

BIM BASED HYGTROTHERMAL MODELLING OF BUILDING CONSTRUCTIONS

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ABSTRACT. The construction industry is currently one of the least digitised. However, due to recent technological developments, building information modelling and management (BIM) systems are increasingly being used to increase the efficiency of constructions and sustainable use of resources and increase the energy efficiency of buildings. In the case of new constructions or building renovations, properly designed hygrothermal behaviour of building materials, elements and structures are unavoidable to achieve the objectives mentioned above. Therefore, we can ensure the comfort of our users and healthy living space. BIM is the most suitable and widespread method for digital management of building stock and related data and integration. With the possibilities offered by BIM, it is possible to integrate building physical modelling right into the architectural design process. However, with standard BIM systems, we cannot embed detailed material properties, weather, or the effects of the natural and built environment in the BIM model for heat and moisture transfer (HAM) modelling for hygrothermal performance evaluation at present. Furthermore, the data exchange process is one-way mainly and unregulated between BIM and numerical simulation tools. In the presented paper, both a Closed BIM and an Open BIM based workflow are presented to bridge the gap between BIM and hygrothermal modelling of building components and constructions, that can contribute to the design of sustainable, economic and hygrothermal optimal building constructions and also could be a basis for artificial intelligence-based optimised design solutions.

KEYWORDS: Building information modelling, heat and moisture transfer, numerical simulation.

1. INTRODUCTION

The construction industry is currently one of the least digitised and among the most fragmented. However, due to recent technological developments, building information modelling and management (BIM) systems are increasingly being used to increase the efficiency of constructions and sustainable use of resources and increase the energy efficiency of buildings. BIM is the most suitable and widespread method for the digital management of building stock. The fragmentation of the AEC industry [1] is present in the building physics focused area as well. Many disciplines should work together until a hygrothermally sound structure is designed. In the case of new constructions or building renovations, properly designed hygrothermal behaviour of building materials, elements, and structures are unavoidable in order to achieve the aforementioned objectives. Therefore, we can ensure the comfort of our users and healthy living space.

With BIM's potential, it is possible to integrate building physical modelling right into the architectural design process. Though BIM has different flavours, national regulations and software developers shape what it means to work with this methodology. Using standard BIM systems, we usually cannot embed material properties, weather, or the effects of the natural and built environment in the BIM model for heat and moisture transfer (HAM) modelling for hygrothermal

performance evaluation at present. Furthermore, the data exchange process is one-way mainly and unregulated between BIM and simulation tools. Even with today's available BIM systems, performing a HAM simulation is usually a struggle because the software developers present no clear workflow.

The possibility of creating multidimensional simulations by using commercial software started in 2000 when the Fraunhofer Institute presented WUFI 2D [2]. In 2013, they demonstrated the potential of coupling multidimensional thermal bridge simulation with a whole building simulation model in 3D [3]. The use of Comsol to model the hygrothermal behaviour of building constructions is even more modest than 2D or 3D WUFI. Simplified building constructions demonstrate this software's capabilities [4, 5]. A few papers deal with simulations of wall and slab connections in 2D [6] or hygrothermal modelling of external wall and window joints [7], or in 3D with different concrete structures to examine the effect of different materials or inhomogeneity [8, 9].

BIM can be classified into Open BIM and Closed BIM, based on the availability of the file format structure it is using. Today, Industry Foundation Classes (IFC) is the commonly accepted semantic standard to describe building-related data. It is generally supported in the AEC industry. However, the framework necessary to run hygrothermal simulations does not

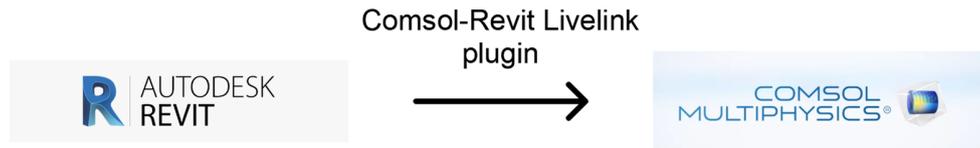


FIGURE 1. Closed BIM workflow based on Revit.



FIGURE 2. Open BIM workflow based on Archicad.

entirely fall into this industry, which means IFC's support is weak. It is an open, international standard [10]. It promotes vendor-neutral, or agnostic, and functional capabilities across a wide range of hardware devices, software platforms, and interfaces for many different use cases [11], offering the possibility to develop an interconnected, accessible data flow among the built assets entire life cycle. Buildings can last for centuries; we do not have enough evidence for the longevity of digital data at this point for a time frame this long.

In our research, we created and tested an Open BIM- and a Closed BIM-based workflow for creating HAM simulations to model, evaluate or optimise the hygrothermal performance of building constructions during the integrated design process. Then, we made a comparative assessment between the two possible workflows and summarised the possibilities and limitations of the different approaches.

2. METHODOLOGY

We chose Comsol Multiphysics to run the HAM simulations because it is validated according to EN 15026:2007 Annex A [12] and showed promising results according to other benchmarks, including Hamstad [13]. The workflows for Closed BIM and Open BIM differ for various reasons.

For the Closed BIM workflow solution, we used Revit 2021 for BIM and Comsol 5.6 for numerical simulation to link the BIM model into the Multiphysics environment, as the schematic workflow shows in Figure 1. A Livelihood solution for Revit made the initial geometry and material setup relatively easy in Comsol, especially if we consider some techniques not included in the manuals but will be introduced in the present paper later.

For the Open BIM workflow solution, we used Archicad 24 as the BIM platform. Since there is no standard format between Archicad and Comsol that is reliable enough to transfer geometry, we used Rhino as an interim step to organise and clean the model. Unfortunately, the IFC format cannot be imported

into Comsol directly; this is why we needed this step. We used the GeometryGym IFC add-on to import the geometry to Rhino, as shown in Figure 2, respectively.

An externally insulated wall corner joint consisting of solid masonry blocks and a mineral wool-based external thermal insulation composite system (ETICS) is considered for testing the workflows.

3. NUMERICAL SIMULATIONS FROM CLOSED BIM: REVIT-COMSOL LIVELINK

Revit is one of the most widespread in the international BIM software landscape. Therefore, a transparent workflow to perform HAM simulations from Revit models is probably needed for professionals. Comsol is a multiphysical finite element-based engine that lets users examine coupled phenomena, such as conjugated heat and moisture transfer in structures or building materials. The Comsol-Revit Livelihood is a proprietary software solution to bridge the gap between BIM and numerical simulation. As such, it is a black box with a bit of hard-to-understand operation.

3.1. GEOMETRY IMPORT

The primary options for sending the BIM elements are based on spaces or 3D views. For our purposes, the latter proved to be more useful: most of the time, it is sufficient to have only a portion of the structure modelled to run the simulation; we are focusing on this scenario. 3D views can use view templates, so hiding excessive geometry by type and instance is a semi-automatic workflow. Certain geometry types, like planes, are not needed in the numerical model, and cleaning is possible in Comsol, but it is worth avoiding the issues. It is essential to set the "Parts visibility" in Revit to "Show parts" only in the 3D view used to synchronise the BIM model to Comsol to ensure that all set layers are visible in Comsol. This way, building materials are transferred to each layer accordingly (see Figure 3).

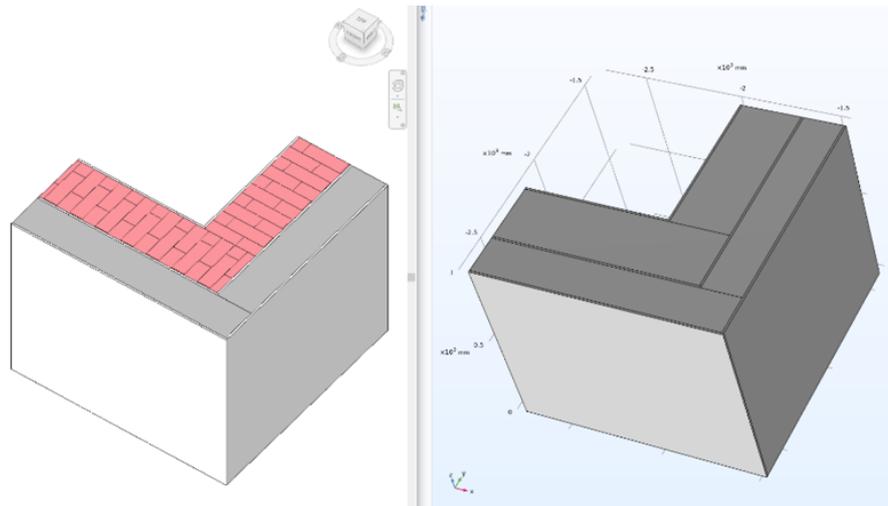


FIGURE 3. The model from Revit 2021 (left) imported to Comsol 5.6 (right).

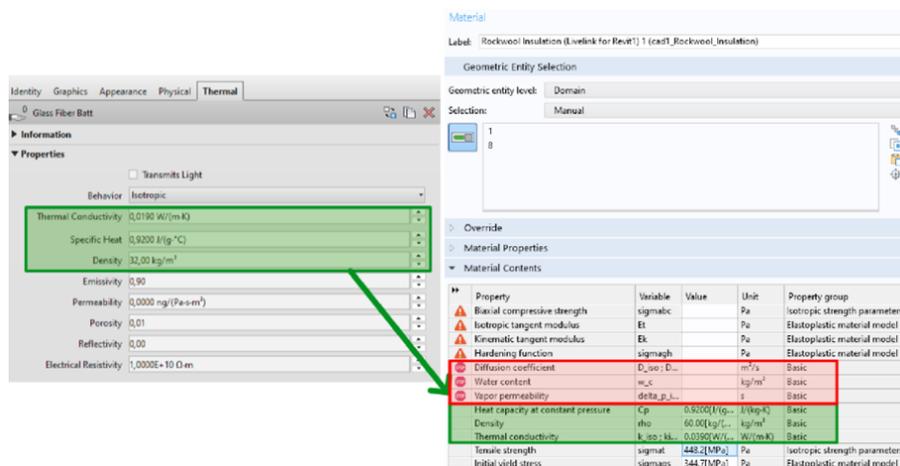


FIGURE 4. Building material properties transferred from Revit to Comsol.

Using virtual operations on the imported geometry based on BIM is possible in Comsol. It could be useful to handle modelling issues on the geometry, especially to form composite faces or domains from separated materials to improve the meshing performance or ignore vertices, faces or domains that are not needed for the HAM simulation, e.g. thin layers that can be handled as surface resistances.

3.2. BUILDING MATERIALS

We tested various scenarios of how the Livelink can be established: the model needs to be created from native Revit elements (walls, slabs, roofs, etc.), imported geometry is not supported as of writing this paper. Using these elements allows us to assign building materials to each geometry. Building materials can be managed in the Material Browser. The necessary building physics parameters are listed in the “Thermal” tab: thermal conductivity, specific heat, and density. Vapour permeability or vapour resistance factor, as well as liquid transport coefficient (or as it is called in Comsol “Diffusion coefficient”) and moisture storage function (“Water content” in Comsol) that necessary

for moisture transport calculations, cannot be added to the materials in Revit. There is an option to sync only the geometry without explicitly syncing material data. The Comsol Geometry import workflow has the Livelink for Revit, which can be used instead of manually importing from CAD formats (STEP provides a stable workflow that can be exported from Revit natively). Parts should be created in Revit before synchronising the selected view to access each wall layer and its properties.

The Livelink process transfers the material properties, and domain selections are created according to parts and materials, which speeds up the preprocessing stage of the simulation work. Boundary conditions are not yet stored in the Revit model at an element level. The parameters required to run a hygrothermal evaluation are not present in the Revit model. They cannot be passed (Figure 4); therefore, we extended them from [14] to be able to perform the HAM simulation.

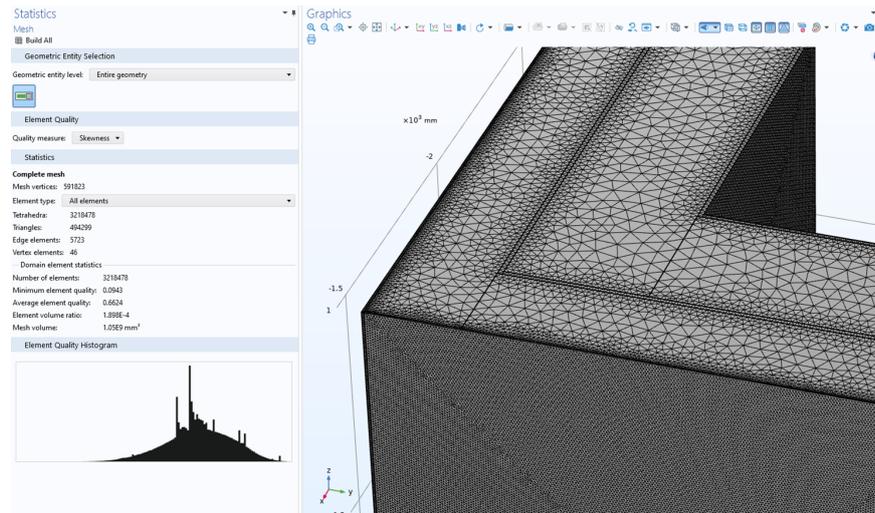


FIGURE 5. Meshed element originated from BIM.

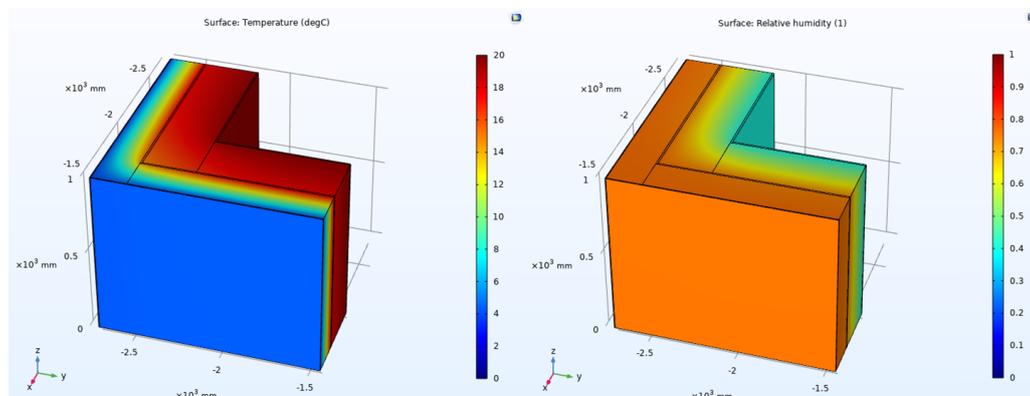


FIGURE 6. Temperature distribution (left) and relative humidity distribution (right) from HAM simulation based on BIM model.

3.3. BOUNDARY CONDITIONS

Rooms/Zones and analytical spaces can be present in the model, and the Comsol Livelink sync now works with Revit Rooms. These are abstract, non-existent elements; BIM uses them to specify how space is occupied: hourly schedules often describe the loads, lighting requirements, occupant number, required internal temperature or relative humidity. It could allow the generation of boundary conditions for the internal surfaces of the numerical model. As the model is referenced to real-world coordinates, solar radiation could be added to the external boundary conditions apart from external temperature and relative humidity. Small scale models often do not include broader context, but at a façade- or whole building level, numerical simulation shading from neighbouring buildings is an important aspect of the design. During our study, boundary conditions were added according to [12, 14] in Comsol as heat flux and moisture flux boundary conditions.

3.4. MESHING

The tested insulated wall corner joint has meshed in Comsol after the import. The model is meshed using

a physics-controlled meshing sequence and extra-fine element size in the software that gave us an average element quality of skewness of 0.6627 without errors and warnings (Figure 5). The different thicknesses of the layers in the model affect the built-in meshing functions since there are considerably significant differences between the thicknesses of the domains included in the model. The element quality can be improved with manual mesh refinement, solution-based adaptive meshing, or previously mentioned virtual operations.

3.5. PHYSICS AND RESULTS

We set the physics in Comsol 5.6 to Heat and Moisture Transport in Building Materials, which models the HAM transfer according to [12]. A stationary solver was deployed for the coupled equations, geometric multigrid for the moisture and smoothed aggregation geometric multigrid for heat transfer. The results using the extended material properties and boundary conditions are shown in Figure 6. Since we put mineral wool thermal insulation on our masonry wall, the relative humidity distribution is high since it lets the vapour through. Besides analysing temperature and relative humidity distribution, HAM analysis also

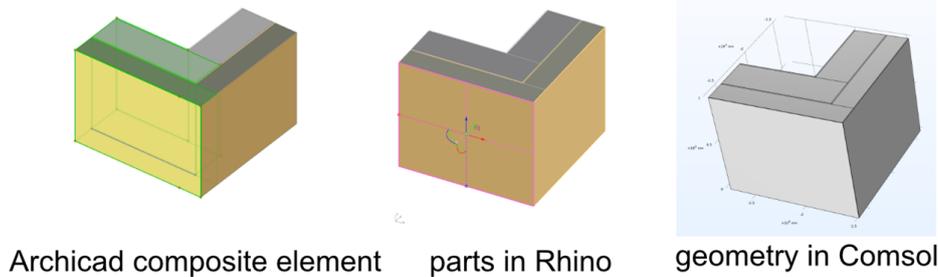


FIGURE 7. Stages of model conversion from Archicad to Comsol.

allows us to check the temperature factor at internal surface points or evaluate the thermal transmittance and the moisture transmittance of building components. The structure's heat flux or moisture fluxes can also be visualised for surfaces, domains and sections, respectively.

4. NUMERICAL SIMULATION WITH OPEN BIM: ARCHICAD-COMSOL

Relying on open standards provides accessibility to and control over simulations' input and output data. Finding errors or workflow issues is easier if we can track the path of each piece of information stored initially in the model. In BIM, the only widespread open standard for comprehensive communication of stored data is IFC. IFC is an international semantic standard maintained by BuildingSMART, with extensive technical specifications covering the materials' necessary building physics properties.

4.1. GEOMETRY

As there is no direct support for neither Archicad's proprietary data model nor the openly available IFC format, the Open BIM workflow is more complicated because we need an intermediary step to convert the geometry into formats that the chosen Multiphysics platform (Comsol) can handle. For this reason, we decided to choose Rhinoceros 7 because the STEP export from it towards Comsol proved to be robust, and it has an extensive ecosystem to extend its capabilities. There are published examples of the Rhino to Comsol workflow previously used for building envelope analysis [15].

The GeometryGym addon lets users import and manipulate the IFC files to Rhino, then export it as STEP towards Comsol. The problem is that although material level data can be stored (even extended) in Archicad and Rhino can display it; we couldn't find a way to attach non-geometric information to the STEP geometry apart from layer information (Figure 7). Unfortunately, building material properties are lost at the export stage from Rhino to Comsol. In order to get accurate representation, it is advised to export the geometry as non-parametric BREP objects, exploding composite structures to their layers in the

IFC Translation settings to ensure that everything is correct. With parametric export, the pipeline can suffer down the line, as the import capabilities of other applications are externalities from the initial export's perspective.

4.2. BUILDING MATERIALS

This means that setting up all the properties in Archicad for the sake of hygrothermal evaluation is not feasible (for quantity take-offs, mass calculation, custom GDL scripting they are useful to include, as the REQUEST command can be used to obtain building physics parameters and do calculations in a custom library part). With recent releases, it is possible to assign custom physical properties to building materials, but they are constant values only, as the default Physical properties (Figure 8). These values are exported in the IFC file, but we did not take care of it since they cannot be used for the last step of the conversion process.

Material parameters need to be done from scratch in Comsol, which isn't much work. The problem occurs when we need to assign materials to the objects (this process is automatic with the help of the Livelink), it is dependent on the Import workflow how selections are stored. Colours and layers are the only attributes that can be converted to domain selections.

4.3. MESHING, PHYSICS AND RESULTS

These processes are exactly the same and should be handled as introduced in Sections 3.3, 3.4 and 3.5, respectively. Since the geometry, mesh, and boundary conditions are the same as described in the Closed BIM process, and simulation results are also the same.

5. CONCLUSIONS

In general, it can be stated that there isn't a satisfying workflow present in the current market. Neither Closed BIM nor Open BIM solutions can provide the necessary granularity in building physics characteristics that we would require and are still far from the detailed HAM modelling possible in Comsol [14]. However, we succeeded and performed simple HAM simulations based on BIM models both from Closed BIM and Open BIM processes. The conclusions are summarised in Table 1.

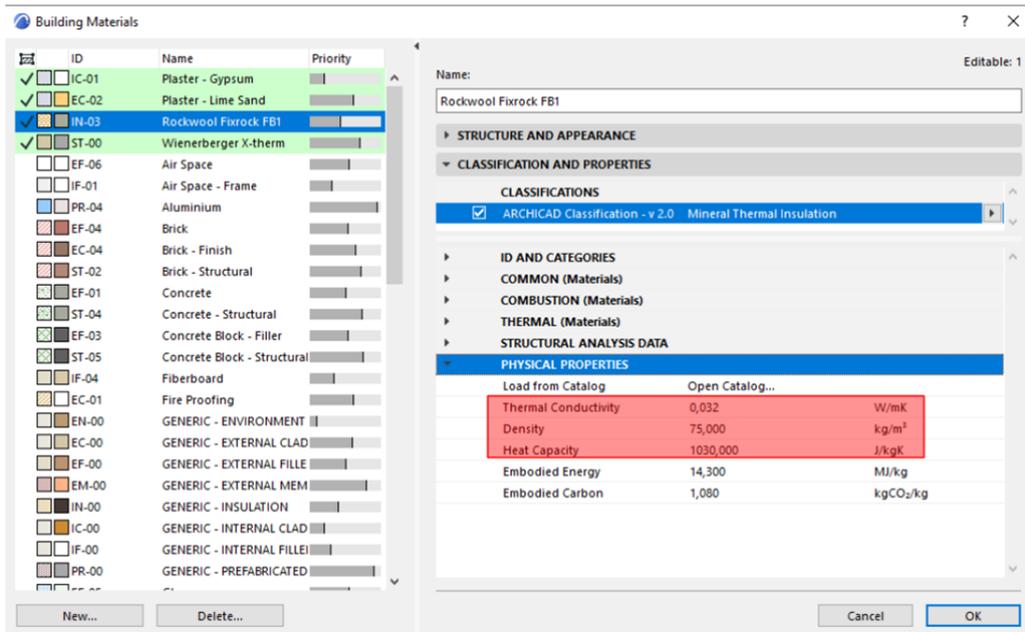


FIGURE 8. Building material catalogue in ArchiCAD with the default available physical parameters.

Process	Closed BIM-based HAM	Open BIM based HAM
Passing geometry from BIM to HAM		No loss of detail
Passing building physics parameters from BIM to HAM	Limited, depending on the input data. With simpler geometry and parts created, lossless connection	No interface is provided for IFC from HAM, although it is a STEP based file format
Creating domains for faster HAM model preprocessing	Part- and material based selections help the work	Layer or colour based indirect sorting is possible
Boundary conditions		No interface is provided as of now; manual work needed
Meshing	Input can be meshed without errors, if sufficiently clean	
Feedback to BIM from HAM	Early-stage development for massing – geometry control	Not implemented

TABLE 1. Summary of the possibilities with BIM to HAM workflows.

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