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An open BIM workflow for the prediction of sound insulation in timber constructions

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Abstract
Nowadays the field of architecture, engineering and construction (AEC) plays a major factor with respect to the global carbon emissions. Architects and engineers are therefore encouraged to choose alternatives such as sustainable timber constructions. However, this involves challenges compared to concrete or masonry constructions, e.g. there is a lack of a seamless planning process in terms of evaluation tools for this construction method, especially for the prediction of sound insulation. The approach of Building Information Modelling (BIM) enables the integration of model-based evaluations and analysis for a complete prediction of sound insulation directly into the design stage. This paper presents a workflow based on open BIM that uses IFC models as a basis for the prediction of sound insulation. In addition to the geometric representations, the IFC data model stores information about the semantic of the involved construction elements. Those information are used to generate an technical model for acoustic analysis.

Keywords: sound insulation, timber construction, BIM, IFC, early-design.

1 Introduction

The construction industry is one of the world's largest consumers of materials and energy and a significant contributor to CO2 emissions [1]. Timber constructions are a more sustainably alternative, not only regarding their production but also in terms of recycling [2]. Compared to classical well-established concrete or masonry constructions it involves challenges for architects, consultants and manufacturers. To gain from the benefits of timber constructions the design stage is crucial for the success of the project and the satisfaction of the later users. Due to the complexity of the construction components this is the case for sound insulation in particular. To-date, there is a lack of prediction tools that consider the diversity of timber construction. Therefore, the trend towards more digitalisation offers a solution: The access to digital building models during the early-design stage for the prediction of sound insulation provides the opportunity to read out relevant key parameters automatically. This is beneficial for the quality of the prediction and the information management during the planning process.

2 Open BIM with IFC

Building information modelling is a digital working method with different types: While closed BIM approaches work with various software from a single provider, open BIM approaches deal with manufacturer-independent data transfer. This is possible through standardised, manufacturer-neutral formats that can be written and read by any software tools. One of them is the well-known IFC format. It is a standardised data schema developed by buildingSMART for the manufacturer-neutral exchange of digital building models throughout their entire life cycle [3]. It provides the geometric representation of building elements and information on spatial and element structures as well as on component parts and their properties. It forms the basis of all Open BIM approaches. This format is based on STEP (Standard for the Exchange of Product model data), which regulates the exchange of product model data. It uses the EXPRESS notation [4]. There is also an XML notation (ifcXML), describing the same data model, but specified by an XSD data schema.

An IFC data model can handle geometric information of elements as well as semantic information. Figure 1 shows a schematic of an IFC file in an abbreviated form: individual building elements are assigned to their respective floors in the building via *ifcBuilingStoreys*. For this purpose, relations (*ifcRelAggregates* and *ifcRelContainedInSpatialStructure*) are used. The information about the geometry is stored in entities that are subordinate to *ifcProductDefinitionShape*. The position of the elements is defined by a local placement relative to the coordinate systems of a project base point and can also be found in the IFC file (*ifcLocalPlacement*). Information about the material is linked to the component via the relation *ifcRelAssociatesMaterial*. The individual layers are enumerated step by step in their entities with the layer thickness in *ifcMaterialLayer* and the material itself in *ifcMaterial*. The entity *IfcMaterialLayerSet* groups several layers together and thus, describes for example, the component structure of an exterior wall. Component openings for windows and doors are assigned to the component via the relation *ifcRelVoidsElement* and the door or window elements are then located in these openings.

Various properties such as the U-value or the fire protection class of the building element can be assigned to building elements using property sets. The relation *ifcRelAssignsProperty* connects the building element with its properties. The association of properties to building elements can be extended and utilized freely for the user defined applications. The workflow presented here makes use of this important fact.

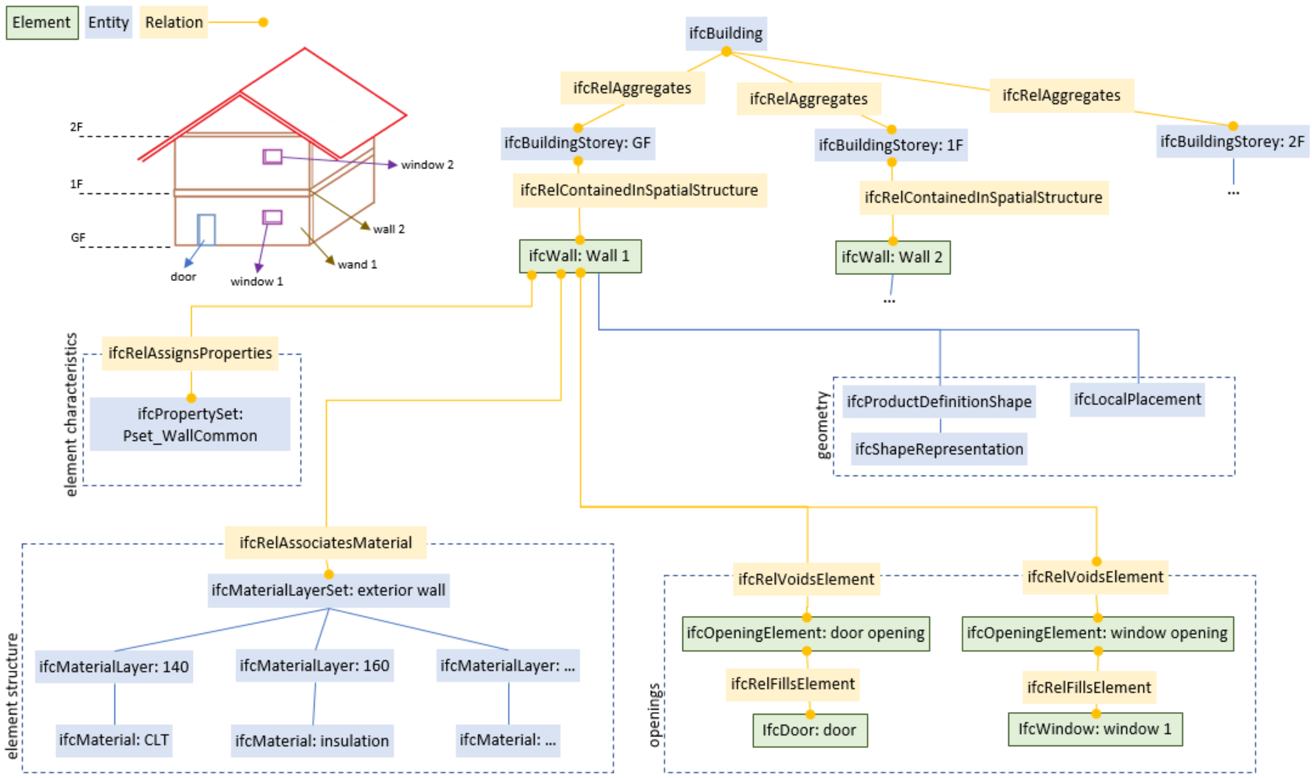

Figure 1– Schematic structure of an IFC file (shortened and simplified)

3 Building physics within the BIM workflow

Embedding building physics planning in a mature BIM workflow brings benefits for all project participants, especially in the early-design stage. A BIM coordinator usually manages the coordination model for architects and principal planners. Individual specialized planning departments work typically with technical models that are adapted to the respective planning task and prerequisites of the software tools used in the individual planning tasks. These technical models are read and evaluated by the planning software. Engineers can automatically query databases, perform calculations and add missing information to the model. The results are then reported back to the architect or planner, who enters them into the global coordination model after approval.
The advantage of this workflow is the high efficiency due to the automated transfer of data. Thanks to the standardisation of the IFC standard, databases and software tools can read and write data sets for elements or properties. Large building models can thus be analysed efficiently using rule-based model checks. In addition, every building element has a unique ID, in both the coordination model and the technical model, so that changes are identifiable.
Figure 2 shows the workflow for the specific field of building acoustics. The modelling software exports an IFC data model that is transformed to a technical model for acoustic analysis in the next step. VBAcoustic and VaBDat are in-house software solutions developed by TH Rosenheim specialized on sound insulation for timber constructions With information from the exported IFC data model the software tool VBAcoustic calculates the apparent sound insulation and apparent normalized impact sound level based on the building elements using databases like VaBDat or values form regulation and guidelines. After calculation the results are evaluated against the requirements to assess if changes are required in the model.

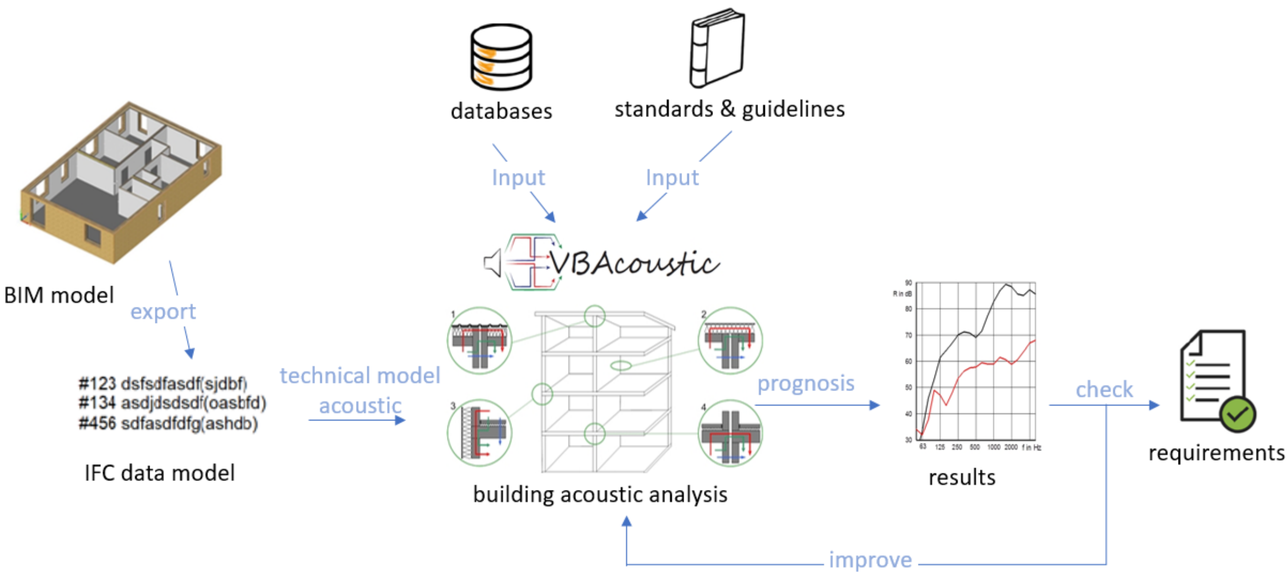

Figure 2 – Overview of the planning process for building acoustics using VBAcoustic for the prediction of the apparent sound insulation and the apparent normalized impact sound level

4 Sound insulation in timber construction

Concerning sound insulation, timber construction has some unique features: the elements are lighter compared to concrete construction and most masonry constructions, and the design of junction details differs. As a result, sound transmission via the flanking elements potentially plays an essential role. Nevertheless for CLT elements the prediction of sound insulation is the same as for solid construction according to DIN EN ISO 12354 [5].

In addition to the direct transmission across the separating element, the transmission via the secondary sound paths is considered. For this purpose, the flanking sound reduction index R_{ij} from DIN EN ISO 12354 and formulated below, is used:

$$R_{ij} = \frac{R_i + R_j}{2} + \Delta R_i + \Delta R_j + K_{ij} - 10lg\frac{l_{ij}}{\sqrt{a_i \cdot a_j}} + 10lg\frac{S_S}{\sqrt{S_i \cdot S_j}} \tag{1}$$

With

R_i, R_j	sound reduction index of elements i or j in dB
S_S	area of separating element in m²
S_i, S_j	area of flanking element i or j in m²
$\Delta R_i, \Delta R_j$	sound reduction improvement index for element i or j for resilient wall skin, suspended ceiling or floating floor in dB
l_{ij}	common length of elements i and j in m
a_i, a_j	equivalent absorption length of an element i or j in m
K_{ij}	vibration reduction index for transmission path i-j in dB

Depending on the geometric configuration, there are 2, 3 or 4 possible sound transmission paths. To name the different paths the letter *d* and *f* are used in lower and upper case. The upper case shows that the element is in the sending room, while the lower case describes an element in the receiving room. The separating element gets the letter *d* and flanking elements the letter *f*. There are mixed transmission paths Df and Fd for partition walls and the flanking transmission Ff. For partition floors, there is the path Df for impact sound transmission and particularly in timber construction the path DFf, which describes the influence of the floating screed on the upper flanking wall. Figure 3 illustrates the different transmission paths.
The various possibilities to form a junction in timber construction are illustrated in Figure 5. These junction types define the values of the vibration reduction index on each transmission path.

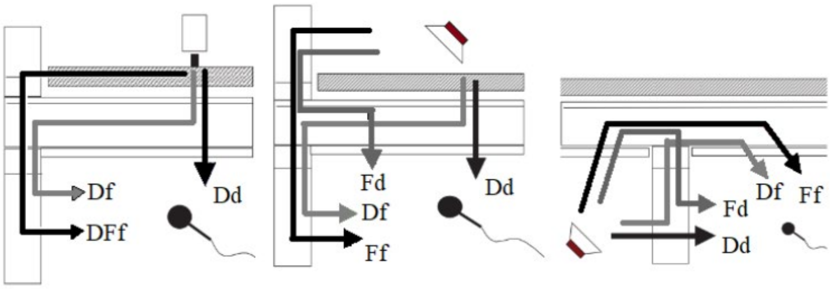

Figure 3 – Sound transmission paths with the paths Ff, Df, Fd and DFf for the impact sound transmission of a ceiling (left), sound insulation of a ceiling (middle) and sound insulation of a wall (right) [6]

5 Sound insulation prediction with IFC

5.1 Sound reduction index of elements

As shown before, implementing the prediction of sound insulation into a BIM workflow in the early-design stage would considerably help the engineer speeding up his calculation and thus, providing the planning team with robust insights in acoustic properties of the construction in the early-design stage. However, engineers can only use the advantages of a digital building model if the necessary data is contained in the model and can be retrieved by the automated algorithms. This is true in particular for the early design evaluation of sound insulation qualities of timber junction details. Since these construction details are typically designed much later in the planning process, our workflow aims for the integration of known or reasonable data for sound reduction indices R_{ij} for given junction details into the early design stage as well as the smooth controlling and modification of those assumed sound insulation properties throughout the planning process with the help of BIM.

Therefore, a team at Rosenheim's Technical University of Applied Science (TH Rosenheim) works on the implementation of the prediction of the sound insulation in the planning process with an open BIM approach [7]. The building model used is an IFC data model with a level of detail that contains building components in their correct position and their component structure (LOD 300, see Figure 4). This level of detail is required as minimum in the acoustic model. For example, the building element layers must be available in the semantic (*ifcMaterialLayer*) to find the correct sound reduction index or impact sound level of the element. Here, consistency with the names of material layers is a big challenge but compulsory to effectively use databases providing additional properties for sound insulation prediction tools. The values for the sound insulation of the individual elements are retrieved from such manufacturer specifications or databases. An example is the database VaBDat that provides one-third-octave-band data for the sound insulation and impact sound levels of building elements, in particular timber elements. In addition, the vibration reduction indexes of junctions are provided for various junction situations. The data provided in the database comes from research projects and manufacturer information.

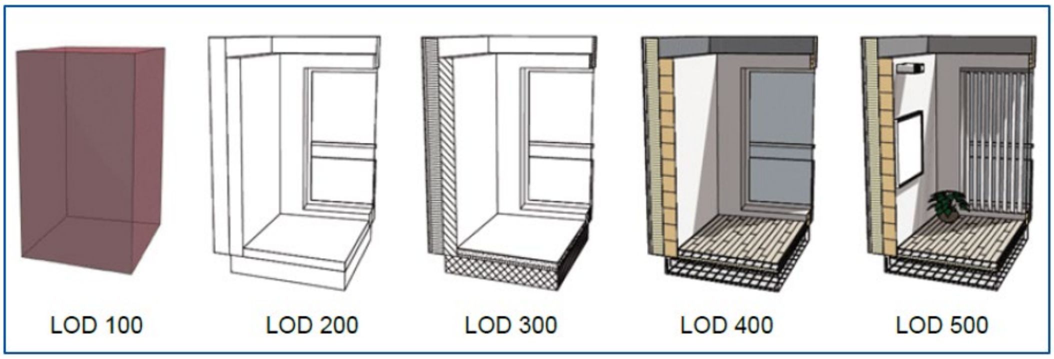

Figure 4 – Example of different Level of Detail in the IFC data model [8]

5.2 Junctions and junction types

Another challenge that is specific to the building acoustics of timber construction is the identification and functional classification of junctions. Here, in addition to the flanking elements, the junction type is required as it is shown in Figure 5). [9] defines and categorizes different junction types to be able to query database or calculate the correct vibration reduction index.

In this early-design stage the IFC data model should include the correct geometry and material layers of the building elements. But connection relations are often not included properly. Additionally, the IFC schema does not provide detailed information on the junction, as required in timber construction and in the categorization, at least not in early design stages and in many cases not at all. Therefore, the IFC data model is analysed for the prediction of sound insulation before the prediction of sound insulation is performed. By filtering the model in several steps with semantic information and with geometric rule sets, we determine the flanking elements for the selected separating element. Subsequently, the exact geometry of all elements in the junction is considered to choose the correct junction type to calculate the vibration reduction index and define the transmission paths.

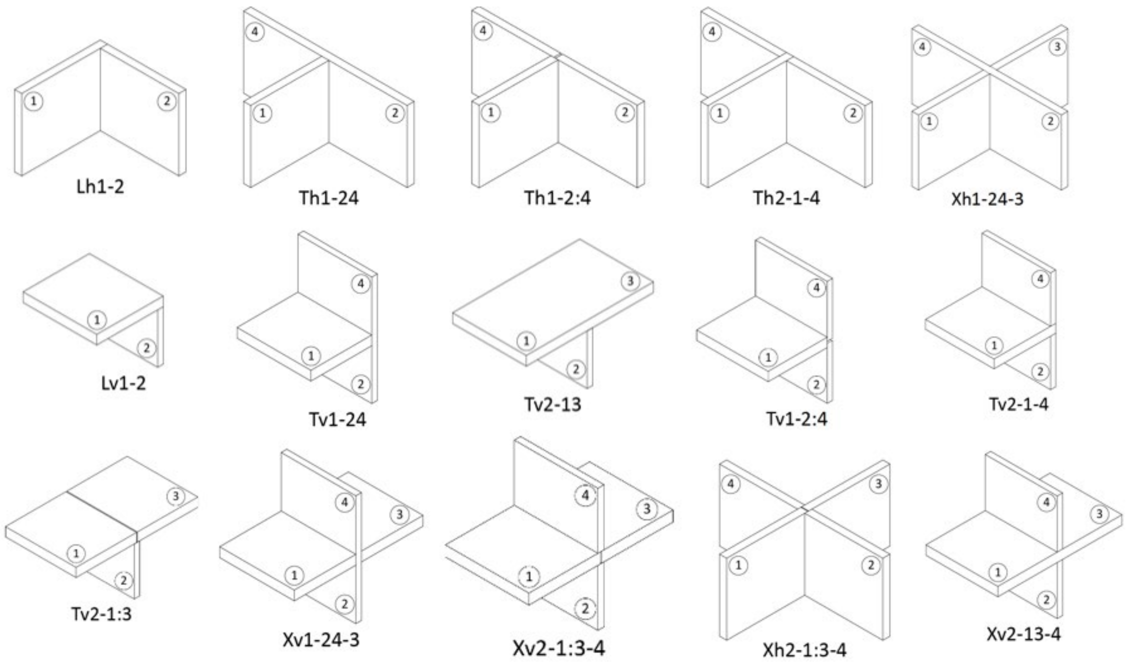

Figure 5 – Types of junctions between building elements relevant for sound insulation according to [9]

5.3 Prediction with VBAcoustic

With the Excel-based tool VBAcoustic, it is possible to calculate the apparent sound insulation or apparent normalized impact sound level according to [5] and [10] in one-third-octave-bands. The database VaBDat is directly coupled with VBAcoustics and ready to provide the sound reduction indexes of elements and the vibration reduction indexes of junctions. If data is not available, the elements can be picked from a catalogue of known or measured configurations, provided by the TH Rosenheim. VBAcoustic also allows to manually insert one-third-octave-band values from other sources.

5.4 Technical model for acoustic analysis

After the analysis of the IFC data model the necessary information about the elements and their junctions is available. This data can be stored in a specific technical model that allows further calculations if needed. The technical model for acoustics analysis already contains all relevant information to predict the sound insulation for the building. It includes the component dimensions, the junction lengths and the exact layer composition of the elements. It also includes relevant junction types as far as this is possible according to the IFC schema. For the acoustic analysis elements are often separated into three layers: the core layer has a sound reduction index R and covering layers or suspended ceilings sound reduction improvement index ΔR or ΔL_n. Also, the junction types only depend on the core layer. This idea can be reproduced in the technical model: A specific representation context (*IfcGeometricRepresentationSubContext*) with this information can handle this additional information. Therefore, the elements are divided into three layers: a core layer with the load-bearing element and two outer layers. The core layer is mandatory, whereas the two outer layers are optional. For walls, these outer layers are, for example, the facade cladding and the thermal insulation composite system. On the inside, this layer often consists of the facing shell. For separating floors or roofs, the load-bearing layer also includes the weighting. The floor structure from the impact sound insulation onwards is already the outer layer. All parts of a suspended ceiling are part of the inner layer. Figure 6 shows this classification using three building components as examples. As can be seen in Figure 7, the load-bearing core layer is relevant for determining the junction types.

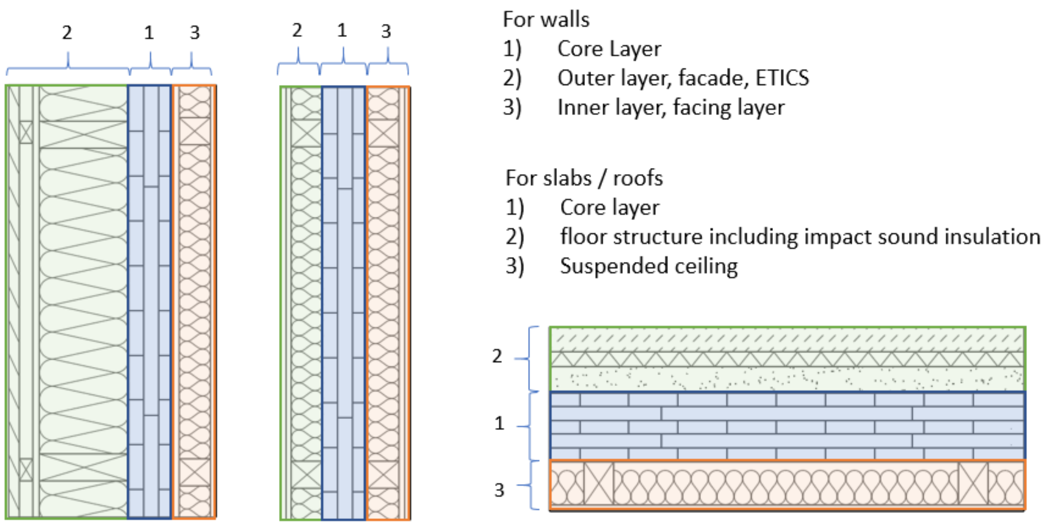

Figure 6 – Example of the inner layer, core layer and outer layer for different elements

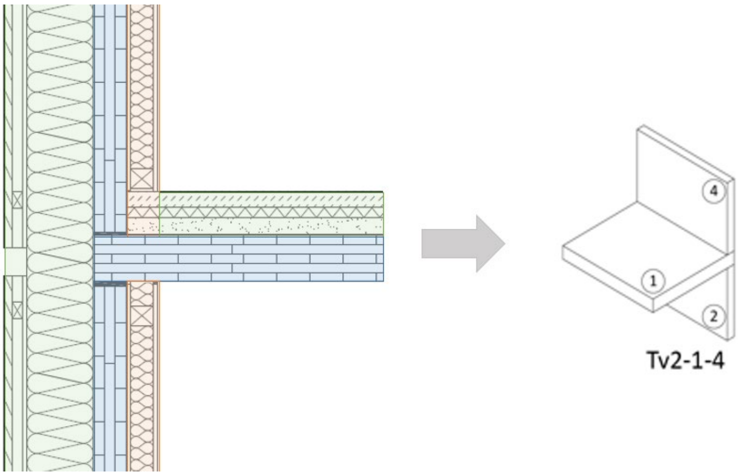

Figure 7 – Example of a junction detail for cross laminated timber elements with a slab and two walls as flanking elements: the core layer determines the junction type Tv2-1-4

5.5 Use Case

In [7] the method to determine the junction type is explained in more detail. A prototype was developed as a .NET framework with help of xbim Toolkit[1] to analyse IFC data models as described before. The use of commercial BIM modellers like Autodesk Revit in combination with open BIM formats was done, to represent a typical workflow in the current daily planning processes. Therefore, the use case building was modelled in Autodesk Revit and exported into IFC4. This IFC data model was then analysed to determine the junctions of a separating wall element. Figure 8 shows the real-world model with multiple storeys. This models is a testing model focussing on walls and slabs to provide the algorithms with all the relevant junction types as described above in a real-world modelling environment. The marked wall is chosen as separating element. Four junctions with two different junction types are successfully recognized with the prototype.

[1] https://docs.xbim.net/

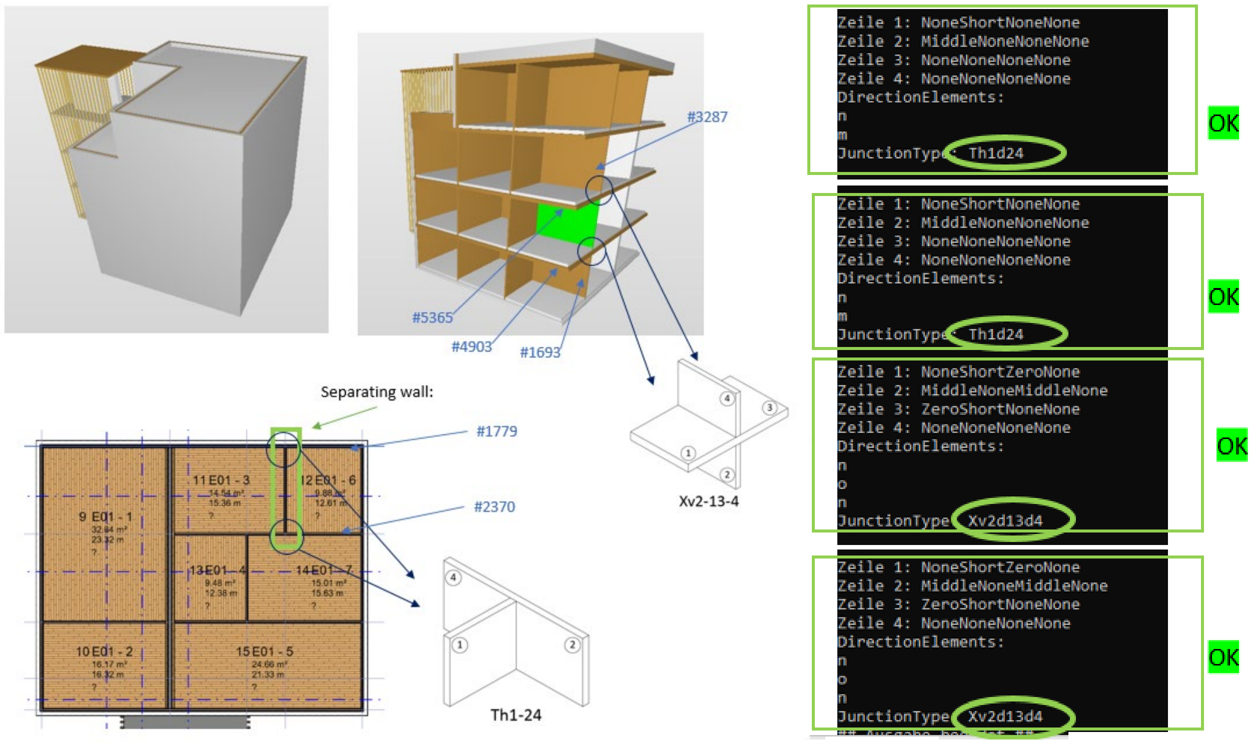

Figure 8 – Use case building with *ifcWall* as separating element and different flanking elements. The results for the junction types determined are displayed on the right-hand side in the console output.

6 Conclusion and future work

The planning of sound insulation is a significant challenge in the design of timber buildings. Many details have to be taken into account for the application in calculation methods, resulting in many different possible input data. So far, there are no suitable software tools that generate the correct input data from BIM models. For this reason, a research project is underway at the TH Rosenheim with the aims to fill this gap. It uses an Open BIM planning process and an IFC data model. Through the conversion into a technical model for building acoustic, components and element junctions can be analysed and interpreted for acoustic analysis. The future work consists of reintegrating the new information about the junction type into the technical data model. This approach helps to save the data for parameter analysis in the early-design stage when the most critical decisions about element types and construction details are made.

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