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Framework for the transfer of building materials data between the BIM and thermal simulation software

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"Yet, 20 years from now (or probably less), BIM will be labeled something completely different, include features yet unimagined, and run on computers that make ours seem as slow and limited as side-rulers. The theoretical underpinnings, however, remain the same and are based on the earliest idea that architect transcends the mundane and that designer-builders need tools to translate their mental models to their collaborators to achieve their visions."

Karen M.Kensek, 2014

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ABSTRACT

Building information modeling (BIM) is a powerful collaboration and project delivery concept which is becoming popular in the architectural and engineering practice. Software developers are constantly extending the boundaries by introducing new features into their programs, such as support for an integrated workflow, thus inviting different specialists to participate in the project at earlier design stages. These type of contributions highlight the importance of decisions concerning the most effective method to export information, invariant of the chosen data model, be it IFC or gbXML. Extensions to existing software are also considered, i.e. plugins. Export of simple geometries is tested within three BIM platforms: ArchiCAD, Allplan and Revit. The main focus of the presented test is exporting of the building materials data and its preservation in the IFC and gbXML format, specifically for import into thermal simulation tools. The application and capabilities of EnergyPlus and ArchiPHYSIK are explored. We summarize our results as a sequence at guidelines and recommendations suggesting optimal workflows for each BIM platform, as well as design for "Customizer" application, which assists in mapping of the needed data, on a per application basis, from IFC or gbXML to the IDF files usable to ArchiPHYSIK and EnergyPlus.

Keywords: BIM, IFC, gbXML, EnergyPlus, ArchiPHYSIK, Allplan, ArchiCAD, Revit, building material, seamless export

KURZFASSUNG

Building Information Modeling (BIM) ist eine Methode die bei der Planung, Ausführung und Bewirtschaftung von Gebäuden zum Einsatz kommt. Ziel dieser Methode ist es Gebäudedaten digital zu erfassen, zu kombinieren und zu vernetzen und diese Informationen auch mittels Computer Model zu visualisieren. Die Inhalte dieser BIM Modelle gehen von der Geometrie des Gebäudes über genaue Informationen zu Materialien, Konstruktion und Ausführungsdetails bis hin zu Haustechnik und Installationsplänen etc. Die dafür verwendeten Programme werden von Softwareentwicklern ständig erweitert und durch neue Anwendungen ergänzt. Dadurch wird es Spezialisten aus verschiedenen Fachbereichen ermöglicht, bereits in frühen Entwurfsphasen an Projekten mitzuwirken. Um diese Zusammenarbeit optimal zu unterstützen und um Informationen nicht zu verlieren, ist eine genaue Analyse der Informationsweitergabe zwischen den verschiedenen Formaten/Programmen die für ein BIM Modell verwendet werden notwendig. In dieser Arbeit werden zwei Formate genau untersucht: IFC und gbXML. Mittels eines Beispielmodels mit einfacher Geometrie wird die Datenübergabe mit drei verschiedenen BIM-Plattformen untersucht: Archicad, Allplan und Revit. Ein Schwerpunkt liegt dabei auf der Weitergabe der Eigenschaften der Baumaterielien mittels IFC und gbXML Format. Besonders für Gebäude Performance Simulationen sind diese Informationen essentiell. In einem weiteren Schritt wird dann die Verwendung der Dateien für Energy Plus und Archiphysik Berechnungen bzw. Simulationen analysiert. Das Ergebnis dieser Arbeit besteht aus einer Reihe von Richtlinien und Empfehlungen, welche einen optimalen Arbeitsablauf für alle BIM Plattformen ermöglicht. Außerdem wird ein Entwurf für eine Applikation vorgestellt welche das übertragen der Informationen in die jeweiligen Programme ohne Informationsverlust ermöglichen soll.

Abbreviations

AEC	Architecture, engineering, construction
ANSI	American National Standards Institute
APH	ArchiPHYSIK file format
BEM	Building energy modeling
BIM	Building Information Modeling
BPA	Building performance analysis
CAD	Computer aided design
CSV	Comma separated variable
DXF	Drawing Exchange Format
gbXML	Green Building XML
GBS	Green Building Studio
HVAC	Heating, ventilation, air conditioning
IDF	Input data file
IFC	Industry foundation class
LEED	Leadership in Energy & Environmental Design
MEP	Mechanical, electrical and plumbing
MVD	Model view definition
ÖGNI	Österreichische Gesellschaft für Nachhaltige Immobilienwirtschaft (Austrian Green Building Council)
OS	OpenStudio
OSM	OpenStudio model
SBT	Space Boundary Tool
UTF-8	Universal transformation format
XML	Extensible Markup Language

CONTENTS

1 INTRODUCTION

1.1 Overview: origins of BIM

A multi-faceted approach to the design has always been the part of the architectural profession. Generally, among architects there exists the intuitive understanding of how all the different factors should be combined together in one building in order to fulfil the purpose of the project. As Kensek (2014) notes, currently the complexity of building projects translates into increased complexity of tools used in modeling. What we refer to as “complexity of the project” is not to be understood as architectural design, but rather as the complexity of collaboration process between the disciplines participating in a building design: architecture, structural engineering, building performance analysis, HVAC, electrical engineering etc. In the course of the last ten or fifteen years CAD was integrated in every one of the aforementioned disciplines insomuch as one could consider it a routine. Using computers to aid not just the design process but the information flow between the various collaborators is the goal of parametric modeling. This collaboration is essentially what constitutes the “I” element in BIM, resulting into the building *information* modeling, making it the next logical step in the development of the design tools (Figure 1).

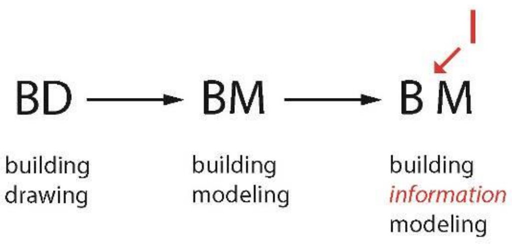


Figure 1 Evolution of the building design process

Once the information is forwarded to the software, it immediately becomes “data”. While dealing with digital data, it becomes important to consider which software is used by the participants of the project, in which formats are they working and how do they handle the data (information) transfer.

Handling this information correctly, improving the interaction of social values and technology in design (Kensek 2014), were the hopes and aspirations of the early developers of BIM.

The integrated and collaborative principle of modelling was first introduced as “parametric modelling” and later transformed into BIM – Building Information Modeling (Van Nederveen and Tolman 1992, Autodesk 2003). As the ideas of how to improve the process of collaboration and information exchange developed further, it became clear that it is not only the tools that need to be modernized in order to respond to the growing complexity of the building design process. We also need to improve our approach to the design, and we need to do it continuously. Mahdavi (1998) describes this understanding as “co-evolutionary development”: as we develop the building design process, we need to improve the tools that we are using. In its turn, the new tools produce the better approaches to the design and cause further development. Thus, when attempting to study BIM at the certain stage of development, we have to deal with the intermediate results of the process that involves the co-influence of human and technology factor.

1.2 Idealized models

Based on the analysis of the collaboration between the architects and other specialists, different idealized models and scenarios were developed to serve as a guideline for the future software development. These models discuss such concepts as concurrent engineering (Yazdani and Holmes 1999), integrated project delivery (AIA 2007), interdisciplinary design (Kovacic et al. 2014) and streamlined parametric modelling. The latter is described in the conceptual scheme by Wei Yan (2014). This scheme can be viewed as a good outline of the above mentioned ideas with the focus on the building performance simulation (Figure 2).

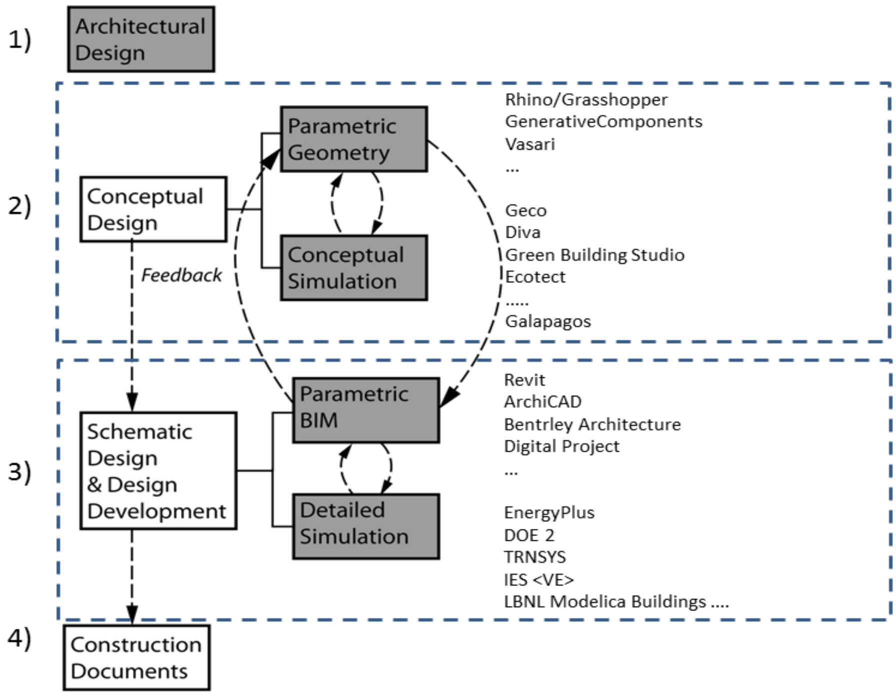


Figure 2 Streamlined parametric modeling, BIM, and building energy modeling, (Yan 2014)

In this case the geometry is altered only in the architectural tools (BIM and parametric tools), after that the data is transferred to the BPA tools for the analysis. Based on the analysis results, the building model is changed again in the BIM tool. This process is repeated as many times as it is necessary for the development of the best performing design option. Such approach is believed to be one of the realistic scenarios of successful development of the BIM concept (Nasyrov 2015), also known as BIM 2.0 (Bernstein 2014).

BPA tools embedded into the BIM platform (see 1.3.2) can be considered an attempt to realize the approach described above. From the BEM point of view, the accuracy of the results produced by the embedded BPA tool and its usage as a reliable source of information is questionable (Batueva 2014); the process of modeling is time consuming or novice-unfriendly (Kim et al. 2015). However, this attempt creates the base for the improved collaboration between architects and energy engineers. Presently, energy engineers still use their own specialized software to perform the building analysis, so the embedded BPA part in the BIM platform looks unreasonable and is rarely used. But with the development of cloud collaboration, energy engineers might be given access to this part of BIM and in doing so, the necessity of import and export of building data will be eliminated, because both groups of specialists will collaborate on the common model.

It can be concluded that at the current stage of BIM development, the major goal is to create the software platform with the maximum level of flexibility and compatibility which will help to detect and underline the parts of collaboration process that can be improved. While reaching this goal, it becomes inconvenient to satisfy the requirements of all the specialists (Donn 2014), but it is necessary to execute this “preliminary” step in order to develop the initial idea of BIM. In some cases this preliminary step is referred to as BIM 1.0 (Bernstein 2014).

1.3 Background

1.3.1 IFC and gbXML

Various specialized pieces of software were developed to link architecture and building performance simulation: Autodesk Ecotect 2008-2015, Graphisoft EcoDesigner 2008-present, Green building solutions by Autodesk, OpenStudio package, etc. Progress in this area has been used to establish the base necessary for further development and extension of BIM to include the building performance tools and execute building energy modeling (BEM). Many of these initiatives are based on using the common data models for the building data exchange: Industry foundation class (IFC) or Green building XML (gbXML).

IFC data model, developed by the International Alliance for Interoperability, now maintained by buildingSMART (Building Smart 2006.) is mostly used to export model from BIM software to be used in civil engineering applications, MEP and HVAC specialists (Dong, et al. 2007). Since the targeted BIM software supports IFC 2x3, this version is predominantly the focus of current research. *MVD (Model view definition)* is an IFC view definition that contains the subset of the IFC schema that is needed to satisfy one or many exchange requirements in the AEC (Architecture, engineering, construction) . The "Coordination view" is currently implemented in software to exchange the information between the architectural design and engineering software. Other view definitions " have much more specific application: "Structural analysis view" supports the data exchange between different structural analysis applications and "Basic FM Hand Over view" assists the data transfer between the design and CAFM and CMMS applications (Computer-Aided Facilities Management and Computerized maintenance management system) (Building Smart 2015).

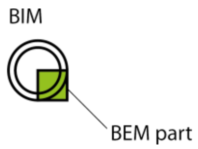
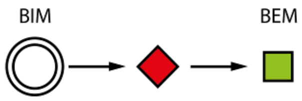
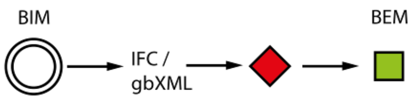
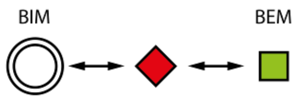
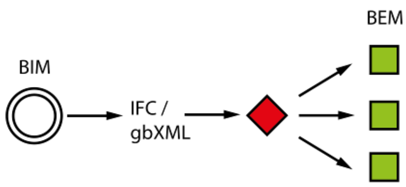
gbXML is an open schema developed by a non-profit organization "Open Green Building XML Schema" (gbXML.org 2008), of which was designed for the exchange of information between the BIM and building performance analysis (BPA) tools (Dong et al. 2007). ArchiCAD Cadimage plugin and Revit support the gbXML 0.36, this version is examined in detail.

In the situation when the preferred workflow lacks accuracy, but the precise BPA models need to be created, intermediate programs and formats (such as IFC and gbXML) were introduced to execute temporary connection between the BIM and BEM tools. Capabilities of this approach are limited (see 1.5), so it can only be considered as an intermediate step. In general, research targeting the improvement of import/export qualities of IFC and gbXML is part of BIM, but it does not claim to solve the problem of collaboration between architecture and other disciplines. Intermediate programs and formats are, however, the only part of BIM research that can presently be introduced in the current practice and potentially lead to improvements in the data transfer process. Overview of IFC and gbXML development reveals how the essential parameters of the building can be digitally exchanged across the disciplines and underlines the missing links in the communication process between specialists. This makes the implementation of these formats an important step of BIM development.

1.3.2 Current implementation efforts

Several main directions can be outlined in the present software development which target the improvement of the data transfer between BIM and BEM (see Table 1).

Table 1 Existing types of BIM to BEM connection

	Symbolic image	**Description**	**Examples**
1		Energy analysis applications embedded into the BIM software	EcoDesigner for Graphisoft ArchiCAD, AX-3000
2		Specific plugins to connect specific BIM program to one BEM tool	ArchiCAD > A-Null plug-in > ArchiPHYSIK, Revit > Revit2Radiance > Radiance (Yan et al. 2013)
3		Programs for post processing the data from BIM to BEM	IFC > Space Boundary Tool > EnergyPlus, gbXML > DesignBuilder > EnergyPlus
4		Plugins for coupling parametric design tools and simulation tools	Ladybug, Honeybee, Galapagos for the Grasshopper (Rhino); Green Building Studio (GBS) for Autodesk Revit
5		Common platforms to connect several BEM tools using IFC or gbXML as import	DeST, (Yi et al. 2007), Autodesk Ecotect Analysis, OpenStudio (Radiance + EnergyPlus)

To the best of our knowledge, the amount of the programs currently representing each group shown in Table 1 is decreasing from the second to the last position (the first position is equal to the number of BIM programs). Typically it is connected to the fact that each following group has greater scope of operations. As seen in Table 1, Group 3 includes one additional step: export format; Group 4 offers the feedback mechanism from BEM to BIM; Group 5 connects several BPA platforms together.

The first group consists of the plug-ins or add-ons developed by the large CAD software producers, such as Autodesk, Graphisoft, Nemetschek, etc. Currently, all of them either have or are developing BPA add-ons to their tools, which are either included in the software package (free version of EcoDesigner for ArchiCAD); could be additionally installed (AX-3000) or are online cloud platforms (GBS for Revit). For more information see section 2.4.

Groups 2-5 contain mixed software, some require commercial license, and the other programs are freeware. Some BEM to BIM connections are relatively well established and are the result of long collaboration process between two software producers. These programs comprise group 2 (Table 1).

Since such programs as EnergyPlus and Radiance do not provide GUI or any assistance in visualizing the simulation results, various applications were developed, which make the usage of simulation engines easier and faster. Such programs offer additional import and export possibilities among other extended options. They are included in groups 3-5.

1.4 Motivation

As Nasyrov (2015) noted, the following components are necessary for the building energy model: geometry, material properties, building systems, site conditions, and building operation information.

Geometry is the foundation of the model, where all other properties are assigned. The quality of the geometry data transfer is widely covered in current research efforts, including such contributions as Ivanova (2014), Batueva (2014), Kumar (2008). Ivanova in her Master thesis (2014) concentrates on the export of building geometry information from ArchiCAD and Revit to EnergyPlus via IFC and gbXML formats. Batueva (2014) studies thoroughly the performance of EcoDesigner embedded into ArchiCAD-17, including the case studies concerning the optimization of windows' orientation. Kumar in his Master thesis (2008) focuses on the interoperability of Revit MEP with the simulation software, namely Ecotect Analysis and IES <VE>. He takes three file formats into account: DXF, gbXML, and IFC. As a conclusion, Kumar suggests Revit template file to assist the information transfer between building and analytical model. The abovementioned studies confirm that import results of the geometry in BPA tools still require certain amount of post-processing either in the analysis tool, via the plugins or additional programs (Bazjanac 2009). *Site conditions* – coordinates and orientation of the building - are normally transferred together with the geometry (Nasyrov 2015).

Building systems and *building operation information* are simulation-specific data which in the present practice are assigned and edited directly in the BPA tool (Nasyrov 2015).

Presented study investigates the transfer of data concerning the building materials from BIM software to the thermal simulation software. The following reasons motivated the choice of this particular aspect of BEM:

- Building materials (composites and layers) are specified by the architect in the BIM model as part of their professional routine.
- It is easy to evaluate the preservation of the building materials data in the model, but at the same time the improvement of this process will save the user considerable amount of time, since he or she does not have to assign the materials manually on all of the building surfaces after each import instance.
- Both BIM and export formats include the necessary entities for the most of the required material properties, yet this data is still poorly transported between the programs.
- There exists a manual workflow, for post-processing the models, for insert the missing material properties, which is done mostly in text editor with the text-based input files. Presumably such workflow can be coded in the simple application.

1.5 Implementation Challenges

There are different software-related and communication-based issues when facilitating the seamless information exchange between BIM and BEM on all design stages. The following aspects are based on discussions with different BIM experts, software developers (see Literature list), as well as the literature review:

1. Conceptual design stage: loss of data prevents the architects and energy engineers from exchanging information and performing multiple building performance simulations to evaluate the design options (see 1.5.1.).

2. Schematic design and development stage: inconsistency within the export and import formats prevents the seamless data transfer (see 1.5.2).

3. Obscure responsibilities for the BEM parameters in BIM programs (see 1.5.3).

1.5.1 Conceptual design stage

Several issues result in the limited use of BPA during the early design stage. Generally, if the simulation is performed, it is done during the last stage of the design for the purpose of the energy certificate (see Figure 2, “Construction documents” phase). However, this might undermine the reliability of the final outcome due to missing links in collaboration between all the participants in the planning process. Currently, these issues are being addressed in the embedded energy analysis applications (Figure 3).

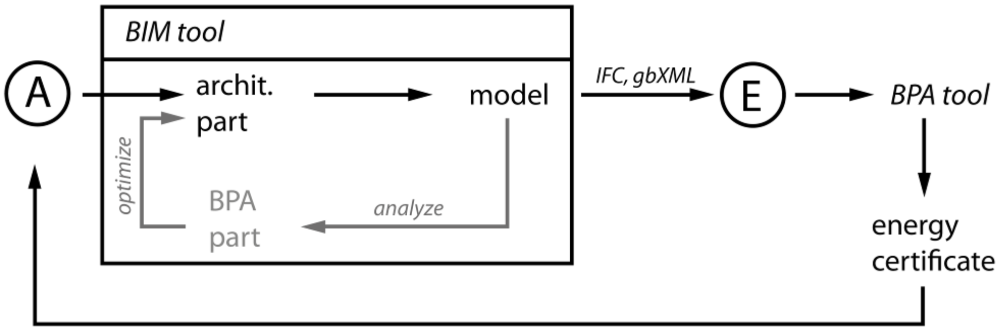


Figure 3 Architect to energy engineer workflow

Secondly, it should be pointed out that the simulation model is not necessarily the exact copy of the architectural model (Kim et al. 2015, O'Donnell et al. 2013). Such elements as building zones (rooms) are the main focus of this discussion. Even in the case when each architectural room stamp results in the same building simulation zone, there is still a difference concerning how the borders of the room are defined. For ArchiPHYSIK, the outside boundary walls should be included into the room boundaries, while architectural room stamps show the netto areas without the walls. This means that different zones should be established for the architectural and for the thermal building analysis purposes. Meanwhile, in such programs as Revit, it is impossible to create two different room stamps inside one space. There is little control over the properties of the spaces and the elements included (e.g. the building phase of the room is defined by the elements forming this space). Additionally, in many cases in the energy simulation, several architectural rooms are typically grouped in the larger zones (as shown in Figure 4). Furthermore, during the simulation various zone layouts might be needed per one architectural design stage.

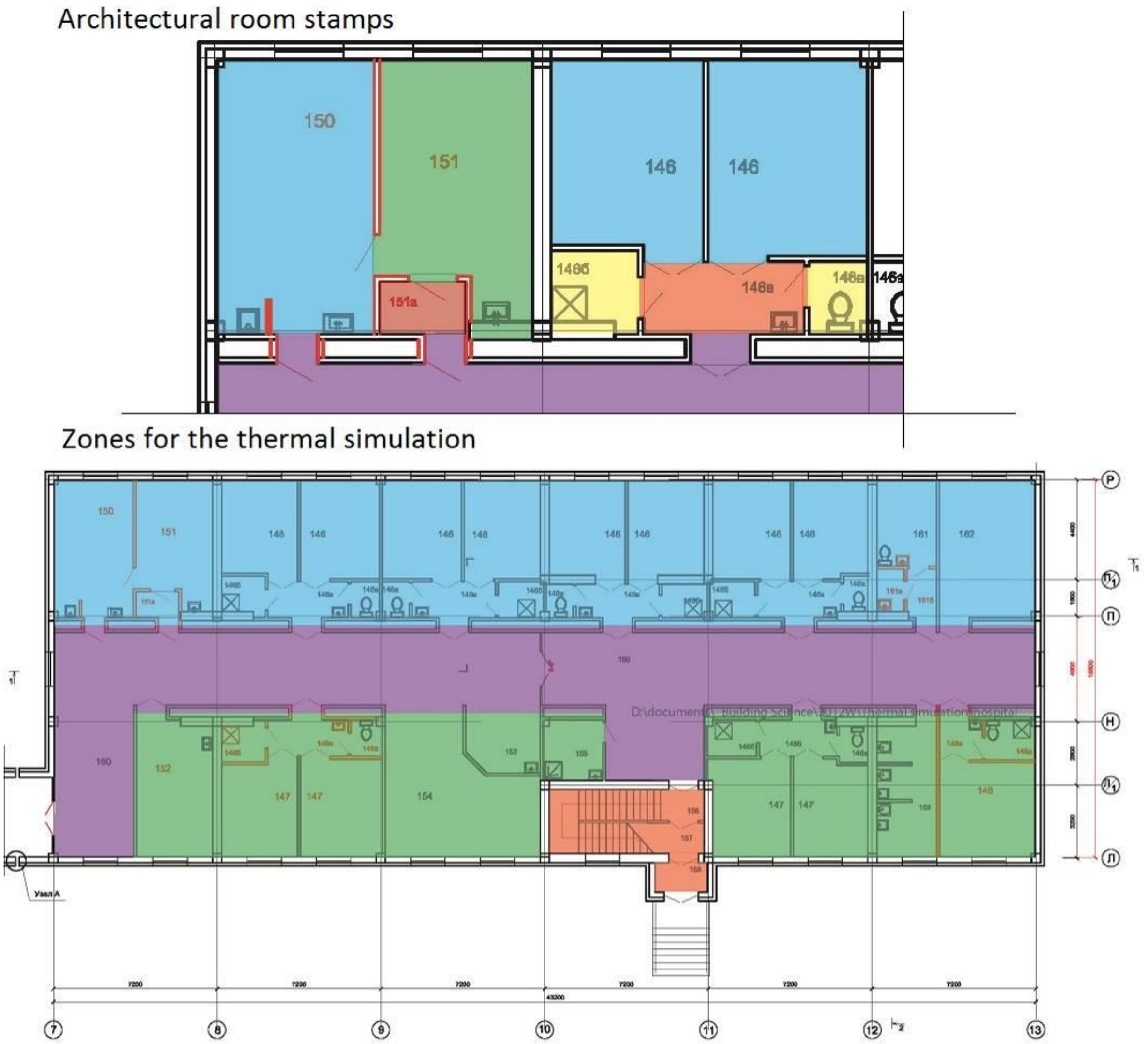


Figure 4 Architectural room stamps and thermal simulation zoning of the hospital building.

One more issue refers directly to the topic of the presented study - transfer of building materials data. Arguably, it is not necessary to have the detailed information about the material layers the early design stage, so the mapping and manual assignment of the materials (like in SBT or OpenStudio plugin) can be accepted as adequate data transfer (see 2.4). As an option, material layers can be simplified as one layer representing the thickness and the U-value of the composite. At the same time, the architect/contractor might want to know what material range is applicable for the particular design option, so the more detailed material information might need to be simulated.

1.5.2 Schematic Design and Development Stage

The problems which occur during the schematic design and development stage refer to the inconsistency of two export formats being employed today, more precisely, the IFC and gbXML (Dong et al. 2007). Both of the formats are open schemas, they are capable of storing the required information and are expandable (see Appendix A).

However, spatial organization of the geometry in the IFC is one of the biggest obstacles in using it for the thermal simulation, as building elements are split into multiple surfaces, thus retaining the thickness of the element geometrically. (see Figure 5). It is known that simulation programs require surface data and add the thickness of elements analytically, as it is executed in the gbXML.

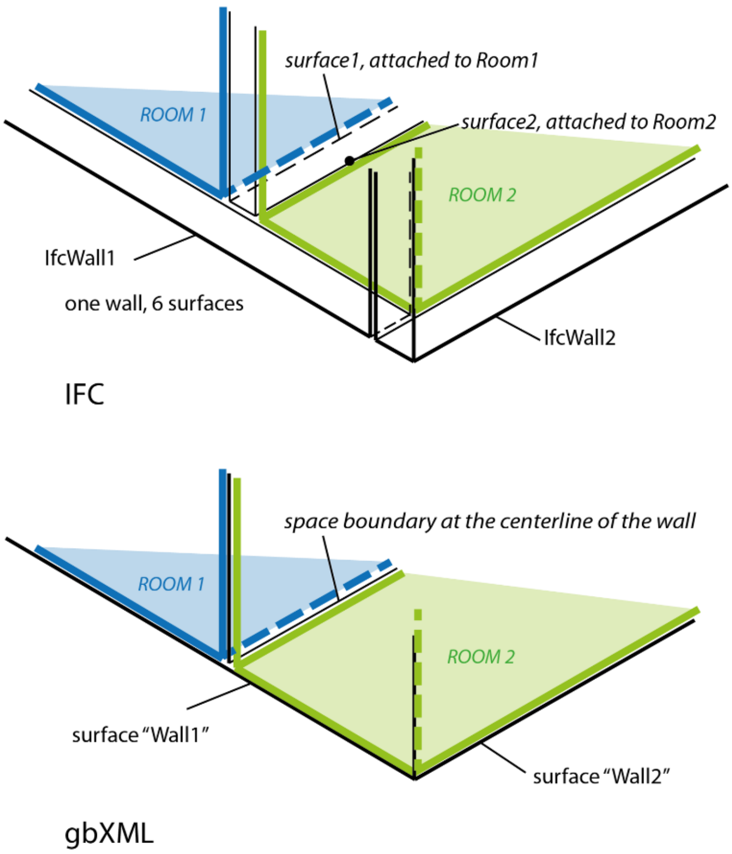


Figure 5 Geometrical structure of the IFC and gbXML

1.5.3 Obscure Responsibility for the BEM Parameters in BIM Programs

The final point refers to the issue of missing links between BEM and architectural modeling. (Hitchcock and Wong 2011) More precisely, energy engineering requires additional information (e.g. material parameters) that is not stored in architectural model, due to the overlapping responsibilities with the architect. Therefore, if nobody is responsible for the simulation parameters in the BIM model, they will not be specified or their export to the gbXML and IFC will not be supported. This way the models for most of the BPA simulations are created using programs such as SketchUp from scratch, and the original geometry from BIM is used only as a reference.

1.6 Thesis structure

The rest of the thesis is structured as follows.

At the beginning of the "*Method*" chapter the criteria for the quality of the data export are defined together with the research questions and workflows to be tested. The basic geometry test case is described in the detail with the elaboration on which material-geometry relations were already taken into account prior to the tests. At the last section of the chapter it is explained why the particular software was considered for the chosen workflow and research questions.

"*Results*" chapter is split into 5 sections corresponding to the number of steps that were executed during the data transfer tests. It is explained, what should be taken into account on each step of the export and import in order to maximize the preservation of the material parameters that are relevant to the thermal simulation. The results are then summarized in the final sections with the relevance to the two simulation programs in focus – *3.4EnergyPlus* and *3.5ArchiPHYSIK*. On the second step the summary for each BIM platform is also available - 3.2.1 *Allplan*, 3.2.2 *ArchiCAD*, 3.2.3 *Revit*.

The results are then further evaluated in the "*Discussion*" chapter. Sections of this chapter are organized in accordance to the *Research questions*, that are first formulated in the "*Method*" chapter.

Section 4.1 responds to the first research question "*Comparing IFC and gbXML, which format performs better for the building material information transfer from BIM to BEM?*" Section 4.2 responds to the second research question "*On which step of the data transfer does the loss of the information occur and why?*". Section 4.3 responds to the third research question "*Is there potential to improve the material mapping from the IFC/gbXML to the simulation files?*"

IFC and gbXML are compared in terms of their capacity to store the relevant information, their performance during the import/export process and the range of the BIM and BEM programs that currently support these exchange formats. Two suggestions towards the improvement of data transfer process are described in this chapter: energy analysis preview for BIM and Customizer program. The latter is provided with the description of the workflow draft in the UML language and a sketch of the desired user interface.

The outcome of the thesis is then summarized in the final chapter "Conclusion and recommendations".

2 METHOD

2.1 Research questions

2.1.1 Comparing IFC and gbXML, which format performs better for the building material information transfer from BIM to BEM?

a) What material-related options can be specified in each of the BIM software, what is their potential for the further export to IFC or gbXML?

The question is related to the BIM programs – Revit, Allplan and ArchiCAD – and their potential of exporting the information to gbXML and IFC formats. It is studied how the building material information is entered in each BIM software, on which step is the information assigned and to which objects of the building model (e.g. can the parameters be specified for the layer or only for the whole building element, is there a possibility to create the custom material parameters, what parameters are available in the program library et al.) It is also studied, is there any additional plugins to improve the process of exporting gbXML or IFC from BIM program or whether the program has the specific workflows that focus on the export of parameters to the above mentioned formats.

b) What is the capacity of each format to transfer the information relevant to BEM?

The following criteria were used to compare the export formats:

- the scope and history of implementation in BIM software and BEM software
- the amount of relevant information that was preserved by BIM software in the files of each format
- the amount of post-processing that is needed to extract the relevant information from the gbXML or IFC file
- the availability of model-checking tools for each format.

Method: simple geometry case is created in each BIM program and then exported via all available options: IFC, gbXML or direct plug-ins, connecting BIM with BEM. Information transfer process is split into 4 steps and each of them is documented. Export formats are then evaluated against the above mentioned criteria, based on the current study results and literature research.

2.1.2 On which step of the data transfer does the loss of the information occur and why?

a) Does the geometry influence the material data export? (If yes, in what way)

The presented study does not concentrate on the geometry. However, building materials cannot be present in the model without geometry, hence it is necessary to define the minimum geometry requirements, that should be satisfied in the model to consider the quality of building material data. Additionally, it should be detected if the geometry layout has an influence on the quality of building material data.

Method: the process of creating the model in Revit, Allplan and ArchiCAD was thoroughly documented, different options inside the test case were examined where necessary – various layouts of wall reference lines, templates and building element properties, et al.

b) What kind of information is lost on each step of data transfer?

In order to improve the quality of data transfer, concrete occasions of missing building materials information were detected. After studying the documented process of creation and export of the models, it is suggested which action led to the absence or misinterpretation of the certain data in the resulting building energy model.

Method: similar to 2.1.1 a) and b).

2.1.3 Is there potential to improve the material mapping from the IFC/gbXML to the simulation files?

a) State of the art in data transfer

Issues in BIM to BEM data transfer cannot be solved with one plugin or application. That is why long-term and short-term goals are set in this area. Consecutive understanding of the current research is a basis for the improvement suggestions.

Method: literature research, communication with BIM experts (personally, via forums or emails.)

b) What can be done to improve the data transfer on its current stage?

The last research questions deals with the overall results of the study, the potential to improve the material data mapping. The results of the tests are viewed in connection with the current efforts in the area of BIM to incorporate BEM and with the long-term goals for the future development of BIM.

Method: similar to 2.1.1 a) and b).

2.2 Overview

In contrast to the geometry, which has complicated import-export diagnostics (Ivanova 2014), there are only three aspects that are important for the building material data in the thermal simulation:

1. Building material composite consists of corresponding layers
2. Material layers have the necessary physical parameters (thickness, conductivity, density, etc.)
3. Building material composite is assigned to the corresponding building element of the geometry (wall, roof, slab, etc.)

These aspects of building material data are used as the framework for the evaluation of the quality of the information transfer. Autodesk Revit 2015, Nemetschek Allplan 2014, and Graphisoft ArchiCAD 17, 18 were used as BIM platforms. Information was exported in 2x3 IFC and 0.36 gbXML for further transfer to the EnergyPlus 8.01 and ArchiPHYSIK 11. In one of the cases the direct export from the ArchiCAD to ArchiPHYSIK was executed (Figure 6).

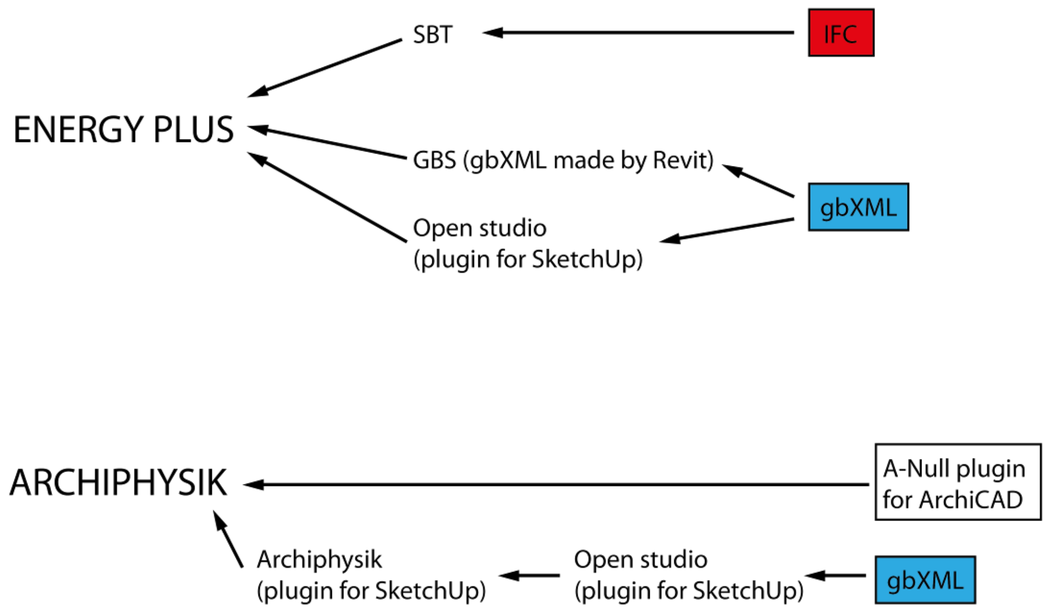
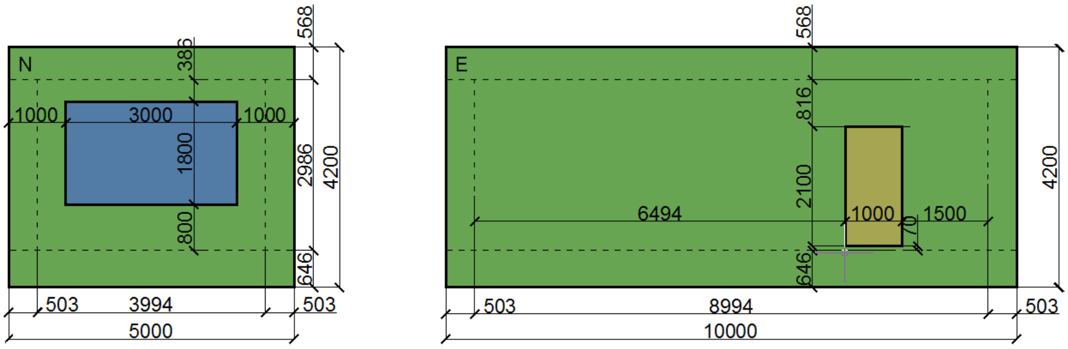


Figure 6 Workflow for the tests

2.3 Modelling the test case

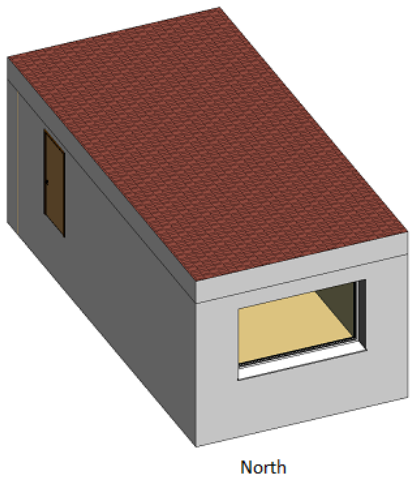
To answer the first (2.1.1) and the second (2.1.2) research questions, the basic geometry case was developed, containing all the typical building elements that are relevant for the thermal simulation: walls, floor slab and roof to define the interior space and two openings – door and window (Figure 7).

Test building model contains the basic geometry scenario with homogeneous layers of the materials. Inhomogeneous layers were simplified to contain only one material (since neither IFC 2x3 nor gbXML 0.36 have the capacity to export the non-homogeneous layers). The full list of Materials with English translation can be found in the Appendix B.



Wall	AWI 01 a Holzständer-Außenwand, hinterlüftet AWI 01 a Composite wooden ventilated external wall
Roof	DAI 01 b Holzsparren-Steildach DAI 01 b Timber rafter pitched roof

Slab	AWI 01 a Holzständer-Außenwand, hinterlüftet AWI 01 a Composite wooden ventilated external wall
Window	Holzfenster mit 2-Scheiben-Wärmescgutzverglazung Double wooden windows with insulating glass



	External boundaries	m	m²
	Southern, Northern wall	5*4,2	21
	Window	3*1,8	5,4
	Eastern, Western wall	10*4,2	42
	Door	1*2,1	2,1
	Floor	5*10	50
	Interior boundaries		
	Southern, Northern wall	3,94*2,98	11,7
	Window	3*1,8	5,4
	Eastern, Western wall	9*2,98	26,8
	Door	1*2,1	2,1
	Floor	3,94*9	35,46

Figure 7 Test case

Previous knowledge and experience gained during the BIM Sustain project course at the TU Wien was used in modeling the test case (see Kovacic et al. 2013, 2014). The following details were taken into account while creating the model:

1. ArchiCAD: wall reference line was set to “face”. This was due to the fact that if the wall reference line is set to “core”, ArchiPHYSIK plugin does not read the areas of the wall correctly (Figure 8, Figure 9). See also Figure 7 for the area reference. While the reference line was changed (Figure 8), the geometry was adjusted in such a way that the outside dimensions are equal in both cases before the export to ArchiPHYSIK (Figure 8). It is important to note that generally ArchiPHYSIK requires the external surfaces of the geometry, while EnergyPlus requires the internal boundary. However the results of the tests for this property have certain degree of inconsistency and require further investigation.

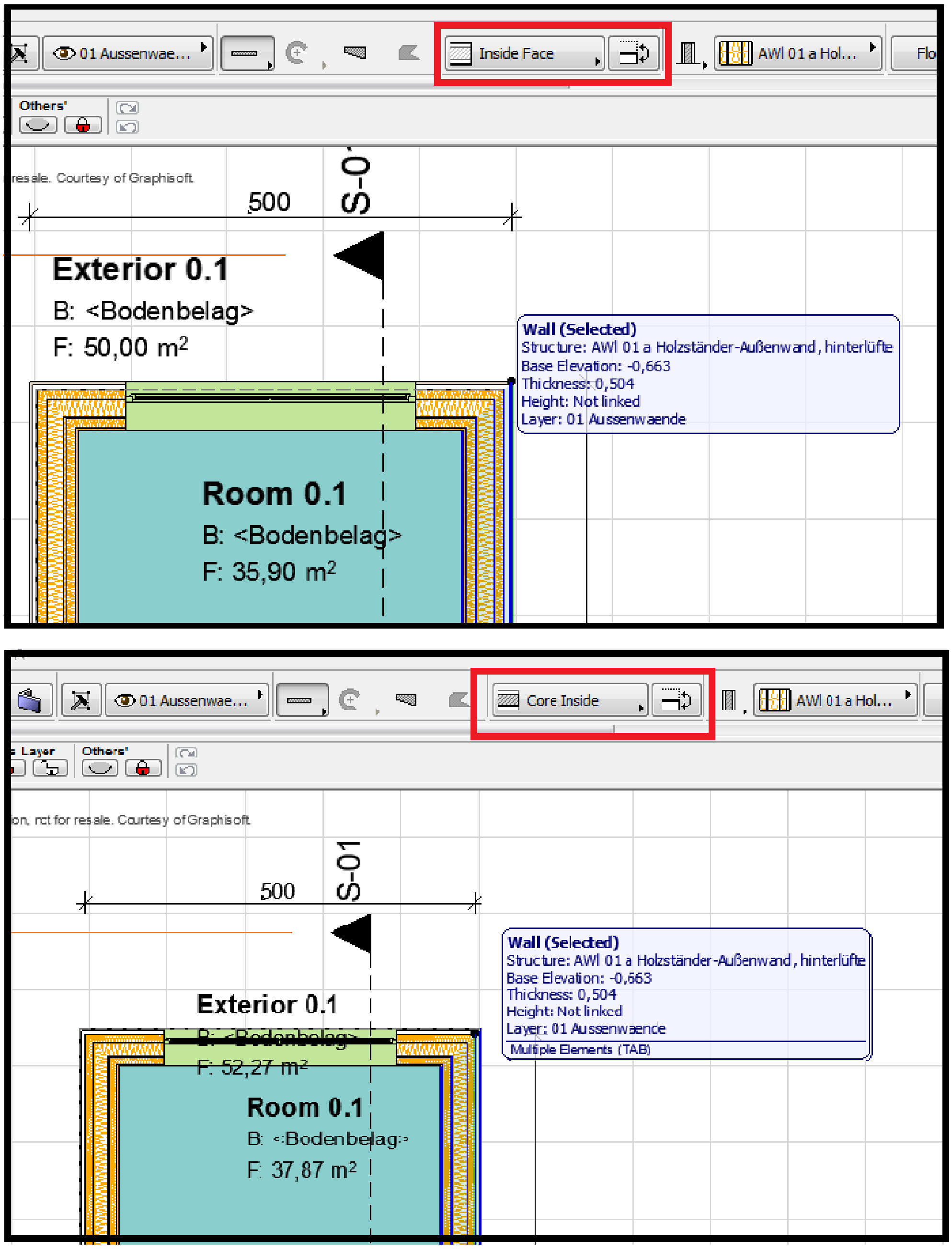


Figure 8 Wall reference line in ArchiCAD 17 (shown in blue)

ArchiCAD wall reference line "core inside"

Übersicht | Grundfläche und Volumen | Gebäudehülle | Anlagenanteile | Verbesserungsmaßnahmen | OI3-Bewertung | LCA-Bewertung

Typ	Btl.Nr.	Bezeichnung	Azimuth	Orie...ung	Neigung	innen	au...	ber...igen	tr...eil	Anzahl	Fläche	H...nt
AW	0001	AWI 01 a Holzständer-Außenwand,...	270,00	W	90	Wohnen	Au...	Ja			9,53	
AW	0001	AWI 01 a Holzständer-Außenwand,...	0,00	N	90	Wohnen	Au...	Ja			4,44	
AW	0001	AWI 01 a Holzständer-Außenwand,...	90,00	O	90	Wohnen	Au...	Ja			9,74	
AW	0001	AWI 01 a Holzständer-Außenwand,...	180,00	S	90	Wohnen	Au...	Ja			4,23	
AT	0002	IFC Door - Single Swing	90,00	O	90	Wohnen	Au...	Ja	T	1	2,10	
AF	0001	IFC Window - Single Panel	0,00	N	90	Wohnen	Au...	Ja	T	1	5,40	
AD	0003	ADh 01 b Massivholzdecke CS	0,00	H	0	Wohnen	Au...	Ja			35,90	
AD	0002	DAI 01 b Holzsparren-Steildac	180,00	H	0	Wohnen	Au...	Ja			35,90	

ArchiCAD wall reference line "inside face"

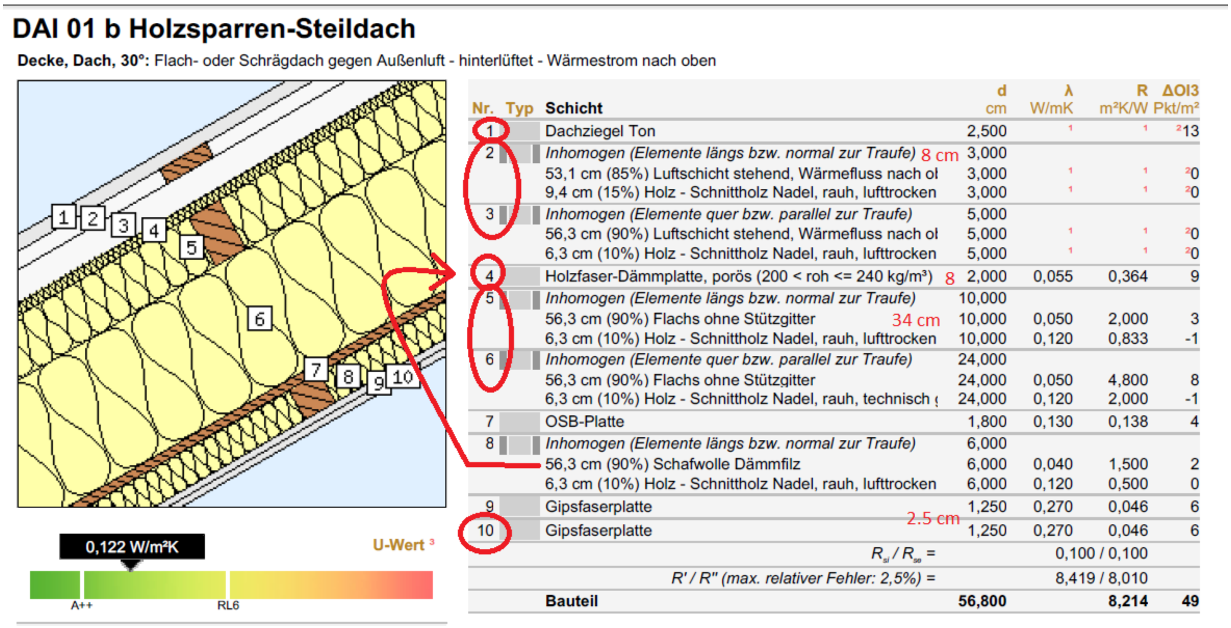
Übersicht | Grundfläche und Volumen | Gebäudehülle | Anlagenanteile | Verbesserungsmaßnahmen | OI3-Bewertung | LCA-Bewertung

Typ	Btl.Nr.	Bezeichnung	Azimuth	Orie...ung	Neigung	innen	au...	ber...igen	tr...eil	Anzahl	Fläche	H...nt
AW	0001	AWI 01 a Holzständer-Außenwand,...	270,00	W	90	Wohnen	Au...	Ja			42,00	
AW	0001	AWI 01 a Holzständer-Außenwand,...	0,00	N	90	Wohnen	Au...	Ja			15,49	
AW	0001	AWI 01 a Holzständer-Außenwand,...	90,00	O	90	Wohnen	Au...	Ja			39,79	
AW	0001	AWI 01 a Holzständer-Außenwand,...	180,00	S	90	Wohnen	Au...	Ja			20,79	
AT	0002	IFC Door - Single Swing	90,00	O	90	Wohnen	Au...	Ja	T	1	2,10	
AF	0001	IFC Window - Single Panel	0,00	N	90	Wohnen	Au...	Ja	T	1	5,40	
AD	0003	ADh 01 b Massivholzdecke CS	0,00	H	0	Wohnen	Au...	Ja			35,90	
AD	0002	DAI 01 b Holzsparren-Steildac	180,00	H	0	Wohnen	Au...	Ja			47,77	

Figure 9 Influence of the wall reference line in ArchiCAD 17 on the surface areas in ArchiPHYSIK 11

2. ArchiCAD: the names and layers of the composites were taken from the Baubook – one of the embedded ArchiPHYSIK databases. If ArchiPHYSIK finds the name of the layer in its database, it automatically assigns the necessary properties from the database.

3. Allplan: building element layers were simplified to fit the program, since it only allows up to 5 layers for the walls and roofs and single layer for the slab. Example for the roof simplification is shown on Figure 10. Layers 2 and 3, 5 and 6 were united (red circles on Figure 10) and layer 8 was added to layer 4. Inside the inhomogenious layers only the insulation layers were taken – in this case “Holz, schnittholz” – Sawn pine wood – was ignored. This way 5 layers were taken for the Allplan (red circles) and layers 7 and 9 were completely ignored.



Nr.	Typ	Schicht	d cm	λ W/mK	R m²K/W	ΔOI3 Pkt/m²
1		Dachziegel Ton	2,500			13
2		Inhomogen (Elemente längs bzw. normal zur Traufe)	3,000			
		53,1 cm (85%) Luftschicht stehend, Wärmefluss nach ol	3,000			0
		9,4 cm (15%) Holz - Schnittholz Nadel, rauh, lufttrocken	3,000			0
3		Inhomogen (Elemente quer bzw. parallel zur Traufe)	5,000			
		56,3 cm (90%) Luftschicht stehend, Wärmefluss nach ol	5,000			0
		6,3 cm (10%) Holz - Schnittholz Nadel, rauh, lufttrocken	5,000			0
4		Holzfaser-Dämmplatte, porös (200 < roh <= 240 kg/m³)	2,000	0,055	0,364	9
5		Inhomogen (Elemente längs bzw. normal zur Traufe)	10,000			
		56,3 cm (90%) Flachs ohne Stützgitter	10,000	0,050	2,000	3
		6,3 cm (10%) Holz - Schnittholz Nadel, rauh, lufttrocken	10,000	0,120	0,833	-1
6		Inhomogen (Elemente quer bzw. parallel zur Traufe)	24,000			
		56,3 cm (90%) Flachs ohne Stützgitter	24,000	0,050	4,800	8
		6,3 cm (10%) Holz - Schnittholz Nadel, rauh, technisch (	24,000	0,120	2,000	-1
7		OSB-Platte	1,800	0,130	0,138	4
8		Inhomogen (Elemente längs bzw. normal zur Traufe)	6,000			
		56,3 cm (90%) Schafwolle Dämmfilz	6,000	0,040	1,500	2
		6,3 cm (10%) Holz - Schnittholz Nadel, rauh, lufttrocken	6,000	0,120	0,500	0
9		Gipsfaserplatte	1,250	0,270	0,046	6
10		Gipsfaserplatte	1,250	0,270	0,046	6
		R_{si} / R_{se} =			0,100 / 0,100	
		R' / R'' (max. relativer Fehler: 2,5%) =			8,419 / 8,010	
		Bauteil	56,800		8,214	49

Figure 10 Simplified Roof layers for Allplan 2014

2.4 Software

BIM and BPA programs which allow the multi-layered structure of building elements have different terms for the layers and the element as a whole (see Table 2). To avoid confusion in this work the term "layer" is used for the single layer of the building element, and the term "composite" is used to represent the composite structure as a whole. Layers combined into composite are referred to as "material".

Table 2 Terminology for the multi-layered materials in the software

		
ArchiCAD	Building material	Composite structure
Revit	Material	Construction
Allplan	Layer	Wall/Roof/…
ArchiPHYSIK	Schicht	Bauteil
Energy Plus	Material	Construction
IFC	MaterialLayer	MaterialLayerSet
gbXML	Material	Construction, Layer
Current study	**Layer**	**Composite**
	Layers combined into Composite = Material	

Autodesk Revit Architecture, Nemetschek Allplan and Graphisoft ArchiCAD are software tools for architects to create the building models. All these tools, during the last decade, are slowly transforming from CAD (computer aided design) to the BIM concept. These programs are fairly similar in their usability and basic functions. Architects mainly choose between competing software based on personal preference.

EnergyPlus (US Department of Energy 2015) is an open source, whole building energy simulation program with text-based input and output. EnergyPlus allows the user to simulate the building performance based on the input model. The output parameters can be calculated for the different time periods, based on the weather files and building model data. Any location on Earth can be calculated, as long as there exists a weather file, so the tool is used worldwide. Simulation file format is IDF. EnergyPlus is the result of merging two simulation engines: DOE-2 and BLAST. Various graphical user interfaces (GUI) are developed for this program. More precisely, OpenStudio for SketchUp and Space Boundary Tool are discussed here.

ArchiPHYSIK (A-NULL 2015) is a building certificate and energy analysis software, developed and mainly used in Austria. This software contains the material databases, energy certificate framework, OI3 and ÖGNI certification norms, evaluates the sound insulation and vapor diffusion. ArchiPHYSIK imports APS and APH model files.

The following plug-ins and intermediate software were used for the presented contribution.

Space Boundary Tool (SBT) (Berkley Lab 2015) is a tool for post-processing IFC files for the EnergyPlus. SBT imports IFC, calculates space boundaries, recognizes the materials from the IFC file and maps it with the composites and layers ("constructions" and "materials" respectively in EnergyPlus) from the user-specified IDF file. It then combines the space boundaries, mapped materials and other necessary information from the IFC (such as site conditions) into the IDF file for the EnergyPlus.

Green Building Studio (GBS) (Autodesk GBS 2015) is cloud-based energy-analysis software which supports the script-based generation of scenarios for the optimization of the building performance. GBS is a direct successor of Ecotect Analysis (Autodesk 2015), whose functions were distributed inside the Autodesk architectural package. GBS only successfully imports the gbXML files made in Autodesk application, but unlike other BPA tools made for the BIM platforms, it also supports export to an external energy analysis tool – EnergyPlus.

OpenStudio (NREL 2015) is a collection of software tools for the BEM using Radiance as a daylight engine and EnergyPlus as a whole-building performance simulation. OpenStudio plugin for SketchUp allows the import of gbXML files into SketchUp; then user can edit the OpenStudio model (OSM) file, assign materials and export them to the IDF file for EnergyPlus.

ArchiPHYSIK plugin for SketchUp (A-NULL 2015) exports the SketchUp models to ArchiPHYSIK. Used in combination with OpenStudio plugin, this add-on allows the transfer of information from gbXML to ArchiPHYSIK. A-Null plugin for ArchiCAD that exports the geometry from this particular BIM platform to the ArchiPHYSIK is also available.

SketchUp 2013 (Trimble 2013) was used for the tests as an intermediate software (in combination with the plug-ins) and as a gbXML viewer. Additionally, *FZK viewer* (KIT 2015) was used for the visual model checking and GUI for the gbXML and IFC file structures. To analyze the IFC structure the *IFC text tree viewer* was used (GeometryGym 2015). GbXML and IFCs were also viewed and visually checked with the help of XML-viewer.

The following simulation plug-ins and add-ons were considered within the chosen range of BIM and BEM software but declined for various reasons:

- *Vectorworks* software (Nemetschek Vectorworks 2015) is mentioned by Cemesova (2013) among the existing BIM authoring tools from Nemetschek. Vectorworks exports model to gbXML and IFC. However it is arguable that it can be considered a BIM tool, since it does not store the parametric information (Cemesova 2013). And even with its limitations, Allplan is more wide-spread in Austrian design practice than Vectorworks.
- *AX-3000* (AX3000 2015) - commercial plugin for the energy simulation, energy certificate and HVAC systems developed in Austria. It can be installed on to AutoCAD/ADT/MEP 2015, Revit Architecture 2015, ALLPLAN 2015 and BricsCAD V15. This tool is mostly used for the estimation of the architectural design. However, it does not offer any connection to the other simulation programs.
- *DesignBuilder* (DesignBuilder 2015) - fully featured EnergyPlus user interface, developed in the UK. Imports gbXML files, exports IDF, Radiance and CSV report files. While importing gbXML does not support the import of the materials, it offers instead to overwrite them with the materials from the template file.
- *Simergy* (Berkley Lab 2014) - fully featured EnergyPlus user interface, developed in the US. Imports IFC files, exports IDF files. Only part of this platform - more precisely, SBT - was used as a standalone application, since it offers the mapping of the materials. Simergy platform itself has the limited options of user control over the materials.

- *EcoDesigner* (Graphisoft 2015, EcoDesigner Star) – simulation add-on for ArchiCAD. It is available in two versions: default installation package with ArchiCAD and EcoDesigner Star version, which should be purchased separately. It is claimed that the gbXML export function is available in the commercial version of the plug-in. According to the e-mail communication with the Graphisoft helpdesk, the EcoDesigner Star plug-in is not available in Austria, because it is designed to support LEED norms, which are not applicable in this region. Instead, ArchiPHYSIK is used in Austria. It is important to note, that the absence of EcoDesigner Star on the Austrian market might potentially be limiting the quality of gbXML export, which is currently performed by the external CAD-image plug-in.
- *Autodesk Ecotect Analysis* (Ecotect 2015) - stand-alone energy analysis tool developed by Autodesk, US. Ecotect Analysis was widely used for the visualizations of the simulation results and BPA. Starting from March 2015 Autodesk has terminated the purchase of licenses and elaborated how the Ecotect features are distributed within the Revit product family.
- *Ifc2SketchUp* (Cadalog Inc 2015) – is a plugin for SketchUp 8 and 2013 versions to import the IFC files. The 2015 version of SketchUp has the embedded IFC import. However, none of them are applicable for the current study, since the intermediate tool is required to alter the geometry for the energy simulation, such as SBT tool (See 1.5).
- *Simplebim* (Datacubist Oy 2015) – is a tool to edit, enrich and validate IFC models. It has the potential of editing the IFC model and might be used to assist the data transfer from IFC to APH. However, the application of this workflow (IFC > Simplebim > SketchUp plugin > ArchiPHYSIK) can be seen as limited, because ArchiPHYSIK is a local tool mostly used in Austria. In general, people involved in Austrian BIM use the ArchiCAD to ArchiPHYSIK plugin or SketchUp plugin (as mentioned by Mathias Bader from ArchiPHYSIK Helpdesk in an email communication).
- *Revit to ArchiPHYSIK plugin.* ArchiPHYSIK 12 manual (A-NULL Development GmbH 2015) confirms that there once existed a special plugin for the direct export of the Revit geometry to ArchiPHYSIK. Workflow video can be found on the official A-Null Youtube channel (ArchiPHYSIK – Energieausweis 2015). However, the support of this plugin was terminated for the reason as the above mentioned software.

3 RESULTS

Four basic steps in the information transfer can be outlined:

1. Specification of the parameters in the BIM model (see 3.1)
2. Export from the BIM tools to the IFC and/or gbXML (see 3.2)
3. Import to the intermediate software (SBT, SketchUp, GBS) (see 3.3)
4. Import to the thermal simulation tools (ArchiPHYSIK, EnergyPlus) (see 3.4, 3.5)

Each of these steps influences differently the quality of the building data. During each step multiple model checking operations were performed to detect the possible loss of the information.

Before the tests were executed, the list of required parameters for EnergyPlus and ArchiPHYSIK was compiled. Subsequently, the availability of these parameters in the BIM platforms and export formats was analyzed (see Table 3). It is important for the thermal simulation that all these parameters are specified for the layers of the material and not for the composite or building element as a whole.

Table 3 Availability of the layer properties in BIM platforms and export formats

N	Property name, units	Allplan	Revit	ArchiCAD	IFC	gbXML
1	Thickness [m]	+	+	+	+	+
2	Name tag	+	+	+	+	+
3	Thermal Conductivity (Lambda) [W/(mK)]	+	+	+	+	+
4	Density [Kg/m^3]	-	+	+	+	+
5	Specific heat (Heat capacity in ArchiCAD) [J/(kgK)]	-	+	+	+	+
6	Roughness [string]	-	-	-	-	-
7	Water vapor diffusion resistance factor (μ)	-	-	-	-	-

Parameters 1-6 are relevant both for the EnergyPlus and ArchiPHYSIK. However, the last parameter is a part of the ArchiPHYSIK input only. It is clear from the table that the *roughness* and *water vapor diffusion resistance factor* for the layers are missing in the BIM programs. Furthermore, IFC 2x3 and gbXML 0.36 do not have the corresponding parameters in the schema. They can be specified as custom layer parameters for some building elements in Allplan. The other two BIM platforms do not have the possibility to create the custom material layer parameters. ArchiCAD IFC Manager allows creating any custom parameter that is needed, but only for the whole building element, and not for the layers.

3.1 Specification of the parameters in the BIM model

During the early stage of the presented research, the potential for BIM tools to specify information will be evaluated. Different workflows for each tool are examined and compared, and any specific requirements of the model are highlighted.

As it was already mentioned, *Allplan* up to version 2014 allows only a limited number of layers to be added to building elements, which restricts the accuracy of the model (Figure 10). At the same time, any custom properties for the layers or for the building elements can be created in Allplan for the multi-layer elements. Custom properties for the building elements can also be created (Figure 11).

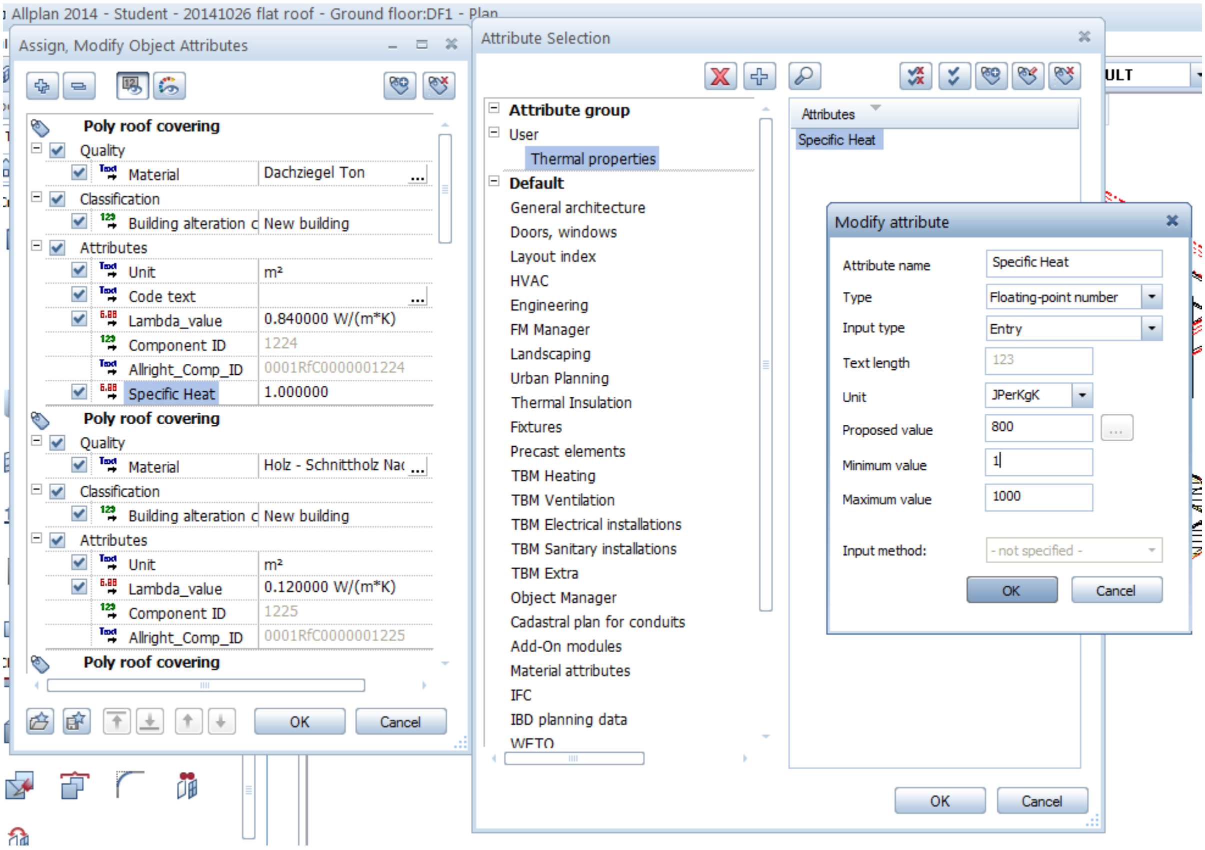


Figure 11 Creating the custom parameter in Allplan 2014

ArchiCAD has special plugin to transfer the information to ArchiPHYSIK. For the EnergyPlus gbXML was used. The export to gbXML in ArchiCAD is executed via a plugin and not via the embedded export, thus, the requirements of the model are stricter than in Revit (see 2.3). There is a possibility in ArchiCAD to edit the IFC settings of each building element, but not the element class (Figure 12). This way the user gets more customization power over the future IFC file. It also complicates the work, since the user needs to assign the same properties twice – first in ArchiCAD itself and then in the IFC section (mapping manager is available). However, it guarantees that the information will be fully exported. The group editing can be done via the “Find and Select” option. All this advanced editing is not available for the material layers, only for the building element as a whole.

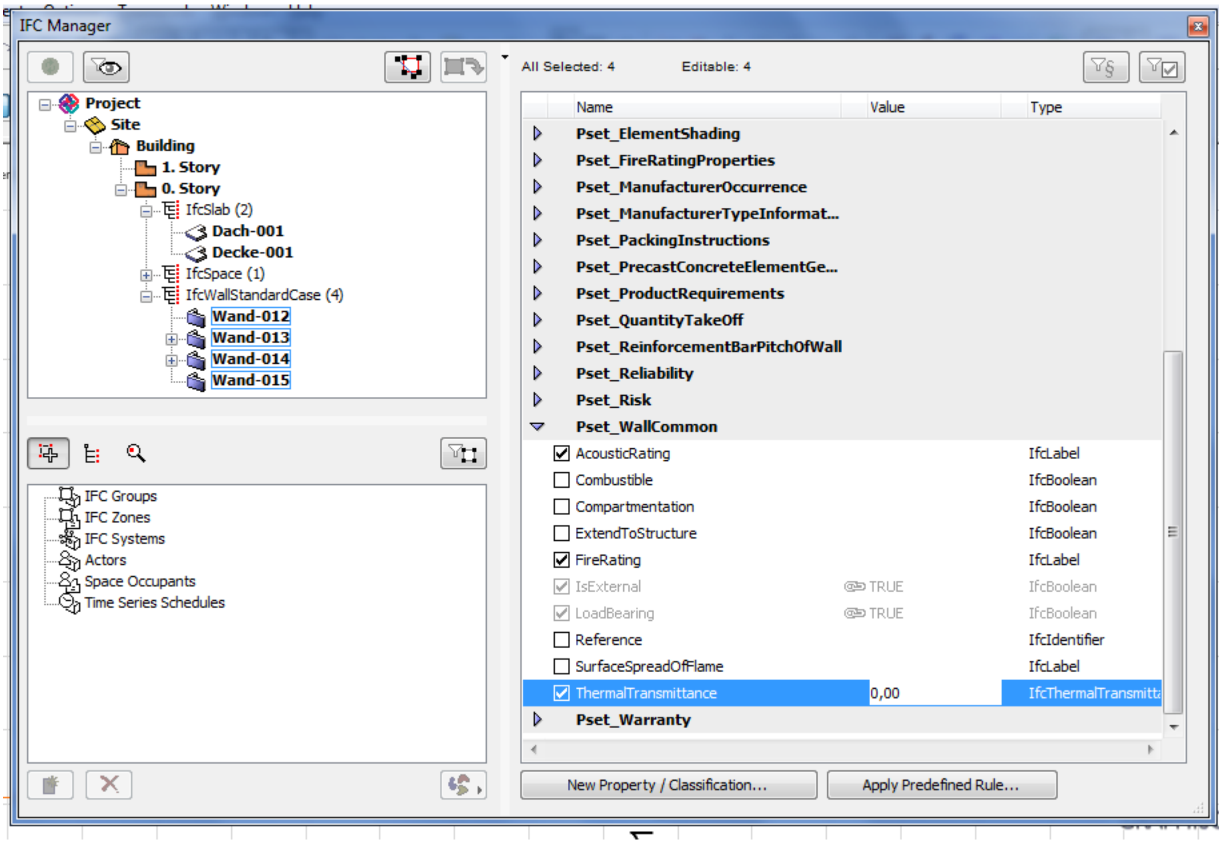


Figure 12 IFC wall properties in ArchiCAD 17

In *Revit* the both gbXML and IFC export was tested. Information from IFC format is extracted with the help of SBT (see Figure 6). Revit has a large number of available material properties, while ArchiCAD has only one group related to the simulation called “physical properties”.

Custom parameters can be assigned to the building elements, but not to the layers (Figure 13).

Generally, the creation of the simulation-friendly model in BIM often involves very specific workflow from the first steps of design (Howard 2007). The larger the number of plugins, the more specific are the requirements to the initial model to avoid the loss of the information.

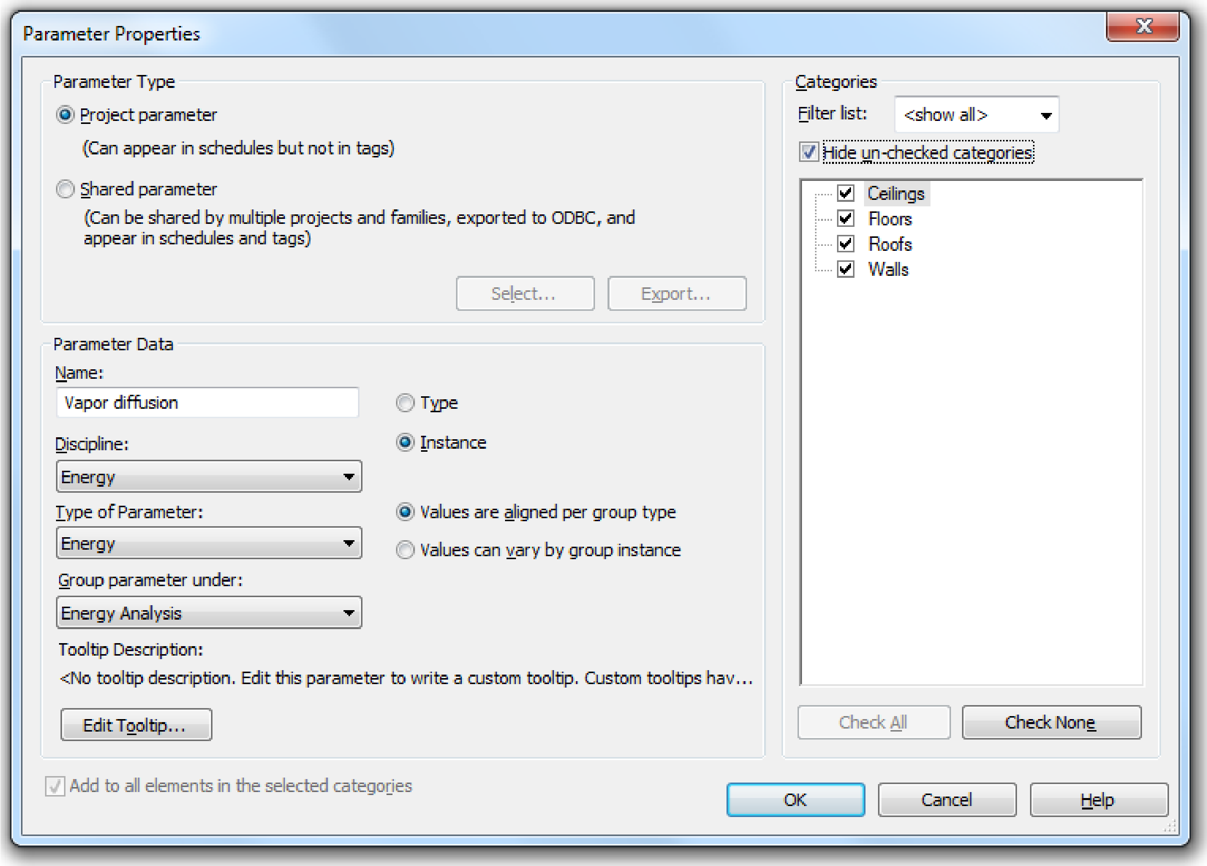


Figure 13 Custom material parameter in Revit 2015

3.2 Export from the BIM tools to the IFC and/or gbXML

The results of the second step of export are summarized in Table 4.

Table 4 Required BEM parameters and their preservation on the first step of export

	Allplan		**ArchiCAD**			**Revit**		
Property name, units		IFC		IFC	gbXML[1]		IFC	gbXML
Thickness [m]	+	+	+	+	+	+	+	+
Name tag	+	+	+	+	+	+	+	+
Thermal Conductivity (Lambda) [W/(mK)]	+	+/-	+	-	-	+	-	+
Density [kg/m^3]	-	-	+	-	-	+	-	+
Specific heat (Heat capacity in ArchiCAD) [J/(kgK)]	-	-	+	-	-	+	-	+
Roughness [string]	-	-	-	-	-	-/+	-/+	-/+
Water vapor diffusion resistance factor (μ)	-	-	-	-	-	-	-	-

1 – with the assistance of CADimage plugin

It appears from the tests, that there is a group of basic material parameters that are well exported from all BIM platforms to the export formats. For the IFC it is connected to the MVD – model view definitions and the translator types that are implemented in the software. In the present contribution these parameters are referred to as “*basic material layer parameters*”. They include the names and the thickness of the material layers, their association with the composites and the building elements.

It should also be mentioned that IFC supports ANSI character encoding and gbXML uses UTF-8. Consequently, the special characters, such as ü, ä, ß, etc., are displayed hexadecimal while viewing IFC (Building Smart 2014). Since ArchiPHYSIK uses XML for its materials library, including the markup characters in the material name causes problems during the import of the APS file (this includes characters such as “<”, “>”, “/” and “=”).

3.2.1 Allplan

Allplan 2014 does not export gbXML, which is adopted by many programs that assist the transfer of the information from BIM to BEM. This makes the use of Allplan models very limited unless more plugins will be created for the BPA tools to import IFC files.

The fact that Allplan 2014 does not allow the full material composite to be modeled in one single element, can be viewed as a serious obstacle for the efficient BIM to BEM data transfer. Two workarounds are possible for this situation: splitting composite in several elements and simplifying the composite. The second approach was taken in the current study, as mentioned in the 2.3. However, the approach with simplifying the composite requires engineer’s involvement at the stage of building a model, which is not always the case in practice.

It is notable that Allplan is able to export the physical properties of the layers to the IFC (lambda value, of which was chosen from the catalogue, and specific heat, of which was custom created are exported), but only for the outside layer of composite, and only using the “Single property value” category instead of using the “Ifc material property” category existing in the scheme (Figure 14, Appendix A).

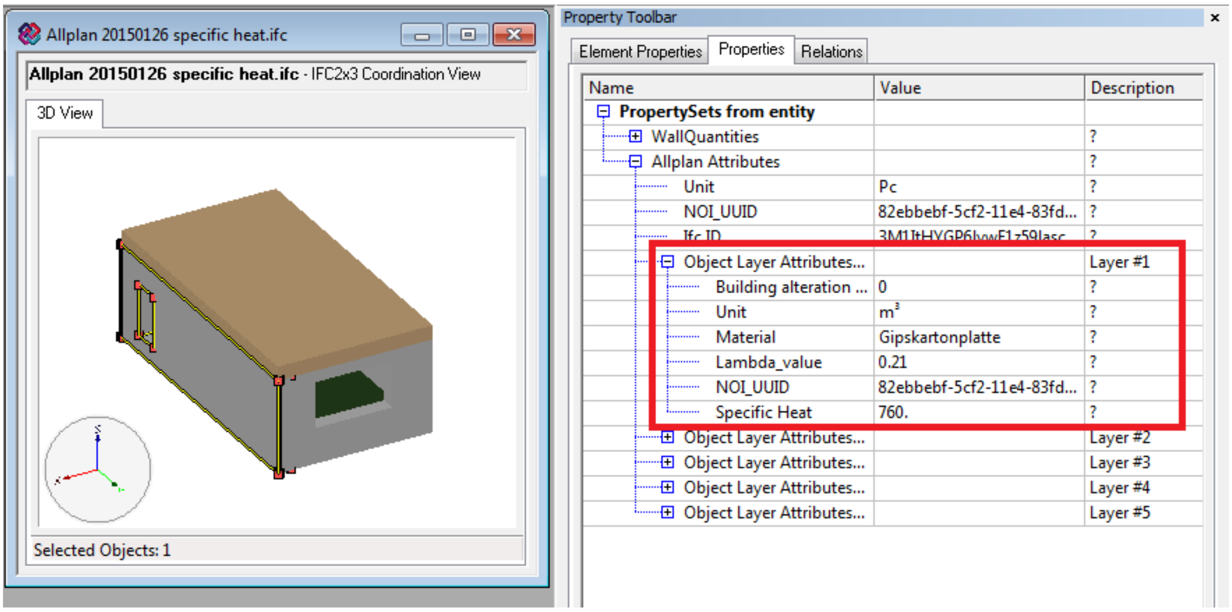


Figure 14 FZK viewer: outside layer parameters in the IFC created by Allplan 2014

The general IFC structure for Allplan is shown on Figure 15. Information represented by "…" is shown in Table 5. On the left side of the table the larger IFC classes are shown (such as "Wall"), while towards the right side of the table classes become smaller.

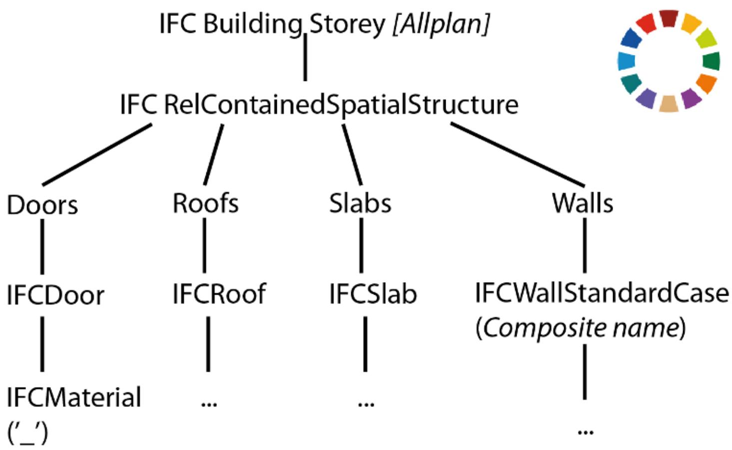


Figure 15 IFC file structure as exported from Allplan

Table 5 Exported IFC Allplan parameters, relevant to the thermal simulation

IFCRoof	IFCPropertySet ('AllplanAttributes')	IFCComplexProperty ('ObjectLayerAttributes', 'Layer N')	IFCPropertySingleValue	Outside Layer - Layer name - Lambda value - Specific heat *(custom property)* Other Layers - Unit - NOI_UUID
	IFCSlab	IFCBuildingElementPart	IFCMaterial (*Layer name*)	
IFCSlab	IFCPropertySet ('Pset_Slab_Common')	IFCPropertySingleValue ('Thermal Transmittance')		
	IFCPropertySet ('AllplanAttributes')	IFCPropertySingleValue	Layer name - Unit - NOI_UUID	
	IFCMaterialLayerSetUsage	IFCMaterialLayerSet	IFCMaterialLayer	IFCMaterial (Composite name)
IFCWallStandardCase (*Composite name*)	IFCMaterialLayerSetUsage	IFCMaterialLayer	IFCMaterial (*Layer name*)	
	IFCPropertySet ('AllplanAttributes')	IFCComplexProperty ('ObjectLayerAttributes', 'Layer N')	IFCPropertySingleValue	Outside Layer - Layer name - Lambda value - Specific heat *(custom property)* Other Layers - Unit - NOI_UUID

3.2.2 ArchiCAD

The latest version of the software – ArchiCAD 18 at the moment (July 2015) does not support the export to the gbXML. The Cadimage plug-in for ArchiCAD 18 is under the development, so the ArchiCAD 17 and the previous plug-in were used to export the gbXML. The resulting gbXML does not contain information about the physical properties, only the basic material properties are transferred. There are certain guidelines to be followed when setting the interior and exterior zones of a model (Cadimage Group Limited 2015).

IFC export in ArchiCAD has an advanced system of customization, including assistance for the property mappings from the ArchiCAD model to the IFC model. However no customization is available for the material layers, only for the building components as a whole. As a result ArchiCAD exports the basic material parameters.

The general IFC structure for ArchiCAD is shown on Figure 16.

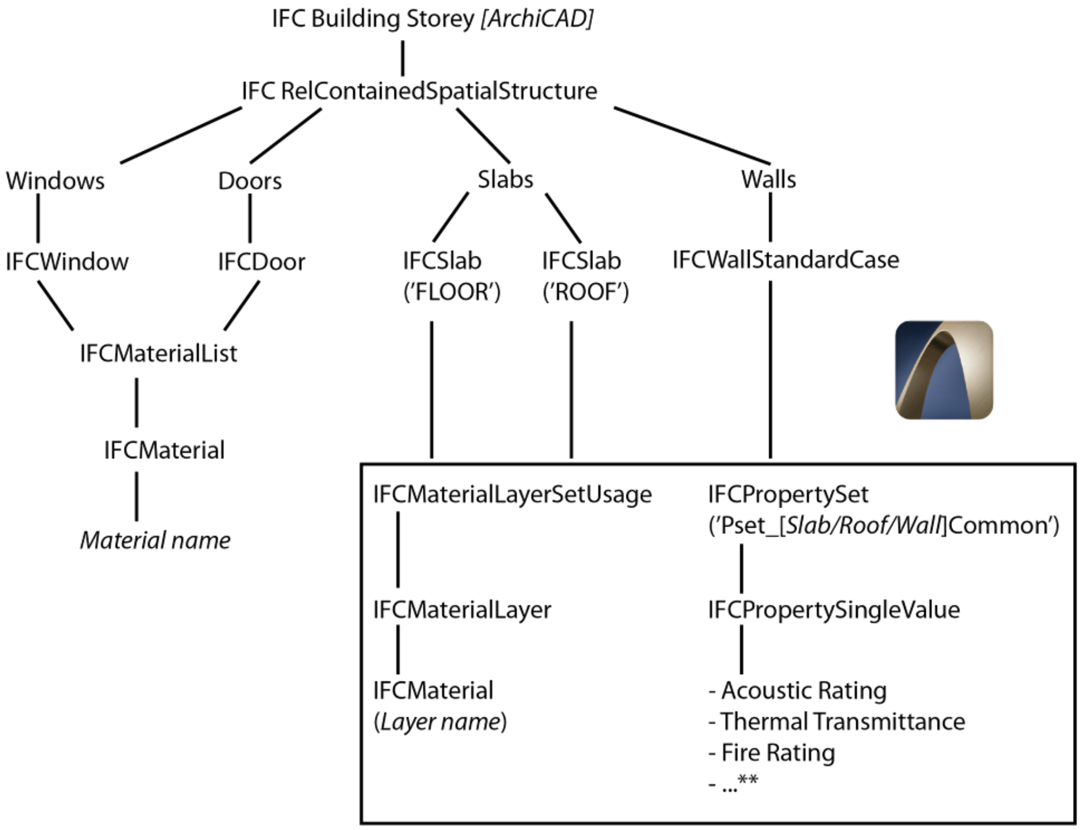


Figure 16 IFC file structure as exported from ArchiCAD

3.2.3 Revit

Revit (versions 2014 / 2015) is the only BIM program in selection which has the embedded gbXML export. As a result, all the information which was specified by the user in the layer properties is preserved in the gbXML. As seen from Table 4, Roughness parameter is presented in Revit and in the both export formats, while its specification in Revit is quite ambiguous. It can be found in the "Type properties" window, which contains the properties of the composite together with the building element. There the user can specify a value between 1 and 6. It is then exported as a description to the gbXML, in the test case the value "3" corresponds to the "VeryRough" characteristic of the "Construction" class in gbXML. In the exported IFC file the parameter has a value "1". There is no reference in the Autodesk Help files about how are those parameters exported. GBS automatically assigns "Rough" to all material layers while OpenStudio assigns "Smooth" to all layers as a default setting. According to the Input-Output reference (EnergyPlus 2015), Roughness material parameter has an influence on the exterior convection coefficient in the Energy plus.

The default IFC exporter in Revit is very basic, however it includes the basic material layer parameters. There is a possibility to install special plugin for Revit that offers the user a choice between several MVDs or the option to create a custom one (Autodesk exchange apps 2015). The plugin does not improve the export of material layer (Figure 17), but allows exporting ifcXML which is easier to use for the visual model checking. Furthermore, it expands the properties of sub-surfaces: Window and Door. For the conducted tests the extended IFC export was used and the template, which already had the Level structure. This structure has a distinct influence on how the geometry is exported in the IFC.

The general IFC structure for Revit is shown on Figure 18. Information represented by "…" is shown in Table 6.

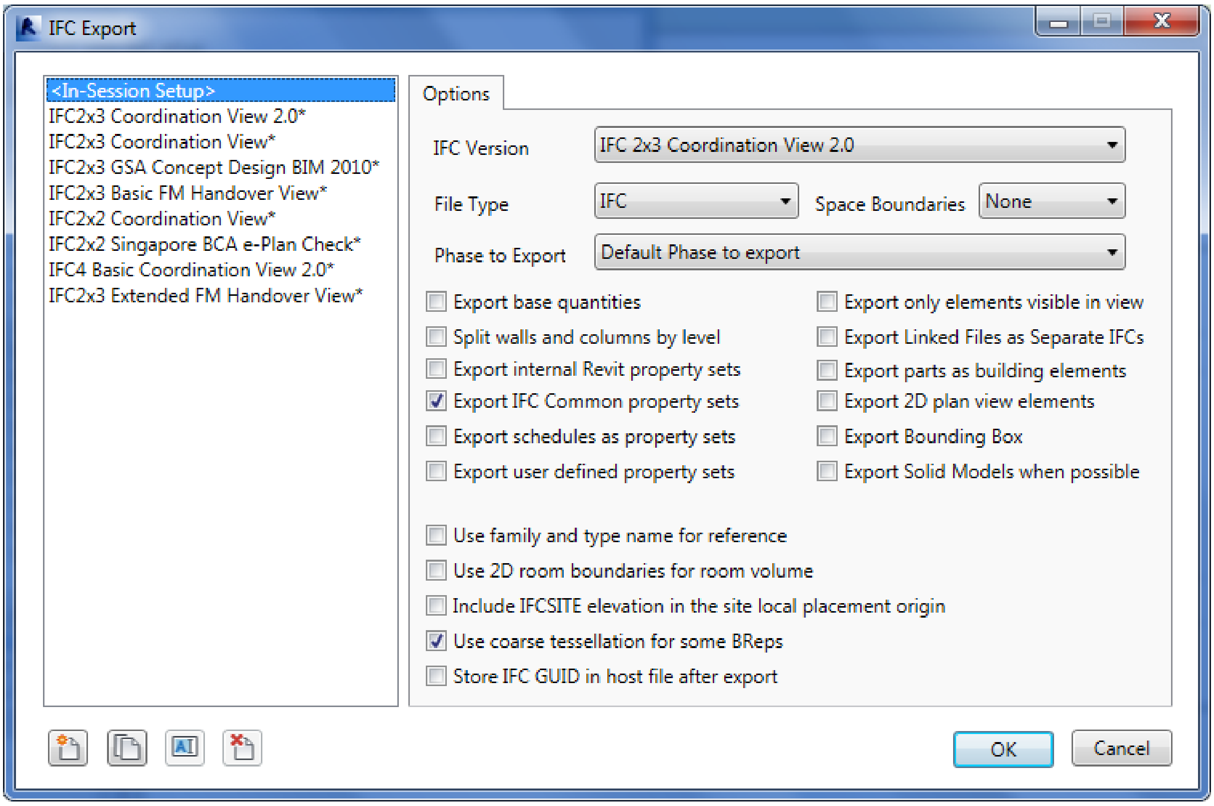
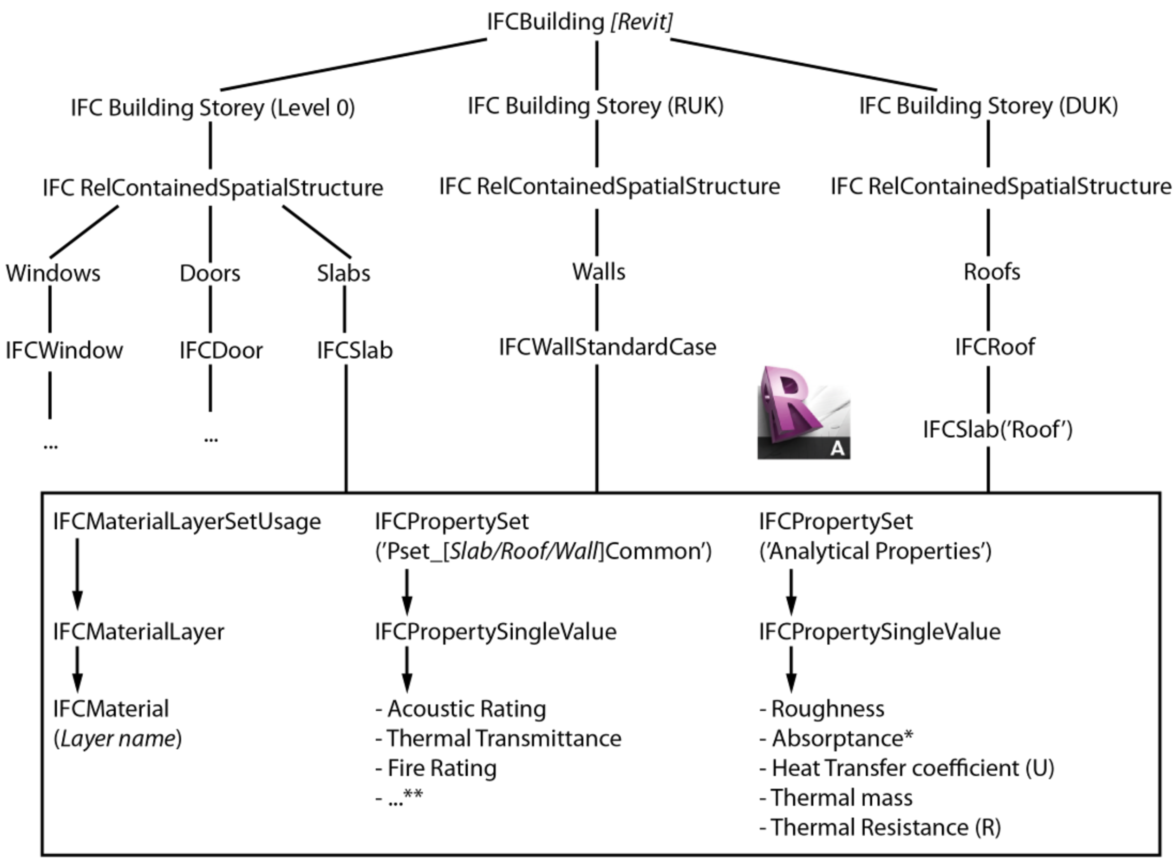


Figure 17 Revit 2015 extended IFC export



* - custom property ** - parameters are not relevant to BEM

Figure 18 IFC file structure as exported from Revit (with the assistance of IFC 2015)

Table 6 Exported parameters for Window and Door elements in IFC from Revit.

IFCDoor	IFCMaterialList	IFCMaterial	- Door Handle - Door Panel - Door Architrave - Door Frame
	IFCPropertySet ('Pset_DoorCommon')	IFCPropertySingleValue	- IsExternal
IFCWindow	IFCMaterialList	IFCMaterial	- Window Frame - Glass
	IFCPropertySet ('Pset_WindowCommon')	IFCPropertySingleValue	-Thermal Transmittance

3.3 Import to the intermediate software

During the third step, the data is handled by a number of plugins (as seen in Figure 6). During this stage every additional plugin adds further restrictions to the BIM model. The results of this data transfer and related loss of information are presented in Table 7.

Table 7 Results of import to the pre-processing tools

		G+M	G, M+P	G+M+P
1	SBT	v		
2	GBS (Revit)			v
3	OpenStudio plugin		v	
4	A-Null plugin (ArchiCAD)			v
5	A-physik plugin for SketchUp	v		

Three types of import are shown:

G+M: geometry is imported with the assigned basic material parameters – name tags of layers and composites, thickness of layers.

G, M+P: geometry is imported, materials with the physical properties are imported, but not assigned.

G+M+P: geometry is imported with the assigned materials and physical properties.

As displayed in the table, only in two out of five cases all the necessary information was preserved: “Revit>gbXML>GBS” and “ArchiCAD>A-null plugin>APS” (highlighted in green in Table 7). OpenStudio plugin recognizes the composites, but fails to import their connection to the surface geometry (highlighted in yellow in Table 7). So the user needs to assign the materials to the corresponding surfaces each time the gbXML is imported. There exists an option to import the IDF composites that are made previously in EnergyPlus, but those need to be assigned manually as well.

In the APS generated by the SketchUp plugin the geometry information is preserved, but the material layers are lost (see the section 3.5). SBT recognizes the relationship of the composites to the surfaces, but only suggests the option to overwrite the materials with the IDF file created separately. It does not use the physical material properties from the IFC (highlighted in red in Table 7).

Certain requirements should be met by the Revit model, in order to create the gbXML which will be well imported by GBS (Autodesk forum 2015):

- the problems with thick multi-layered roof were detected. In the test case the insulation layer of the roof had to be reduced in order to export it successfully to GBS.
- the upper limit of the rooms should be assigned correctly

- the thermal properties are included into the calculation (“Export gbXML” settings in Revit)
- functions of the building elements are identified as “exterior” or “interior”, according to their boundary conditions.

3.4 EnergyPlus

Three data transfer scenarios were tested for the *EnergyPlus* (Figure 6). The most information was preserved during the “Revit > gbXML > GBS” workflow. If the model requirements are met (see 3.3), then the resulting IDF file has all the necessary information, including the thermal parameters of the material layers.

In the workflow “Revit > gbXML > OpenStudio > IDF” the following observation was made: the resulting IDF has all the material layers in the category “Material:NoMass”. It happens because the gbXML generated from Revit also contains R-value as a layer parameter, which is recognized by the OpenStudio as a layer that has no mass. The regular materials have the Conductivity value instead. As a result, all the other parameters are ignored, and only the R-value is imported. If composites containing no mass layers are assigned to the surfaces in the model, EnergyPlus considers it to be a Severe error: “This building has no thermal mass which can cause an unstable solution.” The following workaround can be suggested: gbXML can be edited to delete the R-value parameter from each material layer. This way materials are read correctly by the OpenStudio and all the necessary parameters (thickness, conductivity, density and specific heat) are present in the resulting IDF file. In the workflow with the GBS such error does not occur.

SBT connects the IFC with EnergyPlus. If the user creates the separate IDF file containing the composites and maps it onto the IFC composites, then the resulting IDF is ready for the simulation in the EnergyPlus. SBT recognizes the surface+building material relationship in the imported model but does not make use of the physical parameters which are inside the IFC. This allows the certain level of file customization, but requires manual work of mapping the materials. On the Figure 19 corresponding materials from the opened IFC file and imported IDF constructions file are indicated with the red color.

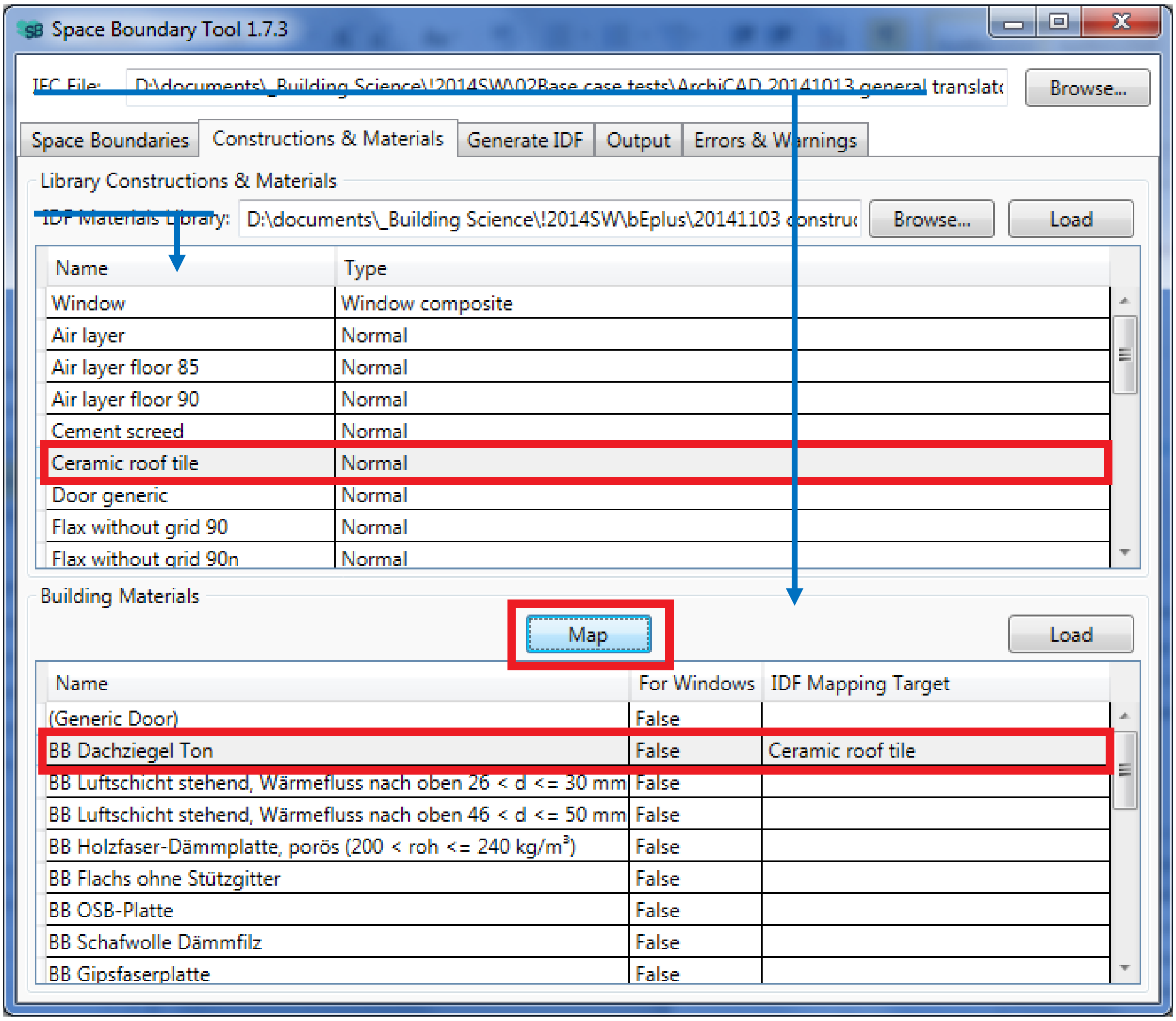


Figure 19 SBT: imported IDF materials are mapped on the IFC file

As follows from the Figure 19, SBT does not offer any material parameters editing. This should be done in the IDF file which is then imported. Consequently, the parameters that are specified in the BIM software are not used, but simply overwritten by those from the imported IDF.

3.5 ArchiPHYSIK

Two data transfer workflows were tested for *ArchiPHYSIK.* The best case scenario is when APS is generated by the A-Null plugin from ArchiCAD. Graphisoft has a long term cooperation with A-Null (ArchiPHYSIK developer), so the translation of the data can be done seamlessly if the special model requirements are met (see 2.3). In case of APS export from the SketchUp, information about the material layers is lost, even if the constructions are assigned properly in SketchUp and layers have the names taken from the ArchiPHYSIK-friendly material catalogue. This also happens if the gbXML generated from ArchiCAD is used in SketchUp for the similar workflow.

There is no connection between the IFC and ArchiPHYSIK (see 2.4), so there is no opportunity to analyze the model, created in Allplan. Available IFC to SketchUp import functions well, but does not simplify the model, so all six surfaces of the wall are imported to the APS file, which is not acceptable for the meaningful calculation.

The possibility to import the building materials in XML format was further explored for ArchiPHYSIK, using the following file structure (Figure 20).

Such a file may contain one or more materials. In case of multiple material entries, the first 8 digits of each following material id should be unique, otherwise ArchiPHYSIK overwrites materials. Created this way, materials are successfully imported to the ArchiPHYSIK library. As an alternative workflow to the ones that were tested previously, ArchiCAD material library can be created for ArchiPHYSIK. Once ArchiPHYSIK recognizes the material name, it assigns the corresponding parameters to the material layers from the library and the user does not need to manually specify them on each import instance (Figure 21).

```
- <catalog id="1fec6660-b366-11e4-ab27-0800200c9a66" created="2015-02-13
  00:00:00.000" modified="2015-02-13 00:00:00.000" country="AT" withdrawn="false">
    <name>gbXML_Projekt_xyz</name>
    <description>Projektkatalog für Projekt xyz</description>
  - <material id="184dde70-b366-11e4-ab27-0800200c9a66" created="2015-02-13
    00:00:00.000" modified="2015-02-13 00:00:00.000" withdrawn="false">
      <groupName>Allgemein</groupName>
      <name>gbXML Baustoff 1</name>
      <description>n/a</description>
      <application>n/a</application>
      <param sym="dimension" val="0.00" src="n/a"/>
      <param sym="density" val="100.0" src="n/a"/>
      <param sym="compressiveStrength" val="0.0" src="n/a"/>
      <param sym="thermCond" val="0.04" src="n/a"/>
      <param sym="heatSpecCap" val="1.67" src="n/a"/>
      <param sym="waterDiffRes" val="18.0" src="n/a"/>
      <param sym="waterDiffResWet" val="0.0" src="n/a"/>
      <param sym="acousticEDyn" val="0.0" src="n/a"/>
      <param sym="lifeTime" val="0.0" src="n/a"/>
      <param sym="peiNotRenewable" val="0.0" src="n/a"/>
      <param sym="peiRenewable" val="0.0" src="n/a"/>
      <param sym="gwp100" val="0.0" src="n/a"/>
      <param sym="ap" val="0.0" src="n/a"/>
      <fireReaction_EN13501>F</fireReaction_EN13501>
      <hatching>SOLID</hatching>
      <colorFront>#000000</colorFront>
      <colorBack>#FFFFFF</colorBack>
      <tags/>
    </material>
  </catalog>
```


Figure 20 XML structure of the building material to be imported to the ArchiPHYSIK (Battisti K. 2015)

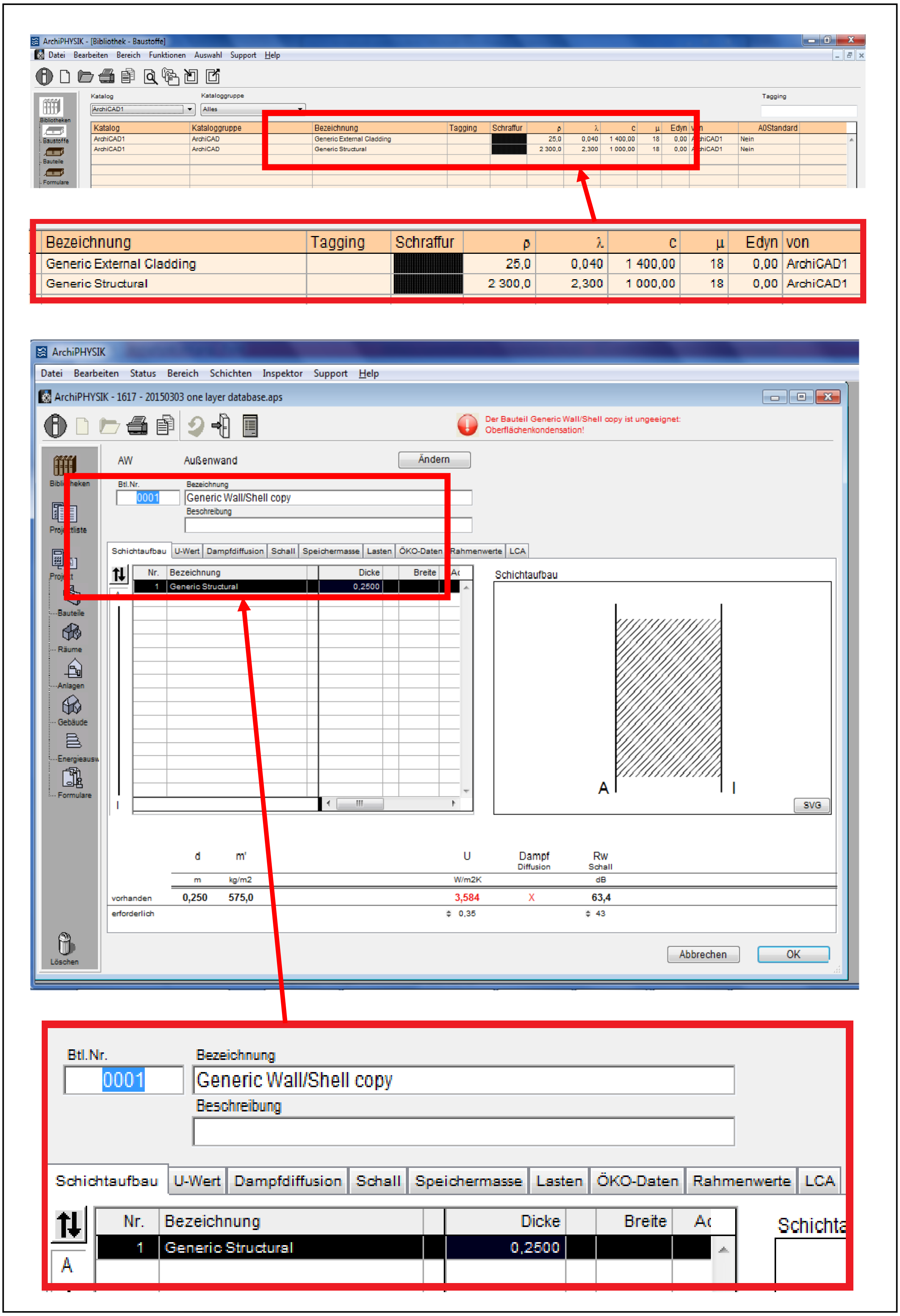


Figure 21 Custom library in ArchiPHYSIK 12 (above); imported APS file in ArchiPHYSIK (below)

4 DISCUSSION

4.1 Research Question 1

Comparing IFC and gbXML, which format performs better for the building material information transfer from BIM to BEM?

It appears from the tests, that for the purpose of the thermal simulation, building materials data is better transferred via gbXML rather than via IFC (Table 4).

Two main factors contributed to such result:

- gbXML is a schema developed to store the specific data necessary for the building simulation, while IFC was developed initially to store the structural information
- all tested BIM platforms do not support the material layer attributes for the IFC, only for the building element and/or composite (Allplan IFC only stores the information about the outside layer of the composite)

Revit serves as a good demonstration of the gbXML format capacity for the thermal simulation, while in case of IFC, Allplan has the largest amount of necessary parameters supported. It exports the layer properties, but does not allow for a realistic number of layers in the single building element.

The experiments concerned with creating and assigning the custom IFC material parameters in all BIM platforms show that these parameters are successfully exported, when the user specifies them in the special properties section of the building element, as shown on Figure 12 for ArchiCAD. In case such customization is offered and supported for the material layers, IFC can store the material information equally well as gbXML (Appendix A).

The issue with using the IFC spatial structure, as shown in Figure 5, can be solved with the help of additional post processing via the floating-point arithmetic using snapping-based technique (Ladenhauf et al. 2015). Currently those programs, which use IFC to make a model for thermal simulation typically ignore the material parameters from IFC and suggest creating them anew instead (SBT, Simplebim Datacubist Oy 2015, O'Donnell et al. 2013).

As for gbXML format, both ArchiCAD and Revit produce similarly structured gbXMLs. "Material" objects in gbXML are organized in "Layer" objects which are then combined in the "Construction" object class. Finally, "Construction" objects are assigned to the corresponding "Surface" objects that represent geometry in gbXML (gbXML.org 2008).

4.2 Research question 2

On which step of the data transfer does the loss of the information occur and why?

As most of the information is being lost on the initial stages of information export - they are either absent in the BIM programs, or not exported to the IFC / gbXML – the certain measures to visualize the exported energy model of the building might contribute to the improvement of the export quality.

Visual preview of the future energy model in BIM software can be offered to improve the export of the necessary data from BIM. One of the common export formats should be taken as a basis of such visualization, namely gbXML or the IFC.

At the moment there are several tools that can view and check the IFC and/or gbXML models. FZK viewer, developed by Karlsruhe Institute of Technology and Solibri Model Viewer are among of them. On the other hand there exist opportunities to view the energy model in the BIM tools (e.g. EcoDesigner in ArchiCAD). However, the latter is not connected to the export and the former option is only suitable for viewing, not editing the model. Visualization of the IFC and gbXML in BIM tool, for architects, who are currently responsible for making the large portion of the BIM model will provide the immediate feedback on how good the data will be exported. In the case of thermal simulation those will include geometry and materials.

It was mentioned before that various MVDs were developed for the IFC format (BLIS Consortium 2012). On the "IFC Solutions Factory" website such MVD projects as "Architectural Design to Building Energy Analysis" and "Architectural design to thermal simulation" can be found. These MVDs could become the basis for the view filtering, described above. Content-wise, gbXML can be considered to be similar to the MVD focused on the building energy analysis, with the difference in the geometry representation.

In ArchiCAD and Allplan the load bearing properties can be specified in the building elements, which automatically places them on the specific layers. Then only the structural elements can be displayed via the "Document" > "Partial Structure display dialogue" menu (Figure 22). Such mode is used to filter out the structural elements and export them to the IFC which is sent to the civil engineers. Similar filtering also exists in Revit. Another example is the gbXML preview implemented in Revit 2015 (Figure 24).

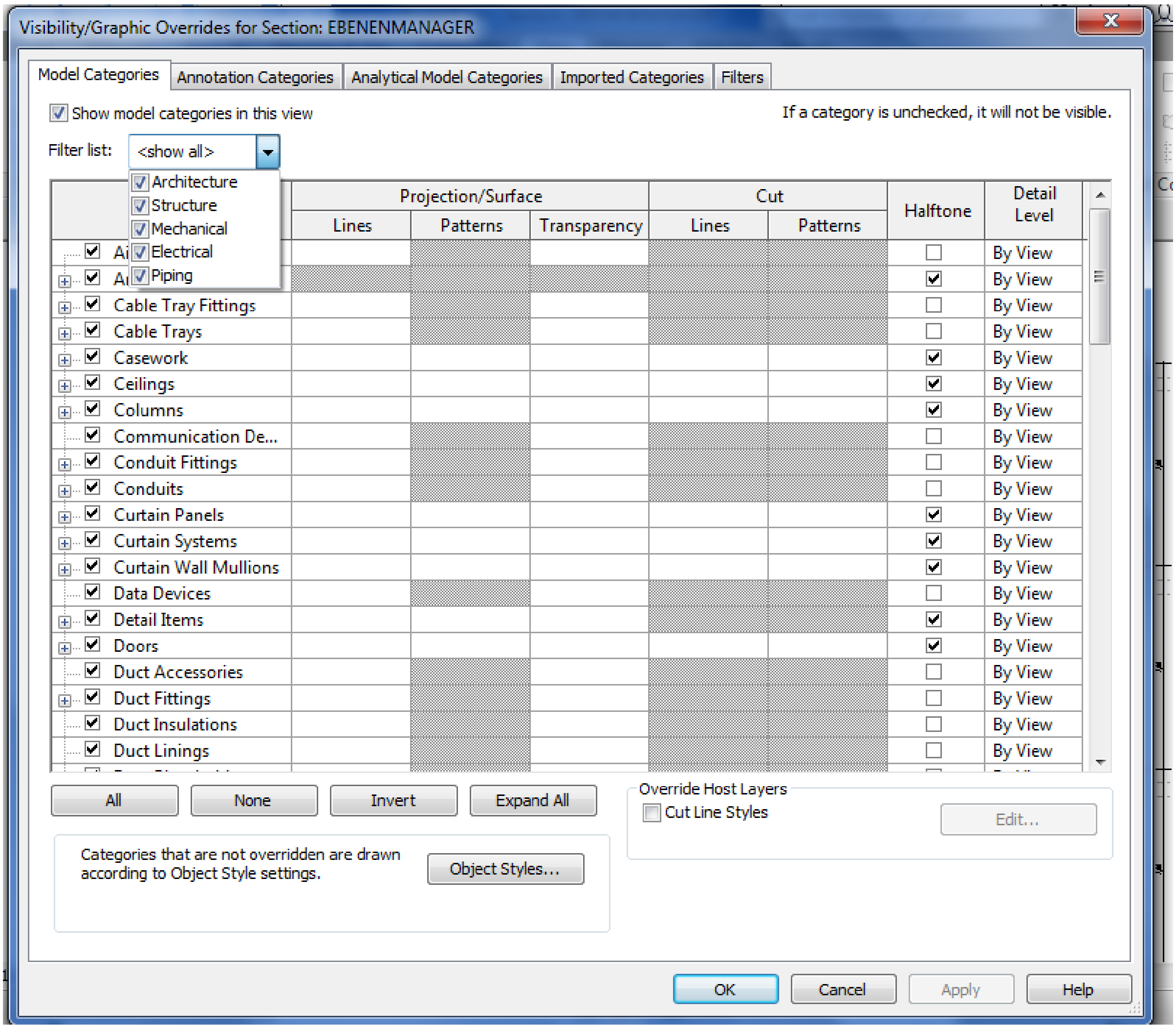


Figure 22 Visibility Graphics window in Revit 2015

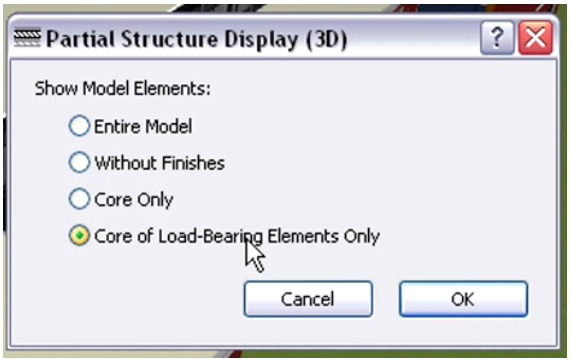


Figure 23 Partial Structure Display window in ArchiCAD 18

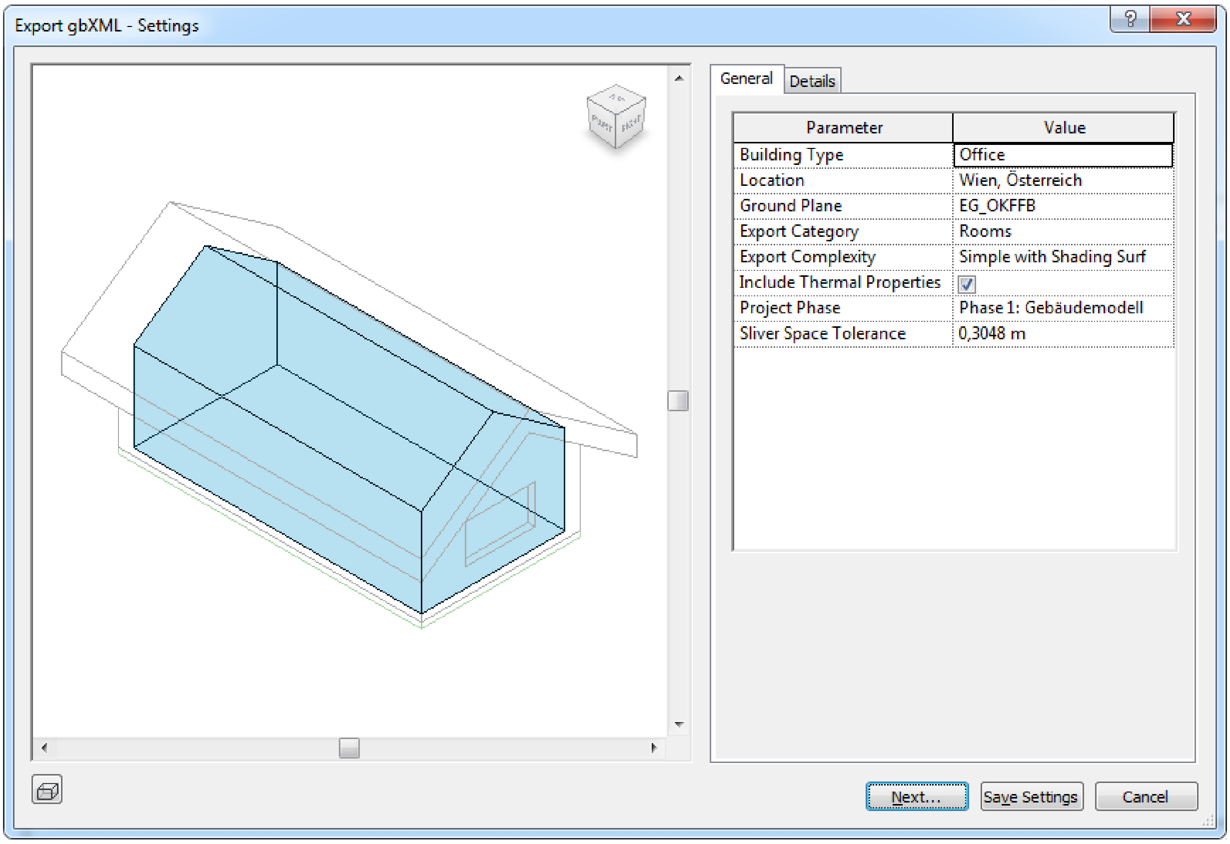


Figure 24 Export gbXML preview window in Revit 2015

On the long term such discipline-based filtering can develop in the future stand-alone BEM tool plugged to the BIM. This tool can provide the BPA specialist the access to the general BIM model, being created by the structural engineer and an architect. Using this tool, BPA specialist could analyze and interpret the model in the real time, avoiding the import and export of the data and, at the same time he/she will not have to buy the full BIM package. Building performance-specific material parameters and labeling could be done via such tool, they will remain in the general BIM model and could be viewed by everyone else in the design group. Script-generated design variations (e.g. window to wall ratio) can also be implemented here (similar to those already existing in the GBS). Theoretically, on the early design stage, the space proposals from the BPA specialist can be shared with everybody in the group and become a basis for the new BIM model.

The major issue for the implementation of such preview is the difference in the room layout for architecture and BPA, which was mentioned above (1.5.1 Conceptual design stage).

4.3 Research question 3

Is there potential to improve the material mapping from the IFC/gbXML to the simulation files?

In response to the third research question, the Customizer program is suggested. It can be viewed as one of the improvement suggestions based on the research presented in the current master thesis.

A text editor can be used as an alternative to the IDF editor to create the input files for the EnergyPlus (EnergyPlus 2013). Such editing is also typically executed during the later stages of the EnergyPlus simulation modeling because there are no possibilities for group editing of materials in IDF-editor (e.g. usage of the “find” and “replace” functions to rename the material or remove the unnecessary data).

ArchiPHYSIK has three formats for the import of the building material file: APS, TXT and XML. As part of the presented study the XML files suggested by Kurt Battisti were tested and successfully imported to the ArchiPHYSIK database (see 3.5).

Both IFC and gbXML contain the necessary data structure to transfer the parameters for the building materials (Appendix A, C). This means that, theoretically, an energy engineer can extract the parameters either from the IFC or from the gbXML.

It is suggested to design a simple tool to assist such data extraction and create IDF files for EnergyPlus and XML files for ArchiPHYSIK using the building material parameters from the IFC and gbXML. The name of the tool is “Customizer” and it inherits some of the SBT material mapping principles (Figure 27) and incorporates the more advanced version of “find and replace” function from the simple text editors. Customizer consists of three working spaces: left, middle and right (Figure 25). Left working space (input) will contain the information found in the BIM model, right working space (output) contains the information found in the thermal simulation files or the empty template, and the middle space connects the input and output by the search queries. IFC and gbXML can be displayed in the tree view, similar to the IFC Tree viewer (Figure 26). The new XML or IDF files can be created, containing the building materials.

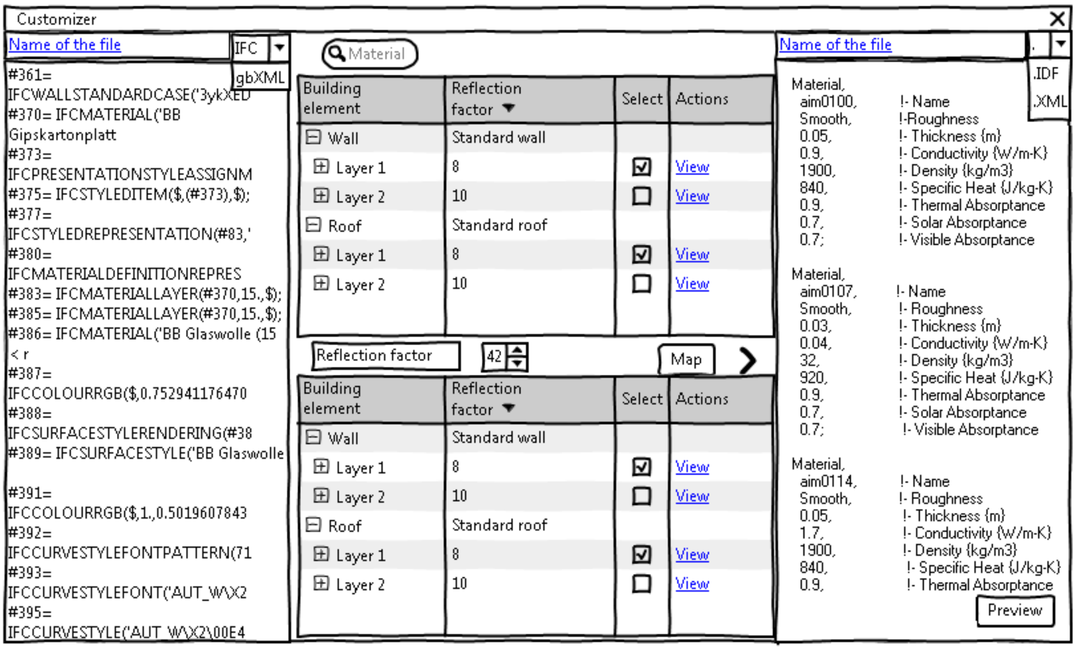


Figure 25 „Customizer" user interface mock-up

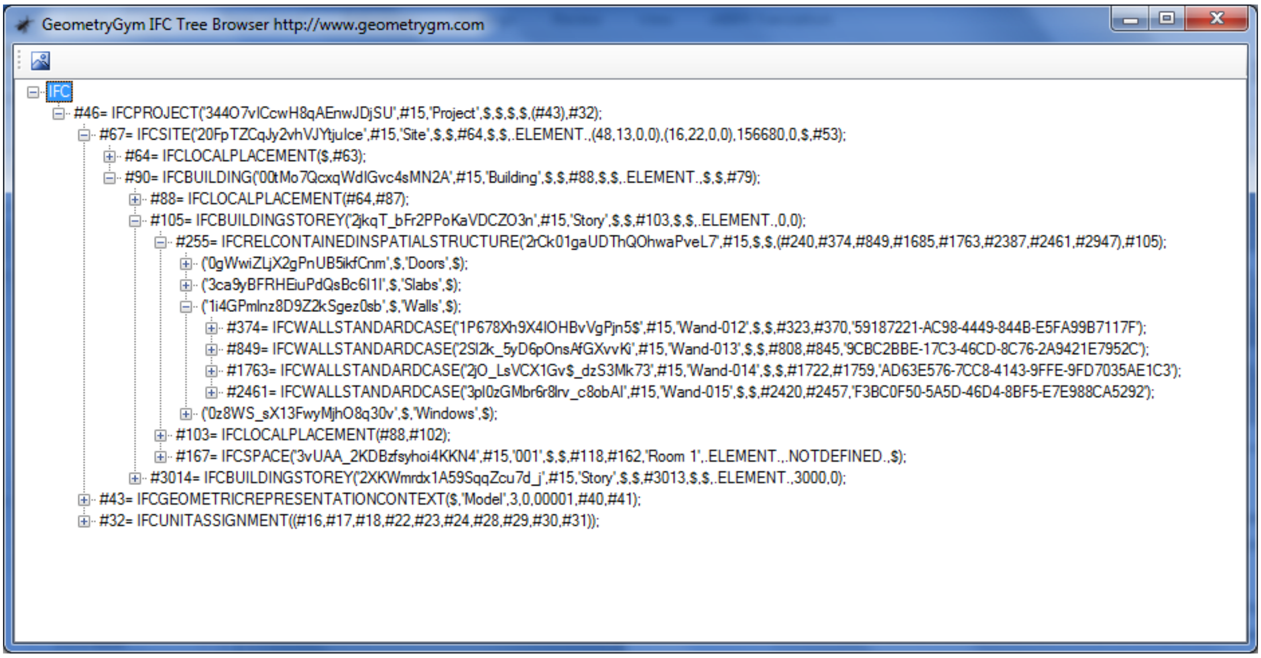


Figure 26 IFC Tree viewer interface (GeometryGym 2015)

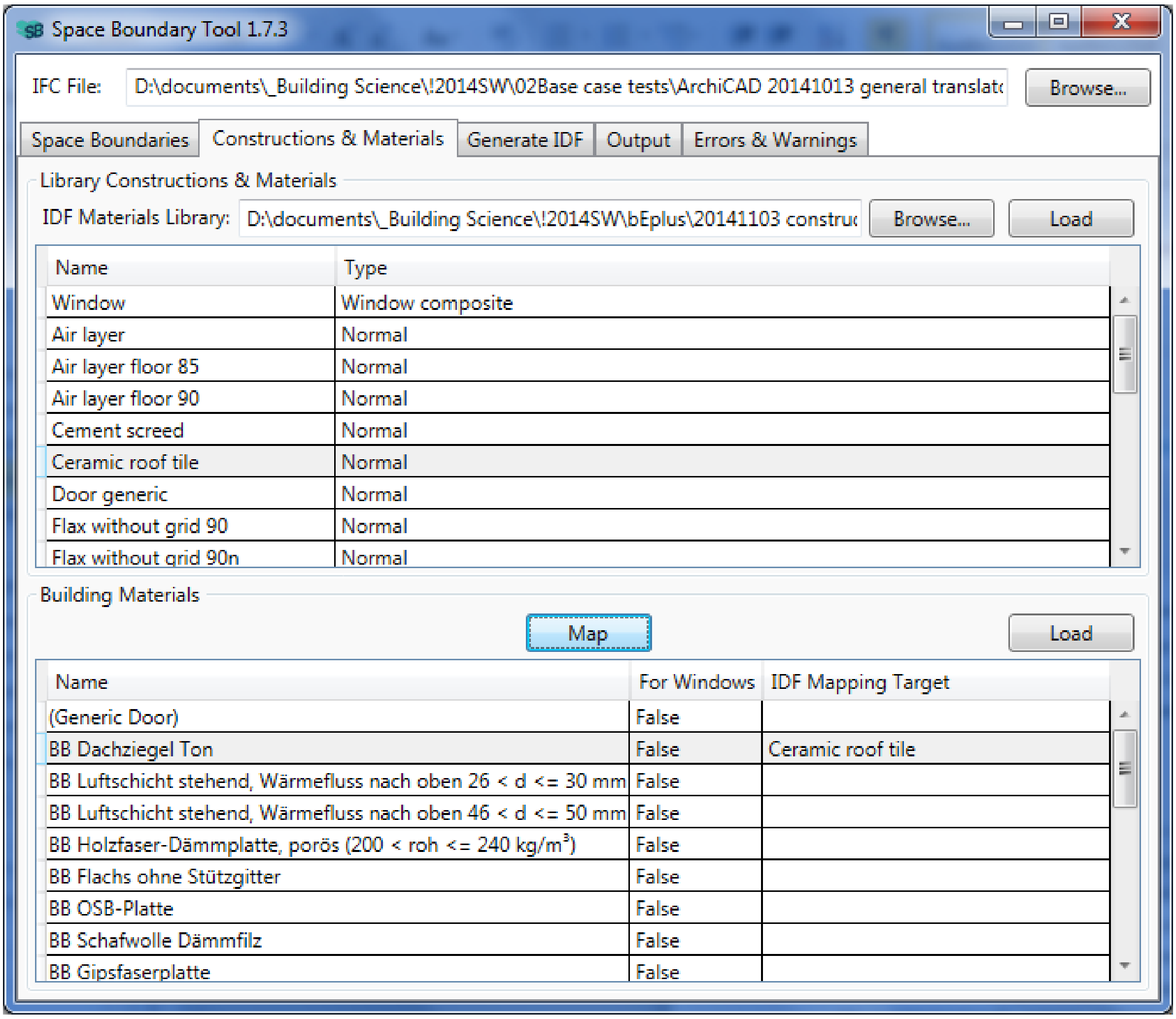


Figure 27 SBT interface with the mapping function

Analysis of the above mentioned workflows (Figure 6) reveals the potential for improvement of the data transfer process between IFC/gbXML and simulation programs (Figure 28).

“IFC to XML” workflow has no potential, as already shown in 2.4. Theoretically, IFC could have been used to extract the properties from the layers, but up to the present moment (July 2015) only Allplan of all BIM platforms exports physical properties for the outside layers of the composite to IFC. Thickness of the layers and composite structure are always defined in ArchiPHYSIK itself, so it is not needed for the XML file.

In “IFC to IDF” workflow Customizer can be used to create the IDF file which is then mapped in SBT onto the space boundaries (Figure 19). Composite, its layers structure and layer properties can be taken from IFC. At the current stage of export development only thickness can be used and other properties should be added manually from the databases. See Table 4.

“gbXML to IDF” workflow can be improved either by adding the missing properties from the IDF database (gbXML from ArchiCAD), or faster editing of IDF files exported from OpenStudio (gbXML from Revit).

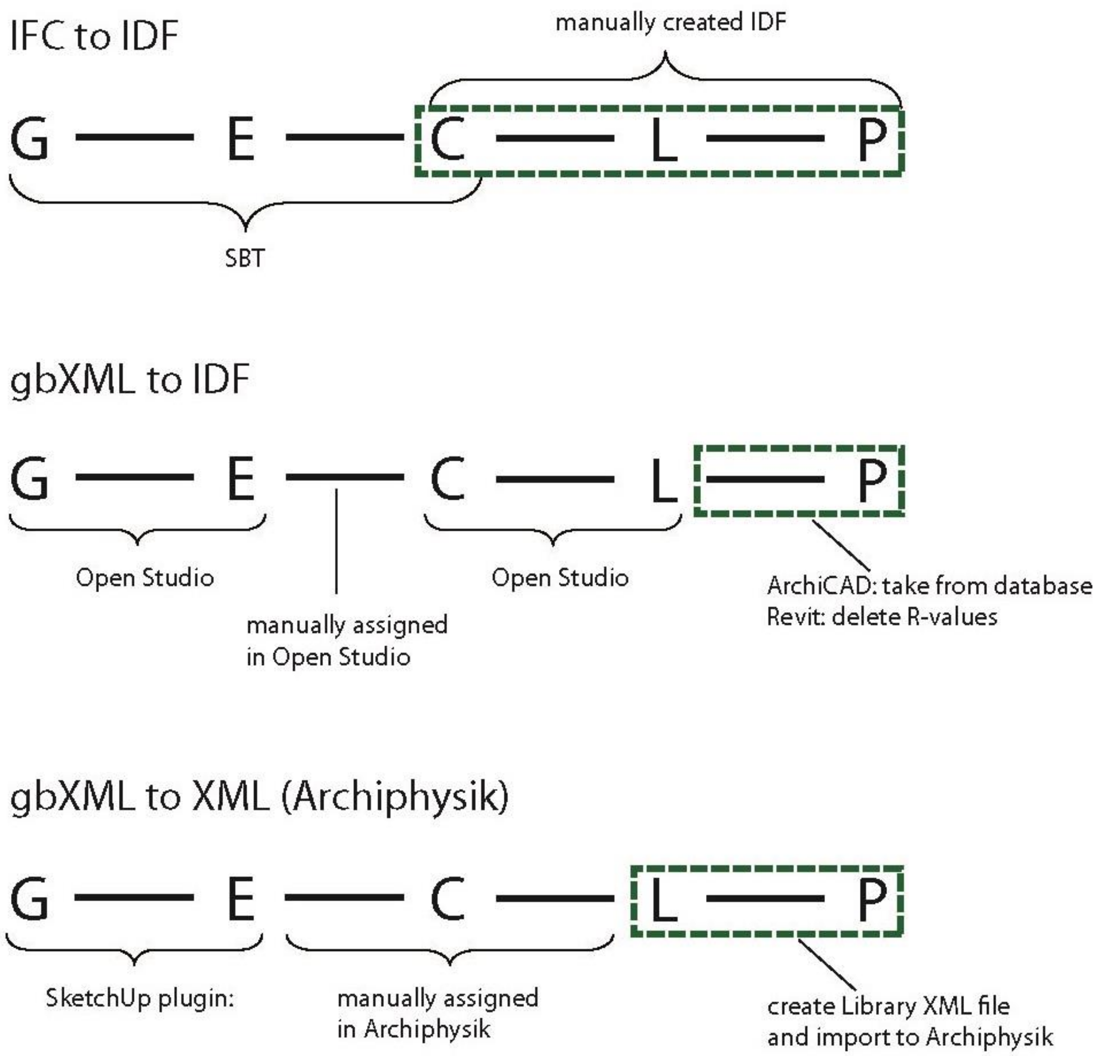


Figure 28 Analysis of the existing workflows and potential for improvement

Legend for the Figure 30 :

—	actions that can be performed in Customizer
G	Building geometry
E	Building element (wall, slab, roof, door, window)
C	Composite of the building material
L	Layer of the composite
P	Layer properties (thickness, name, lambda)

The principle of Customizer application can be summarized in the following scheme:

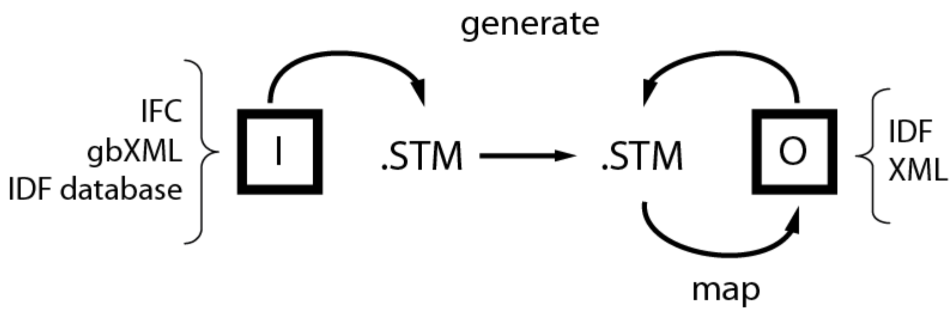


Figure 29 Customizer principle

As shown in Figure 29, IFC, gbXML or IDF database file can be loaded as input - “I” rectangle on the scheme - while IDF or XML file can be obtained as output - “O” rectangle on the scheme. There are two options for the output files: either the existing ones can be enriched - e.g. IDF files already made in OpenStudio; or the new XML or IDF file can be created. Customizer generates the .STM file (which is its own XML-based format), where it stores the building materials data in the form of database. This allows the user to perform the following actions:

1. Review the quality of the output file by comparing it with the information containing in input file (gbXML, IFC or IDF database).
2. Map the missing data on the existing IDF file from the input file
3. Create the materials library for ArchiPHYSIK (XML) or EnergyPlus (IDF) based on the input file
4. Group editing of the layer parameters for the output file (IDF or XML)

More detailed activity diagram can be found in Figure 30.

Here such actions as “Create XML/IDF file” and “Load XML/IDF file” are concurrent in their resulting action and “Edit file” and “Map data” lead to the common decision making: “Do we have all the data?”.

Additionally, a set of template output files will be provided together with the application. These files will be needed for the “IFC to IDF” and “gbXML to XML” workflows, since in those cases output IDF and XML files should be created in Customizer.

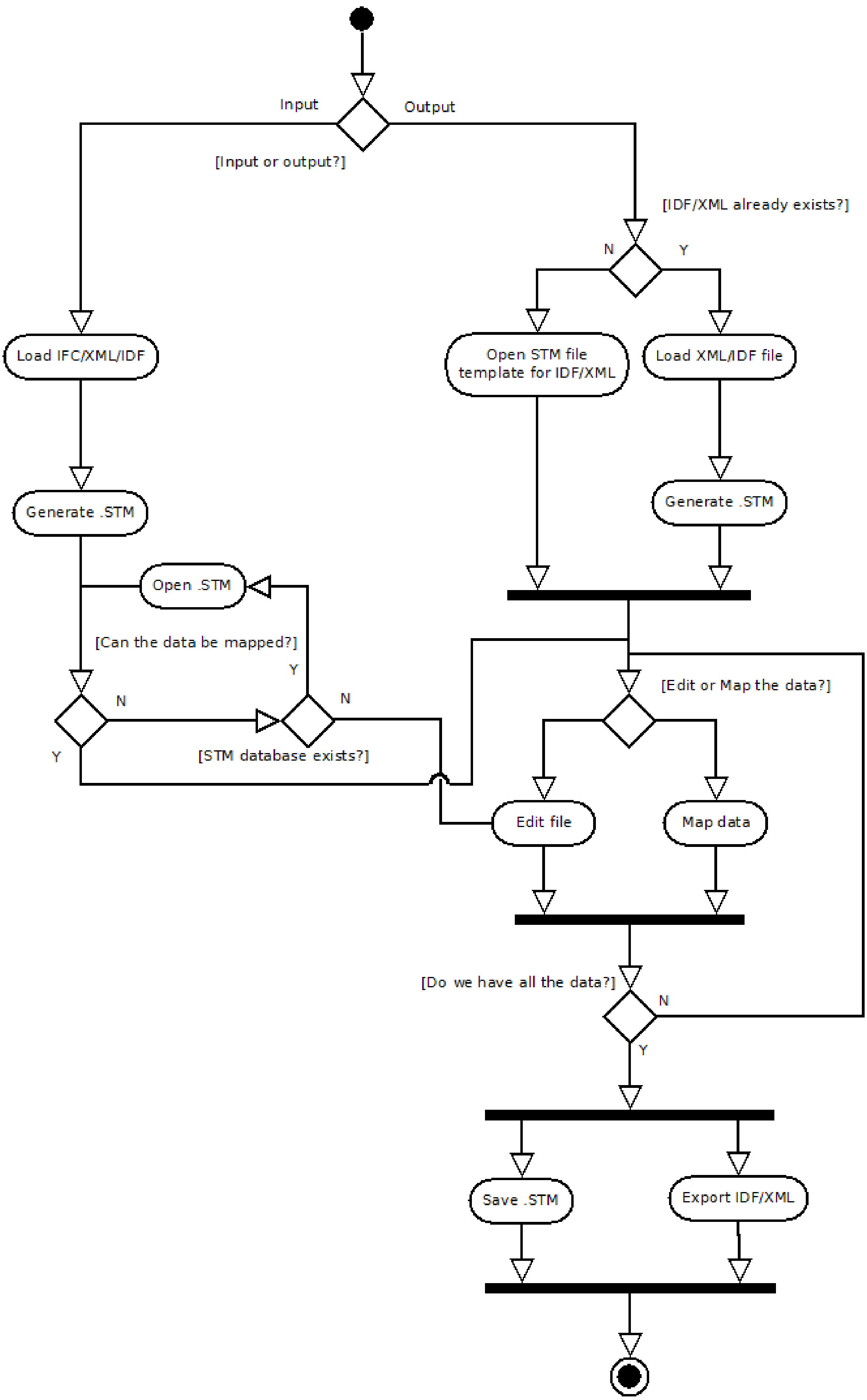


Figure 30 UML Activity diagram for Customizer

4.3.1 Detailed use case example: IFC to IDF.

In this detailed use case, IDF file is created in Customizer, which contains constructions for the import into SBT, as shown scheme on the Figure 28, the IFC to IDF workflow. Since IFC contains only the part of the necessary information, the rest of it can be either taken from the IDF database or entered manually.

In the course of the current study, simple geometry case was created in ArchiCAD and then exported to the IFC using the general translator (Figure 7). This model is also used for the detailed use case, which is illustrated here. The model consists of 4 walls, one slab and one flat roof. Window is inserted into one of the walls, the door into the other. Materials are taken from Baubook (Baubook, Bauteilverwaltung 2014-2015).

In the Table 8 it is indicated which class in IDF and IFC corresponds to the model components in the Customizer file (STM). See Table 2 for the further reference.

STM is a Customizer file format that contains the information, extracted from the IFC (input) or to be imported to the IDF (output). This intermediate format makes it easier to process the data inside the application.

Table 8 Model component names used in Customizer, IFC and IDF

Name in the STM	**Class in the IFC**	**Class in the IDF**
Building element	`IfcSlab, IfcWallStandardCase, IfcRoof`	`BuildingSurface:Detailed`
Composite	`IfcMaterialLayerSet`	`Construction`
Layer	`IfcMaterialLayer`	`Material`

In this detailed use case example, only wall composite is taken (Figure 31), while the workflow for the Slabs and Roofs is identical to the Walls, with the difference in the parameters (Figure 30).

Workflow for the presented detailed use case will be described with the relation to the *working spaces* of Customizer: *left, middle* and *right* (Figure 25). *Left working space* refers to the input file (in this case, IFC); *Right working space* refers to the output file (in this case, IDF) and *Middle working space* is where input and output are mapped and edited.

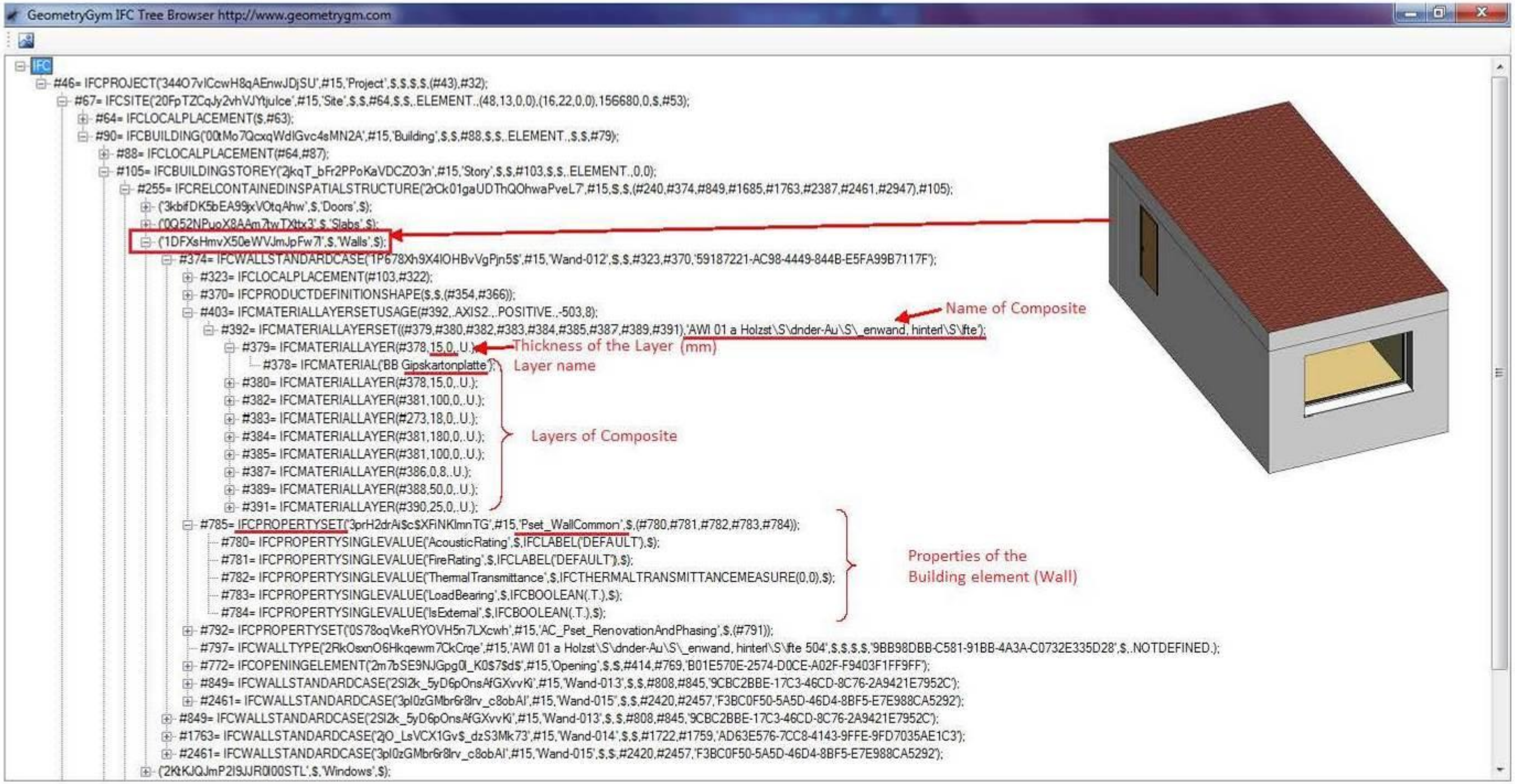


Figure 31 IFC Wall elements. IFC Tree viewer combined with the image of the model

Left working space (input):

1. Load the IFC file (see Figure 31)

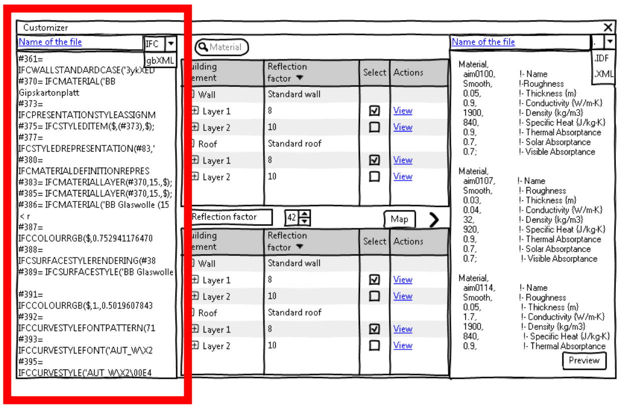


Figure 32 Left working space (input)

Middle working space (upper part, input):

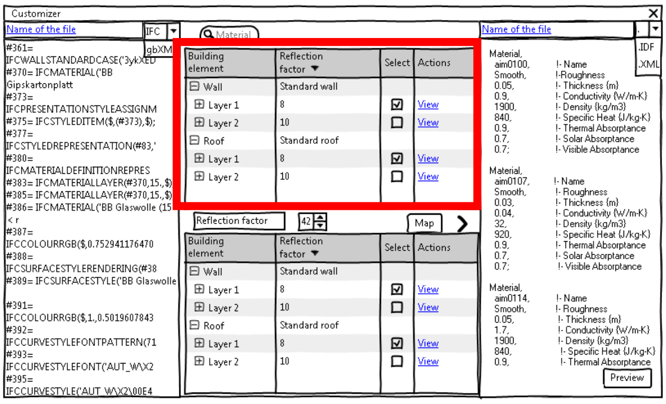


Figure 33 Middle working space (upper part, input)

2. Create STM file

a. Indicate relevant Building element (in this case `IfcWallStandardCase`)

First Customizer searches for all the instances of `IfcWallStandardCase` class, in case they have identical `IFCMaterialLayerSet`, it only takes one instance for the STM file.

b. Indicate relevant parameters in the IFC

Inside the selected instance of the `IfcWallStandardCase` class such classes as `IFCMaterialLayerSet` and `IFCPropertySet` are read with all their nested instances.

c. Save these parameters as a form of a report

On this step the relevant data from the IFC is extracted and displayed to the user in the tree-like structure (Figure 34).

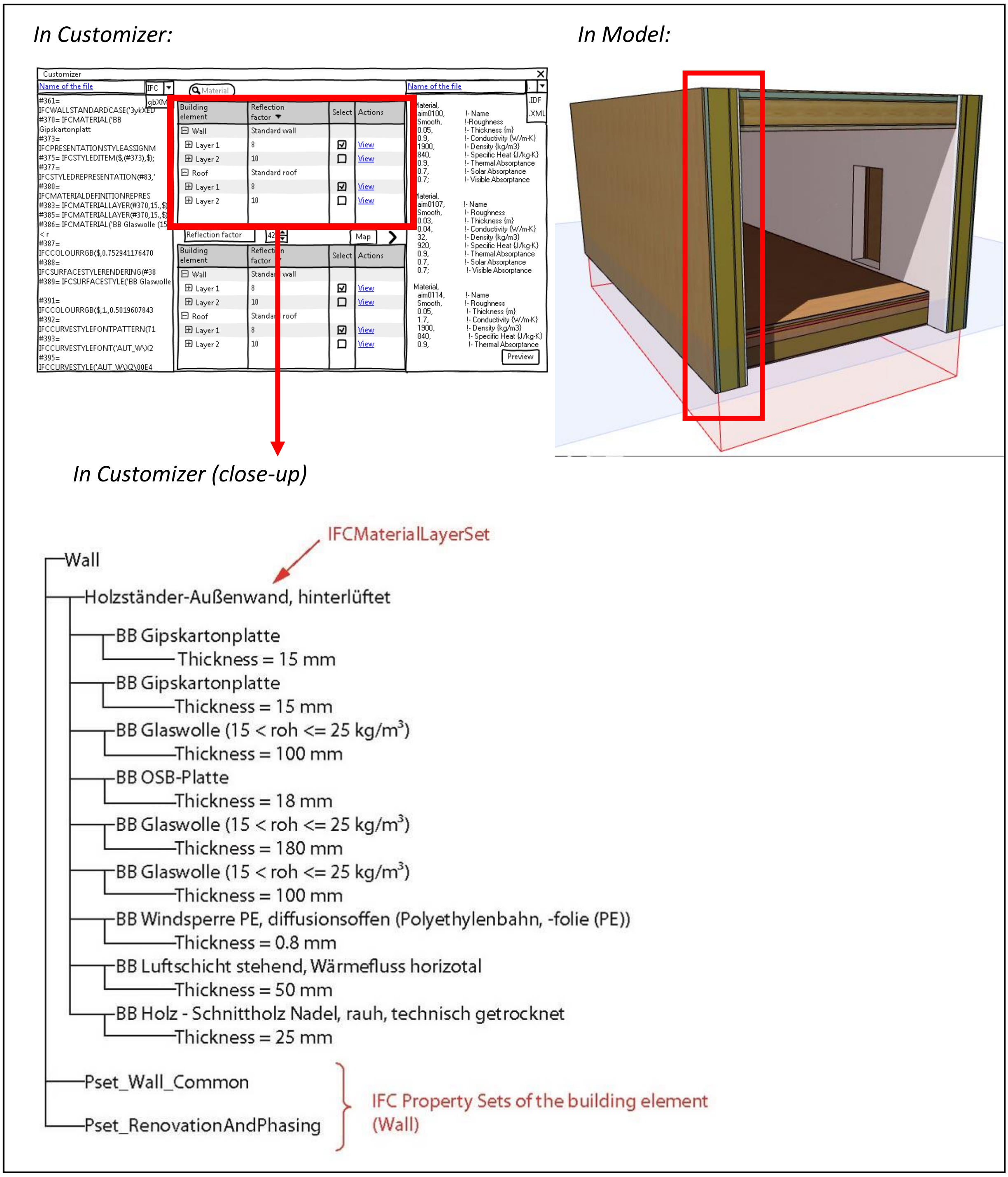


Figure 34 STM created from the input

Middle working space (lower part, output):

Since the output IDF file does not exist yet, the empty STM template should be used instead.

3. Open STM template

a. Adjust the number of required layers for the Wall composite in the output STM (in this case 9 layers)

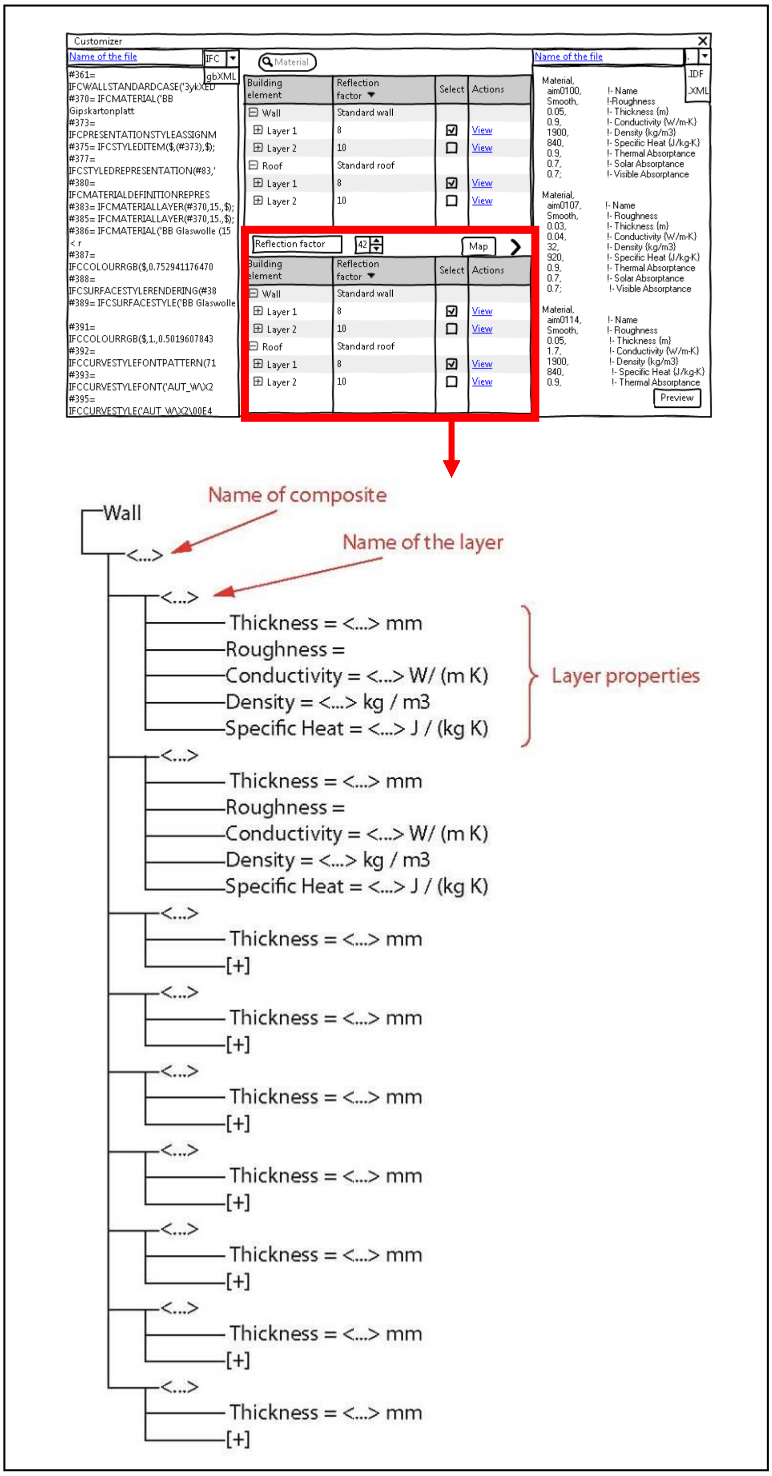


Figure 35 Empty STM template for the output file

4. Map the data

The relation between the instances of input STM file and output STM file are set up manually by user in the middle working space of the program (Figure 36). User choses two corresponding instances and clicks “Map”, similar to the workflow in the Space boundary tool (Figure 19).

Possibility to have a “default mapping” suggestion from Customizer can be also considered on the implementation stage. The program could recognize the relationship between the elements in the input STM and output STM and make a suggestion on how the instances should be mapped, leaving it for the user to correct the elements, which are matched incorrectly.

It is clear that after the mapping there still will be missing layer parameters, that do not exist in the imported IFC file. They will be highlighted by the Customizer (Figure 37). The system of the warnings and error reports can be developed as a feedback to the user, similar to the one existing for the Energy plus software (US Department of Energy, 2015).

5. *Optional*: load the ASHRAE database

On this step the input file could be changed to use IDF materials database from ASHRAE (ASHRAE, 2015). This database comes together with the default installation package of Energy plus software and can be imported as a reference for the missing parameters. User can find similar materials and fill map the data from the database.

6. *Optional*: enter the missing properties manually (equals to the “Edit” activity in Figure 30)

Here some additional functions, such as “find ” and “replace” can be useful, being that Customizer has already structured the information in the STM file, the user does not need to take care of the correct punctuation to separate the IDF classes.

7. Save STM output file as IDF constructions file.

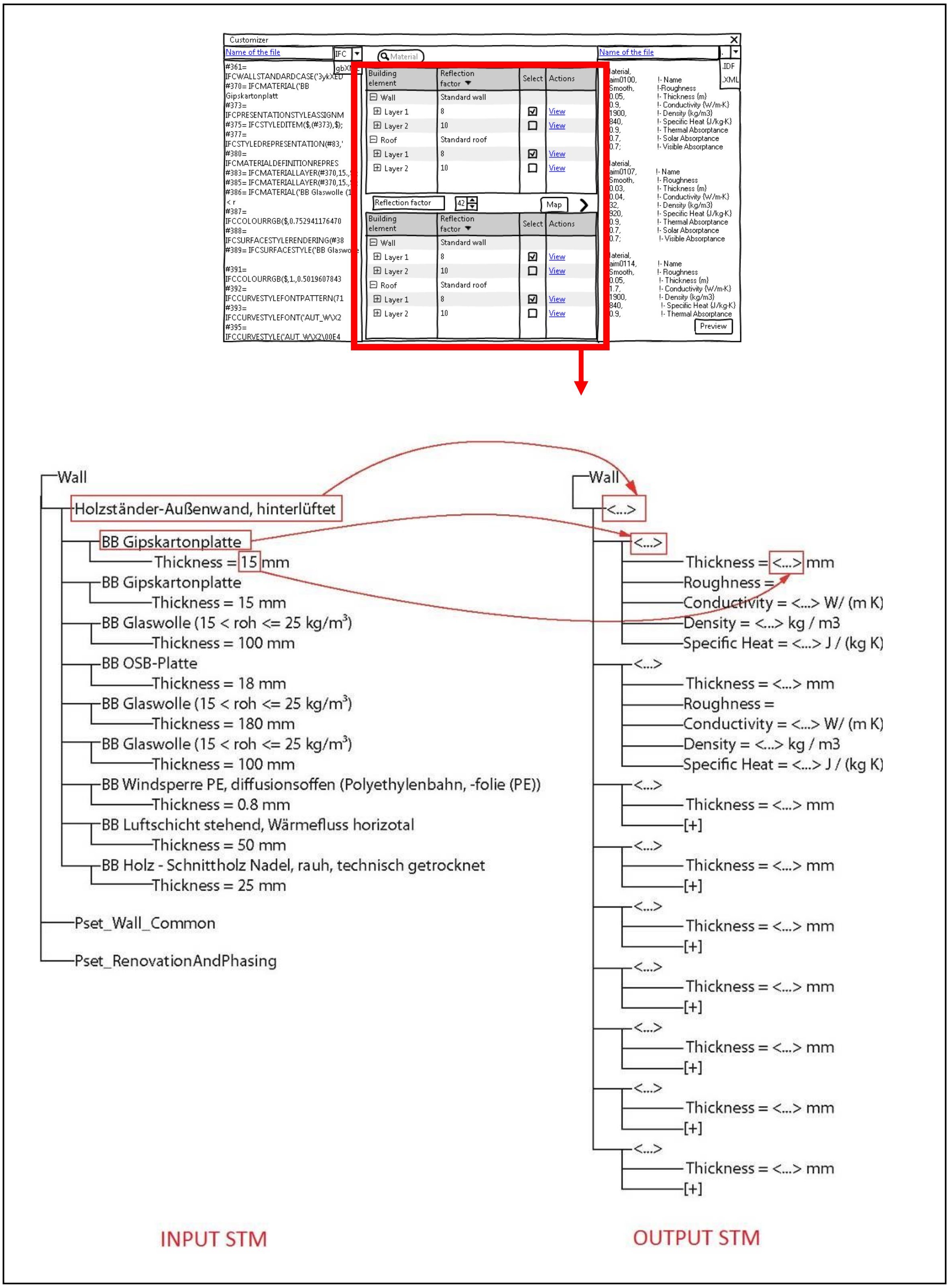


Figure 36 Mapping the data from the input STM to the output STM

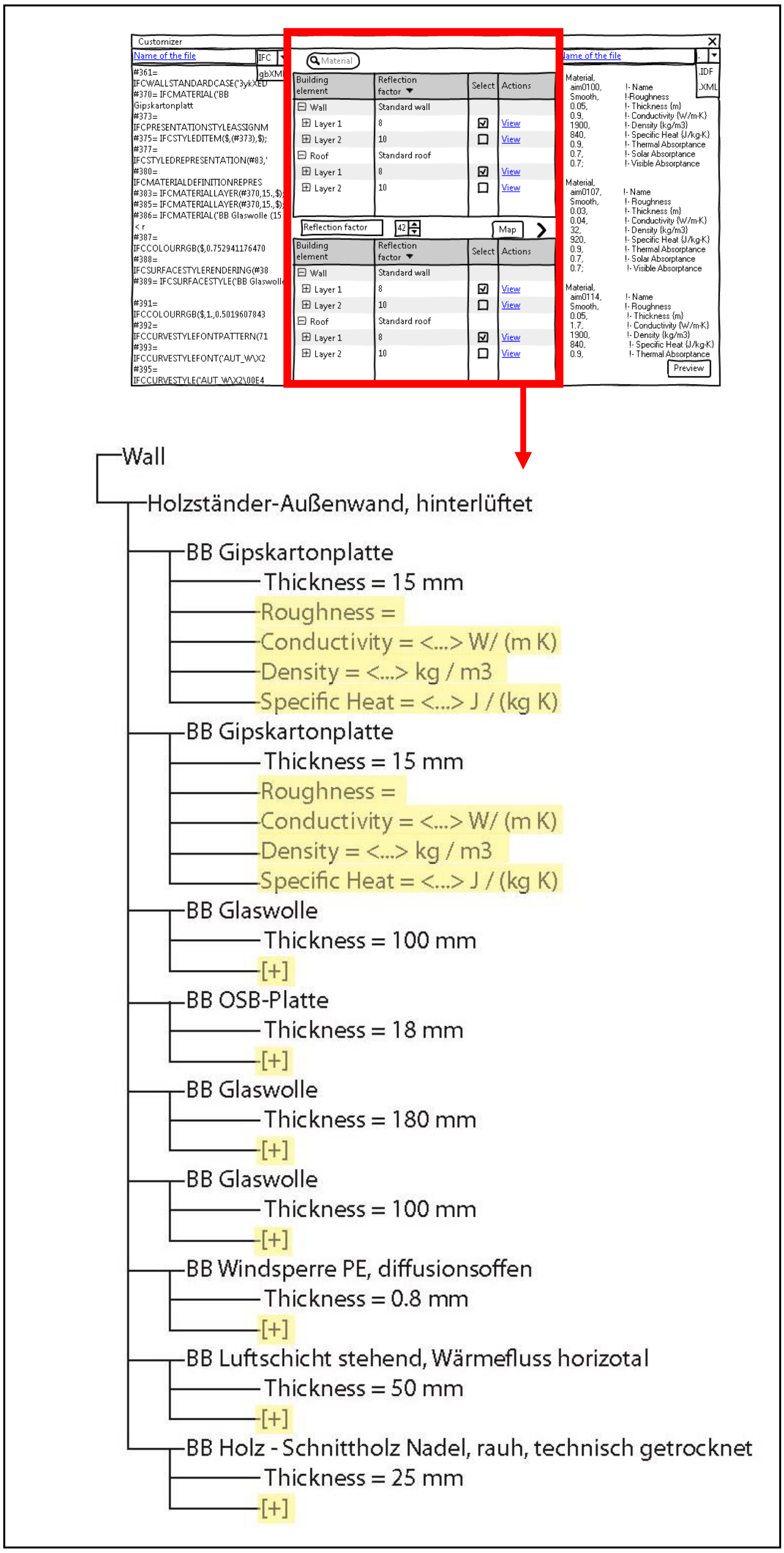


Figure 37 Missing parameters in the output STM file

5 CONCLUSION AND RECOMMENDATIONS

In the course of testing different workflows to export the building material data from BIM platforms to thermal simulation programs, it becomes clear that most of the resulting files require additional editing and adjustment. Such editing is time consuming and often represents routine repetitive actions, which prevent the users from collaboration outside the level which required by the building standards. Exporting the building data from BIM to BEM at the current stage of the technology is often more complicated than drawing new simplified geometry that will serve as the basis of the thermal simulation.

However, the efforts to improve the data transfer continuously bring the industry closer to the desired level of data exchange: understanding BIM as a database where all the participants can simultaneously review, check and design the building model.

Conducted research confirms that both IFC and gbXML exchange formats have the capability to store the necessary information about the building materials. However, only some of the BIM platforms support gbXML because of its use being limited only to the area of building performance; while IFC, which is widely adopted, is not fully implemented in BIM to include the necessary physical parameters and requires additional steps of defining the space boundaries in order to be applicable in BEM. Generally, IFC and gbXML model checking and export preview is detached from the process of creating the BIM model. This results in the loss of information which is already specified in the BIM model. The suggested Energy analysis preview could improve the data transfer and raise the awareness of the exported model quality among architects, who are responsible for the creation of the BIM model nowadays.

Finally, as a step towards the further improvement of the building material data transfer, the Customizer tool is suggested. Its simple design allows the user to easily view the available information, map it on the existing thermal simulation files or create the new ones. Implementation and testing of this tool can be viewed as a subject of the future research of the building material data transfer from BIM to BEM.

List of Figures

List of Tables

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APPENDIX A: THE SUMMARY OF IFC 2X3 AND GBXML 0.36 MATERIAL-RELATED PROPERTIES

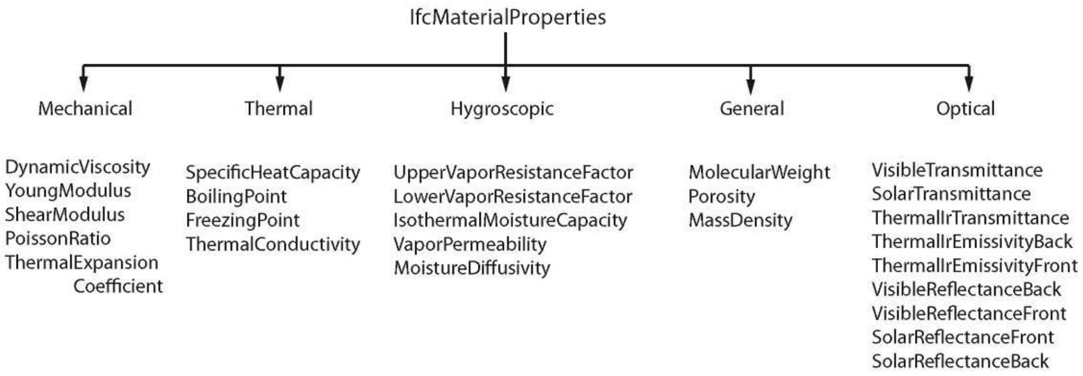

Figure 38 IFC material properties.

Table 9 IFC building element properties

	IFCWall	IFCRoof	IFCSlab	IFCDoor	IFCWindow
Reference [type ID]	+	+	+	+	+
AcousticRating	+		+	+	+
FireRating	+	+	+	+	+
Combustible	+		+		
SurfaceSpreadOfFlame	+		+		
ThermalTransmittance	+		+	+	+
IsExternal	+	+	+	+	
LoadBearing	+		+		
Infiltration				+	+
SecurityRating				+	+
GlazingAreaFraction				+	+
FireExit				+	
SelfClosing				+	
SmokeStop				+	+
HandicapAccessible				+	
Compartmentation			+		
ExtendToStructure	+				

Table 10 gbXML material and building element properties

	Construction	Layer	Material	
Name	+	+	+	Name
Description	+	+	+	Description
U-value	+		+	ImageTexture
Absorptance	+		+	R-value
Roughness	+		+	Thickness
Albedo	+		+	Conductivity
Reflectance	+		+	Density
Transmittance	+		+	SpecificHeat
Emittance	+		+	Permeance
Cost	+	+	+	Cost
PercentExisting	+		+	RecycledContent
FireFace	+		+	Fire
LayerId	+		+	Porosity
LoadCalcInputParameters	+		+	IndoorAirQuality
InsideAirFilmResistance		+	+	Reference
MaterialId		+	+	CADMaterialId

APPENDIX B: FULL LIST OF BUILDING MATERIALS

Roof

Table 11 Roof material

Roof	**DAl 01 b Holzsparren-Steildach** ***DAl 01 b Timber rafter pitched roof***	**d**[1] cm	**λ**[1] W/(mK)	**R**[1] (m²K)/W	**Density**[2] kg/m³	**Specific heat**[2,3] J/(kgK)
1	Dachziegel Ton *Ceramic roof tile*	2,5	0,84	-	800	1900
2	Inhomogen (Elemente längs bzw. normal zur Traufe) *Inhomogeneous (elements measured perpendicular to the Roof edge)*	3	0,025	-	1,2	1003
	53,1 cm (85%) Luftschicht stehend, Wärmefluss nach oben *53,1 cm (85%) Air layer, not moving, heat flow upwards*					
	~~9,4 cm (15%) Holz - Schnittholz Nadel, rauh, lufttrocken~~ *~~9,4 cm (15%) Wood – Sawn pine wood, rough, air dried~~*					
3	Inhomogen (Elemente quer bzw. parallel zur Traufe) *Inhomogeneous (elements measured perpendicular to the Roof edge)*	5	0,025	-	1,2	1003
	56,3 cm (90%) Luftschicht stehend, Wärmefluss nach oben *56,3 cm (90%) Air layer, not moving, heat flow upwards*	5				
	~~6,3 cm (10%) Holz - Schnittholz Nadel, rauh, lufttrocken~~ *~~6,3 cm (10%) Wood – Sawn pine wood, rough, air dried~~*	5				

4	Holzfaser-Dämmplatte, porös (200 < roh <= 240 kg/m^3) *Wood fiber insulation, porous (200-240 kg/m^3))*	2	0,055	0,364	240	760
5	Inhomogen (Elemente längs bzw. normal zur Traufe) *Inhomogeneous (elements measured perpendicular to the Roof edge)*	10	0,050	2	43	1380
	56,3 cm (90%) Flachs ohne Stützgitter *56,3 cm (90%) Flax without supporting grid*					
	~~6,3 cm (10%) Holz - Schnittholz Nadel, rauh, lufttrocken~~ ~~*6,3 cm (10%) Wood – Sawn pine wood, rough, air dried*~~					
6	Inhomogen (Elemente quer bzw. parallel zur Traufe) *Inhomogeneous (elements measured crossways, parallel to the Roof edge)*	24	0,050	2	43	1380
	56,3 cm (90%) Flachs ohne Stützgitter *56,3 cm (90%) Flax without supporting grid*					
	~~6,3 cm (10%) Holz - Schnittholz Nadel, rauh, technisch getrocken~~ ~~*6,3 cm (10%) Wood – Sawn pine wood, rough, technically dried*~~					
7	OSB-Platte *OSB Panel*	1,8				

8	Inhomogen (Elemente längs bzw. normal zur Traufe) *Inhomogeneous (elements measured perpendicular to the Roof edge)* 56,3 cm (90%) Schafwolle Dämmfilz *56,3 cm (90%) Insulation felt of Sheep wool* ~~6,3 cm (10%) Holz - Schnittholz Nadel, rauh, lufttrocken~~ *~~6,3 cm (10%) Wood – Sawn pine wood, rough, air dried~~*	6	0,04	-	43	960
9	Gipsfaserplatte *Gypsum fiber board*	1,25	0,27	0,046	1200	940
10	Gipsfaserplatte *Gypsum fiber board*	1,25	0,27	0,046	1200	940
	Total **U-value: 0,122 W/(m^2K)**	**56,8**		**8,214**		

1 Baubook http://www.baubook.at/BTR/PHP/Win_E_Ausdruck.php?SBT=56964&SW=5

2 Engineering toolbox http://www.engineeringtoolbox.com

3 ASHRAE 2005 Materials database of EnergyPlus

4 http://www.rfcafe.com/references/general/density-building-materials.htm

~~Crossed~~ crossed out text represents the layers that were ignored while modeling the composite for Allplan

Wall

Table 12 Wall material

Wall	**AWl 01 a Holzständer-Außenwand, hinterlüftet** **AWl 01 a Composite wooden ventilated external wall**	**d[1]** cm	**λ[1]** W/(mK)	**R[1]** $(m^2K)/W$	**Density[2]** kg/m^3	**Specific heat[2,3]** J/(kgK)
1; 2	Gipskartonplatte *Gipsum board*	1.5	0.210	0.071	240	760
3	Inhomogen (Elemente vertikal) *Inhomogeneous (vertical elements)*	10	0.039	2.564	25	920
	56,3 cm (90%) Glaswolle (15 < roh <= 25 kg/m^3) *56,3 cm (90%) Glass wool (15-25 kg/m^3)*					
	~~6,3 cm (10%) Holz - Schnittholz Nadel, rauh, lufttrocken~~ ~~*6,3 cm (10%) Wood – Sawn pine wood, rough, air dried*~~					
4	OSB-Platte OSB Panel	1.8	0.130	0.138	496	190
5	Inhomogen (Elemente horizontal) Inhomogeneous (horizontal elements)	18	0.039	2.564	25	920
	52,2 cm (83%) Glaswolle (15 < roh <= 25 kg/m^3) *52,2 cm (83%) Glass wool (15-25 kg/m^3)*					

	~~10,3 cm (17%) Holz - Schnittholz Nadel, rauh, technisch getrocken~~ *~~10,3 cm (17%) Wood – Sawn pine wood, rough, technically dried~~*					
6	Inhomogen (Elemente vertikal) *Inhomogeneous (Vertical elements)* 56,3 cm (90%) Glaswolle (15 < roh <= 25 kg/m³) *56,3 cm (90%) Glass wool (15-25 kg/m³)* ~~6,3 cm (10%) Holz - Schnittholz Nadel, rauh, technisch getrocken~~ *~~6,3 cm (10%) Wood – Sawn pine wood, rough, technically dried~~*	10	0.039	2.564	25	920
7	~~Windsperre PE, diffusionsoffen (Polyethylenbahn, -folie)~~ *~~Wind barrier PE, permeable (Polyethylene foil)~~*	0.008	0.5	-		
8	Inhomogen (Elemente horizontal) *Inhomogeneous (horizontal elements)* 53,1 cm (85%) Luftschicht stehend, Wärmefluss horizontal *53,1 cm (85%) Air layer, not moving, heat flow horizontal*	5	0,025	1,2	1003,5	1003

	~~9,4 cm (15%) Holz - Schnittholz Nadel, rauh, lufttrocken~~ ~~*9,4 cm (15%) Wood – Sawn pine wood, rough, air dried*~~					
9	Holz - Schnittholz Nadel, gehobelt, technisch getrocknet *Wood – Sawn pine wood, smooted out, technically dried*	2.5	1,2	-	560	2301
	Total **U-value: 0.116 W/(m²K)**	**50.308**				

1 Baubook http://www.baubook.at/BTR/PHP/Win_E_Ausdruck.php?SBT=56964&SW=5

2 Engineering toolbox http://www.engineeringtoolbox.com

3 ASHRAE 2005 Materials database of EnergyPlus

4 http://www.rfcafe.com/references/general/density-building-materials.htm

~~Crossed~~ crossed out text represents the layers that were ignored while modeling the composite for Allplan

Floor

Table 13 Floor material

Floor	**ADh 01 b Massivholzdecke über Außenluft, Nassestrich** ***ADh 01 b Solid wooden floor to outside air with screed***	**d**[1] cm	**λ**[1] W/(mK)	**R**[1] (m²K)/W	**Density**[2] kg/m³	**Specific heat**[2,3] J/(kgK)
1	Massivparkett *Solid parquet*	1	0,15	0,067	552	1420
2	Zementestrich *Cement screed*	5	1,7	0,029	1900	840
3	~~Baupapier~~ ~~*Building paper*~~	0,088	0,17	0,005	-	-
4	Glaswolle (roh > 40 kg/m³) *Glass wool (density >40 kg/m³)*	3	0,04	0,750	32	920

5	Splittschüttung (leicht zementgebunden) *Stone chips filling (lightly cemented together)*	5	0,9	0,056	1900	840
6	~~Dampfbremse PE (Polyethylenbahn, -folie (PE))~~ ~~*Vapour barrier PE (Polyethylene foil)*~~	0,02	0,5	0	-	-
7	Holz - Schnittholz Nadel, rauh, technisch getrocknet *Wood – Sawn pine wood, rough, technically dried*	16	0,12	1,333	560	2301
8; 9	Inhomogen (Elemente längs) *Inhomogeneous (elements lengthwise)* 56,3 cm (90%) Hanfdämmplatte *56,3 cm (90%) Hemp insulation board* ~~6,3 cm (10%) Holz - Schnittholz Nadel, rauh, technisch getrocknet~~ ~~*6,3 cm (10%) Wood – Sawn pine wood, rough, technically dried*~~	16	0,04	4	310	1300
10	~~Windsperre PE, diffusionsoffen (Polyethylenbahn, -folie)~~ ~~*Wind barrier PE, permeable (Polyethylene foil)*~~	0,008	0,5	0	-	-
11	Holz - Schnittholz Nadel, gehobelt, technisch getrockne *Wood – Sawn pine wood, smooted out, technically dried*	2.5	1,2	-	560	2301
	Total **U-value: 0.104 W/(m^{2}K)**	**64.616**				

1 Baubook http://www.baubook.at/BTR/PHP/Win_E_Ausdruck.php?SBT=56964&SW=5

2 Engineering toolbox http://www.engineeringtoolbox.com

3 ASHRAE 2005 Materials database of EnergyPlus

4 http://www.rfcafe.com/references/general/density-building-materials.htm

~~Crossed~~ crossed out text represents the layers that were ignored while modeling the composite for Allplan