as to extend the study to BIM to LCA (life-cycle assessment) workflows, an additional early-decision making tool for sustainability.

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