Journal of Physics: Conference Series

PAPER • OPEN ACCESS

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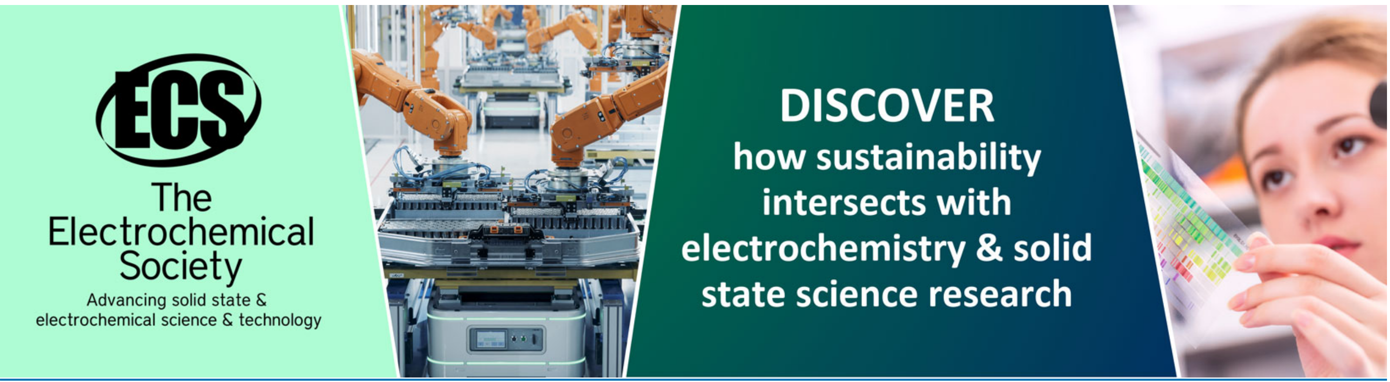
To cite this article: N D Svane *et al* 2021 *J. Phys.: Conf. Ser.* **2069** 012135



Semi-automatic geometry modelling: faster and streamlined building simulation models

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Abstract. The architecture, engineering, and construction (AEC) industry experiences a growing need for building performance simulations (BPS) as facilitators in the design process. However, inconsistent modelling practice and varying quality of export/import functions entail error-prone interoperability with IFC and gbXML data formats. Consequently, repeated manual modelling is still necessary. This paper presents a coupling module enabling a semi-automated extract of geometry data from the BIM software Revit and a further translation to a BPS input file using Revit Application Programming Interface (API) and visual programming in Dynamo. The module is tested with three test cases which shows promising results for fast and structured semi-automatic geometry modelling designed to fit today's practice.

1. Introduction

The use of simulations to support the design of buildings has taken on increased importance. Yet, it has not reached its full potential in the design process because of the immense effort to prepare a simulation run concerning the modelling of building geometry [1, 2] and setup of systems [3]. To expand the possibilities in simulation design, a rapid and accurate transfer of relevant data from the design model to the simulation software is essential. Today, there are generally three approaches to data transfer from design to BPS tool; full-automatic transfer, manual transfer, or a combination of the two, in the following referred to as semi-automatic transfer [4].

The fully automated transfer requires an interface that understands the data structure of both the design tool and the simulation tool and can translate the source information into the rules and syntax of the simulation tool [1]. Ideally, as a combined model that can manage both the modelling and the performance simulations with result visualisation in the model after each run. However, the main weakness of this approach is the constraint to that particular software for all involved parties [5].

Another form of an anticipated full-automatic transfer is a data format that facilitates interoperability between software platforms. BuildingSMART has developed the International Foundation Classes (IFC) to support the three-dimensional definition of building geometry and allows for direct import into BPS tools that have implemented IFC model export/import. Unfortunately, many studies show that generic information exchange, e.g., with the use of IFC or gbXML, is inadequate and error-prone, causing geometric misinterpretations and data loss. These inaccuracies are, in many cases, due to inconsistency in the practice of modelling the design model [6, 7, 8] and the quality of IFC export/import converters [9, 10]. Modelling consistency is essential when having the intention of a complete automatic transfer [11], though it is necessary to bear in mind that the primary purpose of the architect design model is to unify the design wishes of the building owner, aesthetic considerations, and spatial experiences and not to comply with different BPS tools. Moreover, the simplifications and assumptions required to run a BPS model make it challenging to convert an IFC file to an operational BPS file.

In sharp contrast to the fully automatic transfer stands the manual transfer, which still is a highly prevalent method in the AEC industry [4]. The process consists of a manual transformation of design tool information to the data required by the different simulation software. Commonly, several parallel programs are necessary to assess the many criteria for energy consumption, thermal comfort, air quality, daylight, acoustics, etc. Typically, various professionals perform the modelling work and analyses. Consequently, the interpretation of the BIM model depends on the intended analysis as well as the modeller. This time-consuming, manual modelling and simulation must recur when the architect model is updated, which habitually happens several times in each design phase and at phase shifts. Apart from being time-consuming, the manual preparation of BPS suboptimally exploits the specialist skills and comes with a high risk of errors difficult to detect [3].

The idea of a semi-automatic approach, a combination of automatic and manual processes, is known in Academia but has not yet found its proper place in the industry. Several of the described semi-automatic approaches concerns a conversion, checking, and enrichment of the IFC file [7, 12]. But again, this approach is limited to IFC-compatible software and the build-in IFC conversion tools.

In a recent study, the most suitable method for automated geometry extract to the Danish Building Code Compliance Check Be10 (now Be18) has been analysed. The research involves comparing three processes; export to IFC, export to gbXML, and Revit API. The overall study goal is to achieve a 100% correct geometry extract according to the Danish Building code. Both the IFC extract and the Revit API methods show reliable geometry extract, yet, due to the advantages of bi-directional communication and the possibility of implementation directly in the Revit interface, the Revit API method is found to have the most definite potential [13]. Similarly, another research development involves linking the Revit API to the software ICEbear and Be15 (now Be18) [14]. This method is user-friendly and reliable. However, the ICEbear software is based on a simplified program algorithm, for which reason full remodelling may be necessary when the design detail level evolves.

Common to these studies and the present study is the intention to create an efficient connection between a design and a simulation tool for individual purposes, contrasting the use of a generic model transfer, such as IFC, encompassing required information for all purposes.

1.1. Background for current research

The overall goal of the current research project is a transition in the use of BPS in the design process. In place of using building simulations to document that the design complies with the requirements, the simulations should be used proactively as a means to find the most sustainable building and system design. This transition is twofold and involves a module for pre-architectural design and a module for after-architectural design.

In the first part, we wish to develop a module for guidance in early building design phases to facilitate consequence exploration of potential design decisions and making high-quality early estimations. The module bases on thousands of prerun Monte Carlo simulations of generic room geometry and includes the most prevalent rooms in industrial and commercial buildings, such as offices, meeting rooms, and teaching rooms. Since the prerun simulations are executed in a detailed calculation software, we avoid having unconsidered simulation parameters when moving to detailed design stages. By visualising the prerun simulations graphically, e.g., with Parallel Coordinate Plots, the guidance module can assist the building layout determination process, e.g., finding indicative glass percentage, the need for mechanical cooling, and estimation of the needed airflow.

Secondly, we intend to streamline and structure the modelling process that follows the architect's Revit BIM model concerning modelling geometry, systems, and schedules. An essential step in this direction is a quality-assured geometry extract from the design model to minimise errors caused by manual processes usually dependent on skills, information level, and complexity. The geometry extract forms the basis for the two following steps:

1. A further and more thorough exploration of design solutions by creating and visualising Monte Carlo simulations adjusted to the current level of detail knowledge. At this point, the module supports the determination of more detailed parameters, e.g., the inlet air temperature, the necessary shading coefficient, and the cooling coil size.
2. The final compliance check representing the constructed building and system design.

This paper's focus is on the module for after-architectural design concerning a geometry extract translated to a BPS geometry model. Parallel development of the module involves enriching the geometry model with space information not present in the BIM model, such as system data and schedules. Using a user interface, predefined schedules for internal loads and HVAC systems depending on room type, e.g., office, meeting room, classroom, etc., can be added. These templates are based on industry guides and statistics from existing BSim simulations.

2. Method

The starting point and the core of this research is the semi-automatic methodology, which involves automation of everything in the BPS creation that can be reasonably automated, but at the same time, involves and requires the use of the specialist's expertise. The idea of the method and the coupling module is to make the modelling process and the results consistent in a way that is both efficient and attractive throughout the AEC industry. In other words, the method must fit into today's established practice. We have set up the following requirements for the semi-automatic coupling module that we elaborate briefly in the following:

1. The module must only impose minimal conditions on the architect's modelling technique
2. The extract must be visualised for easy manual approval
3. The module must be generic to translate to any BPS file or building analysis program.

Ad 1) The idea of requiring all architects and designers to construct the BIM model with a completely homogeneous modelling technique and consider the different inputs and limitations in the specific simulation tools has, by experience, proved to be an unsustainable basis for development and cooperation. Instead, the module must understand and unify different modelling techniques known to date. This, of course, requires a continuous adaptation to new modelling techniques.

Ad 2) When automating a big part of the modelling process, it is helpful for the specialists to have the opportunity to manually inspect the process along the way as a means to understand and adjust the output of the automation fully. For this reason, we have included visualisations and manual approvals in the module at different essential points.

Ad 3) The geometry extract is not only obligatory for BPS concerning energy and thermal comfort but also forms the basis of analyses on fire safety, acoustics, etc. Hence, we see the current module as part of a *module library* with the geometry extract as the foundation stone. Each module can then translate the geometry extract according to the different simulation tools and calculations.

2.1. Software

In the current research, the method is demonstrated with the design software Autodesk Revit and the Danish simulation software BSim, since these programs are most commonly used by the host company in the present industrial doctorate program, enabling verification of the module with previously manually built models. However, we see the semi-automatic approach as transferable to other design and simulation software.

When BIM models are shared across companies, an issue on responsibility and affiliation in the event of changes to the models arise, typically addressed with an overall joint model owned by the architect. Other parties use linked versions of the architect model to perform analyses and calculations within their fields of expertise [11]. Therefore, we have based the semi-automatic module on the creation of a linked Revit subject model for indoor climate and energy analyses (IE-template).

The BPS software BSim enables dynamic simulation of indoor climate, energy and humidity conditions in buildings. BSim allows several types of input files, including STEP (Standard for the Exchange of Product Data) and disxml files, containing the vast majority of the information to build a model with references to a material database and a weather file [15]. The key to creating a disxml file is a reference id (rid) attribute with a unique number for referencing the different elements. This reference strategy ensures that the software can distinguish the same type of elements between each other and make proper references across all model elements. The model structure contains the geometric elements Vector3D, Vertex, Edge, Face, and Cell. Two Vertex points will form an Edge, a number of edges form a closed polygon called a Face, a Face can be added materials, windows, and doors, and a collection of faces will construct a model shell named Cell [16].

DynamoRevit is an open-source visual programming platform that enables automation and customisation of the BIM workflow. We have used DynamoRevit in two steps. Firstly, to extract and convert the chosen room geometry according to Danish measurement rules, and secondly, to perform the necessary translation of the extract to the BSim topology. Where Dynamo programming falls short in functionality, Python and C# nodes have been added.

The topology of BSim is very similar to that of an exploded simplified space solid in Revit, which also has the ability to carry the engineering data necessary for BPS. Therefore, we have based the module on the placement of spaces in the Revit model via the build-in function *Place Spaces Automatically*, after which the chosen spaces are passed to the Dynamo environment. This method will only pass on selected geometry and detach the selected geometry from the architect's modelling technique. As the only requirement, it is necessary to use the Revit Families correctly, e.g., windows are modelled as *Windows* and not as *Wall* or similar.

The module has requested a rigorous model check aiming to handle both different modelling techniques and translation issues. We have used models known to be inconsistent for this model check, e.g., with normal vectors on windows pointing in the wrong direction. To test the module's functionality, we have used three different Revit models varying in size and complexity and compared them to manual measurements, presented in Table 1. The module testing is performed by the module's developing team; however, we plan to test the functionality on outside parties before long.

3. Workflow

The workflow consists of both automatic and manual processes, which we have illustrated schematically in Figure 1. As earlier explained, the module is launched by the placement of Revit *Spaces* in the model, after which the Revit function *Zone* is used to add the opted *Space(s)* to a *Thermal Zone* in the BPS environment.

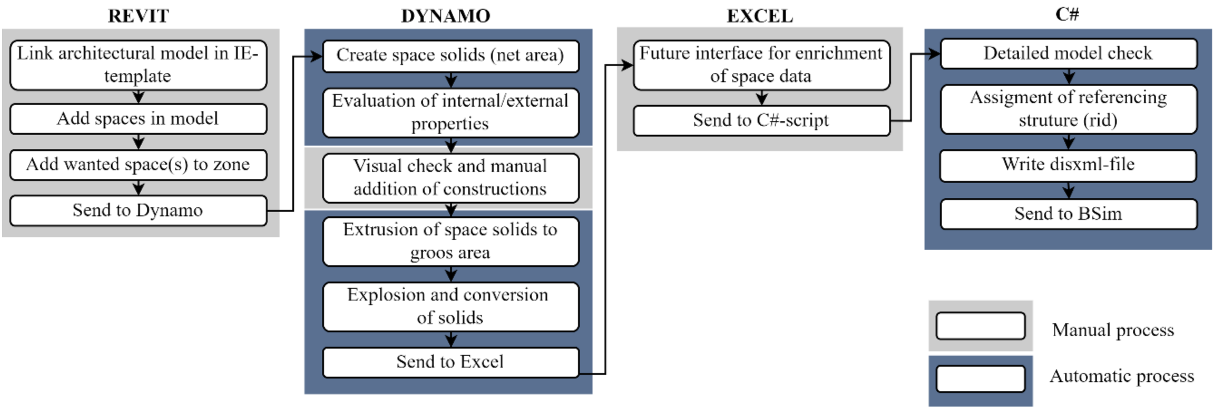


Figure 1. Schematical workflow of module.

At this point, we recommend performing a manual visual check of the space location, e.g., to examine and adjust the limit and base offset in buildings with level differences. The *Thermal Zone* geometry, including windows and doors, is then passed to the Dynamo environment, where all surfaces, windows, and doors are automatically evaluated. By projecting a point from the surface and assessing whether the point is in another space or outside the building, we define the interior and exterior faces.

The Danish standard DS 418 states that the gross area must be used for thermal transmission analyses, while the Revit space geometry is based on net areas. This measurement contradiction can be handled in different ways, two of which we have tested. One way to handle the area measuring is to automate a point projecting throughout all surfaces, thereby interpreting the construction thicknesses needed to get the gross area. However, when working in a linked Revit-file, the constructions are conceivably formed in cooperation between the architect, structural engineer, et al., meaning that the constructions are composed of several linked construction layers that make it complex to automate their reading. Furthermore, in the early stages, the constructions are often erroneously assembled for visual purposes only.

Therefore, we have chosen a different approach that also involves a visualisation and interaction step. This step implies that the Dynamo geometry is visually sent back to Revit, imposing a quality check by the specialist. Additionally, instead of automating the construction readings, the specialist must manually build the constructions using the BSim database added to the Dynamo environment. This step is important to enable diverse analyses and fully detach the BPS from the architect's modelling technique. Furthermore, this ensures that the simulations are generated with specialist knowledge and not only based on design representations. The surfaces are coupled with each other by performing an offset while keeping a connection to the respective room boundary polygons.

The space solid is then extruded either half or the full thickness of the defined constructions at inner and outer walls, respectively (figure 2 left), thereby achieving the gross area while maintaining the internal zone volume.

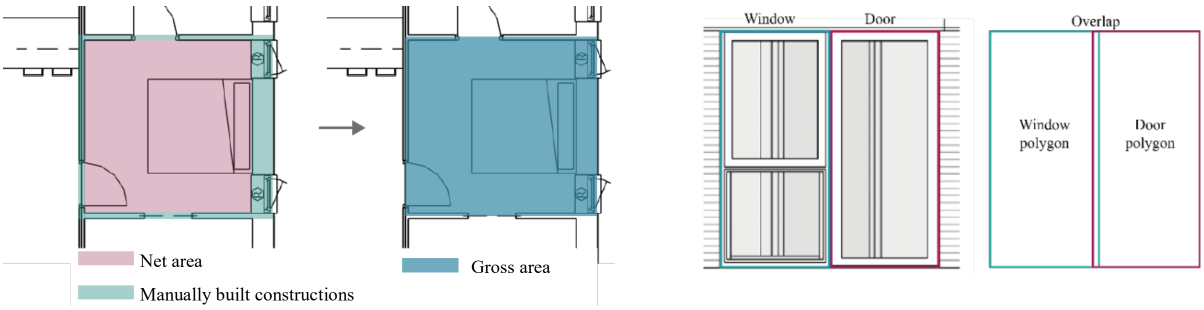


Figure 2. Space extrusion to obtain the gross area based on manually built constructions (left) and example of boundary overlapping (right).

The following part of the module concerns converting the obtained geometry data to the disxml format of the BSim input file. As earlier described, all solids are exploded to translate the solids into faces, edges, and vertexes as in the BSim topology (figure 3 left). Windows/doors are correspondingly translated by extruding the bounding curves for the window surfaces as a polygon throughout the associated wall and then cropping them by each other (figure 3 right) [16].

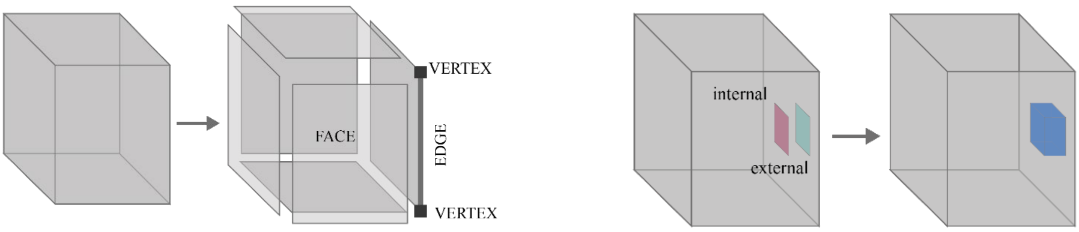


Figure 3. Exploding solids into faces, edges, and vertexes (left) and extrusion of internal/external window surfaces as a polygon (right).

Data for both spaces, windows and doors are then grouped in data collections according to the BSim topology and exported to Microsoft Excel. This export is not a needed feature in the current stage; still, it is performed as a preparation for the planned development regarding the enrichment of the model with predefined system and schedule data.

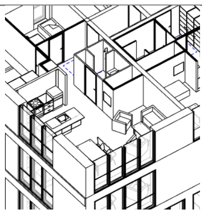
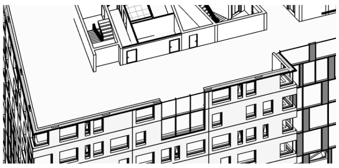
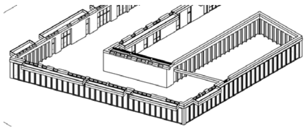
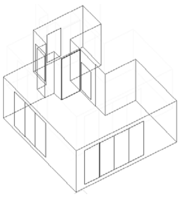
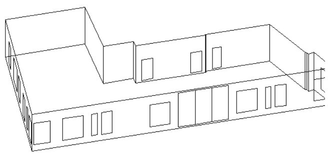
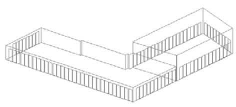
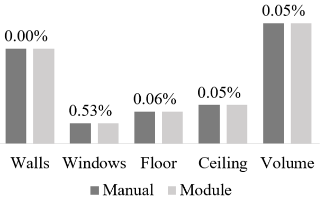
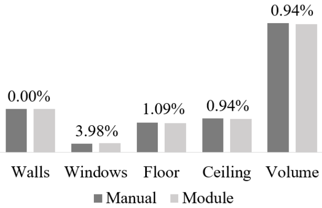
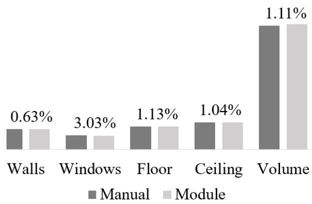
Even though the topology of BSim is similar to the outcome of an exploded solid, the conversion causes several translation issues, where boundary overlapping is one of the most severe cases. In Revit, windows and doors are designed in separate Families, and when separate window and door families are situated right next to each other, the conversion into polygons can cause slightly overlapping polygons and thereby incorrect extraction. To handle these issues, we have implemented an overlap evaluation of window/door polygons where necessary cropping is performed, as illustrated in figure 2 to the right.

After the model check execution, the disxml file is generated and sent to the BSim software where the model is built, where normal vectors are automatically added with the first file save.

4. Results

We have tested the method's functionality using the module on three different Revit models containing various complexities, including double-height spaces, odd-shaped spaces, and space separation lines to stress test the module. The results, presented in Table 1, are compared to manual measurements concerning area, volume, the position of windows/doors and assignment of interior/exterior properties.

Table 1. Results of testing with three different BIM-models.

	Model 1	**Model 2**	**Model 3**
Revit 3D view			
BSim 3D view			
Complexities	Merge of two rooms to one zone	Angled corners Irregular shaped Space separation lines	Irregular shape Double height room Many windows
Window position	✓	✓	✓
Int./ext. properties	✓	✓	✓
Area/volume comparison			

In general, we see minor differences in area and volume and correct placement of windows and doors, as well as a valid assignment of interior/exterior properties. The most significant differences in the area comparison are allocated to the window/doors, especially when the number of windows increases. We consider this divergence to come from the necessary cropping of window polygons, which indicates that this part of the method is the least robust and might need further development.

5. Discussion

The current results show a comparison of manual versus semi-automatic geometry. We plan a further analysis to compare the semi-automatic extract with different specialists' modelling, which is interesting because the manually performed geometry contains a high degree of human interference. This analysis is planned to culminate in assessing the acceptable size of deviation when using the semi-automatic module compared to the variations due to human understanding and potential simplification.

The developed window extract method further develops a previous script for energy calculations, where the individual window areas and the window location are insignificant. But when working with detailed analyses, correct placement and window area distribution are significant. Therefore, we wish to investigate whether the method of window geometry extraction can be improved. Here, the process described by Petersen et al. (2018) [14] is relevant to investigate.

5.1. Time consumption vs. time-saving

The present method is based on linking a Revit architect design model in the developed IE template, estimated to take about 15 minutes per project. Therefore, the method is most applicable when creating larger or multiple BPS models from the same Revit model to make up for the initial working time. However, we expect that the future will command a greater need for an IE template for several different BPS specialists so that the initial work will be negligible compared to the benefits.

We estimate that the entire modelling process can be handled in approximately 30 minutes for the first thermal zone. For additional zones in the same Revit model, the total modelling time is about 15 minutes, regardless of the room's complexity. Compared to manual modelling, which greatly depends on the design and complexity of the room, we assess that a manual modelling process typically takes 2-4 hours per room. This time consumption is necessary at every update of the architect design model as manual adjustments are complex. Thus, we see a significant time-saving potential when using the presented semi-automatic transfer method from early phases until the final design and when analysing several rooms per model. We believe that with full implementation of the method, an aspiration to not only perform analyses on critical rooms but also include non-critical and representative rooms to make a better estimation on system simultaneity will arise.

5.2. Continuous customisation and maintenance

The method is applicable on all Revit models, even with a low level of detail, however, some limitations need to be addressed or handled manually. This primarily concerns the inclusion of complex exterior shading systems such as angled slat systems or shading systems with perforated metal.

The presented model testing is performed with three models with different complexities. Thus we see a need for further testing and a continuous adaption and maintenance of the composed method, e.g., at changes in regulations, guidelines, software, etc. Permanent use of the method will continuously show the need for adaption and development, just as software developments can bring about simplifications and improvements.

The input file still needs several inputs to perform a complete dynamic simulation, such as usage loads, schedules, and HVAC systems. As previously described, this part is under development and will further improve the BPS speed and consistency.

6. Conclusion

This paper has presented a developed module for a semi-automatic transfer of geometric data from Revit to the BPS software BSim. The approach is chosen based on review of previous full-automatic and semi-automatic attempts and because the approach meets the wishes of time-saving while allowing specialists to be involved and manually adjust. The method places no demands on the linked Revit model structure since geometry extracts are based on the Revit *Spaces* and therefore detached from the architect's modelling technique. Hence the method is also applicable to Revit models with a low-detail level. The generalised methodology enables the possibility to expand the module to a *module library* for diverse analyses and software and overall to prepare and perform BPS simulations more structured and effectively.

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