Resilient Structures and Sustainable Construction
Edited by Pellicer, E., Adam, J. M., Yepes, V., Singh, A., and Yazdani, S.

ISBN: 978-0-9960437-4-8

ROBUST IFC FILES TO IMPROVE INFORMATION EXCHANGE: AN APPLICATION FOR THERMAL ENERGY SIMULATION

QIAN CHEN[1], YUNUS EMRE HARMANCI[2], YAOWEN OU[2],
and BORJA GARCIA DE SOTO[1]
[1]*Dept of Civil, Environmental & Geomatic Engineering, Institute of Construction and Infrastructure Management, ETH Zürich, Switzerland*
[2]*Dept of Civil, Environmental & Geomatic Engineering, Institute of Structural Engineering, ETH Zürich, Switzerland*

Despite many efforts from software vendors, AEC community and researchers, interoperability is still one of the main issues regarding reliable and robust transfer of information among different applications. In most cases, the Industry Foundation Classes (IFC) files fail to provide proper interoperability between geometric building models (architects) and thermal simulation software (engineers). This causes time consuming interactions and manual corrections prompt to errors. This paper evaluated two approaches for an efficient and robust transfer of IFC models considering space boundary characteristics to conduct thermal energy simulation (TES). The first approach was a multi-platform process which IFC files could be used by different TES tools. The second consisted of a single-platform process in which a single CAD software with built-in energy simulation capabilities was used. The two processes were tested with a simple residential building. Results indicated that the first process still required manual corrections and its performance was influenced by the TES tool used. The second approach addressed the interoperability problems, but caused "software dependency". It was found that geometry data reflecting different levels of space boundaries significantly influenced energy simulation results, indicating that proper definition of space boundaries improved the robustness of IFC files. This showed that IFC files can be enhanced to facilitate TES. This study also showed opportunities for improvement regarding interoperability and suggested other ways to tackle this problem.

Keywords: Space boundaries, Interoperability, Industry foundation class, Building information model, Building energy model.

1 INTRODUCTION

Attempting to optimize the building design from the energy saving point of view can be seen as the ultimate goal of conducting a thermal energy simulation (TES), which refers to the simulation of the internal energy present in a building due to temperature variations. The state-of-the-art approaches to realize TES rely on the integration of parametric Building Information Modeling (BIM) and energy simulation engines through standard data exchange formats (El Asmi *et al.* 2015). For instance, the energy model that is imported into Simergy (i.e., an energy simulation engine) for TES purposes is generated from Autodesk Revit (a BIM authoring tool) in the form of an IFC file (i.e., an exchange format). Although numerous BIM-based tools and processes have been developed for TES to be used during the design phase (Ahn *et al.* 2014), a robust information transfer of required information to deliver accurate TES results through standard data schemes is still proved to be inefficient and not intuitive. Incongruent information and a lack of rule-based information translation or interoperability also cause the TES processes to encounter iteratively manual model checks and modifications (Wimmer *et al.* 2015). Therefore, a robust and reliable translation process of building information is required for improving the TES results.

Several achievements have been made to refine the information exchange interface in order to reduce interoperability problems. One major solution is to overcome the mismatches between the BIM library of architectural design and the TES-required energy modeling information, that is, to transform the spatial geometry into thermal geometry with a robust exchange format (Eastman *et al.* 2011). A set of data requirements for TES has been developed to improve the quality of geometry models through space boundary surfaces (Maile *et al.* 2013). Furthermore, a physical BIM library has been investigated to perform semi-automatic translation from the building design models to TES engines using BIM authoring tool's application programming interface and object-oriented physical models (Kim *et al.* 2015). However, the results by these attempts imply that there is still a lack of reliable object relationships and corresponding transferring processes between BIM and TES. Therefore, this paper aims to provide a robust process of building information exchange by comparing the multi-platform and single-platform processes for TES, while finding the missing links embedded in the IFC file based on the effects of space boundary conditions. A more consistent implementation of a robust IFC file proves itself to improve the quality of TES results and to facilitate multi-domain collaborations.

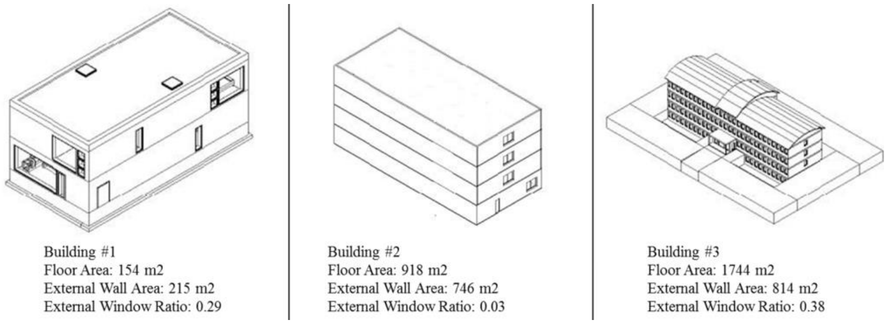
2 BUILDING GEOMETRY REQUIREMENTS OF TES

Current practice shows that an architectural design model is usually transformed into a TES view through an IFC file, which contains geometry information of various building elements, such as IfcWall, IfcCartesianPoint (BuildingSMART 2016). Within the context of thermal energy analysis, space boundaries play a vital role, which are virtual objects related to spaces or rooms in buildings. They are represented with two levels in an IFC file. The first level of space boundaries is defined by the surfaces of building elements bounding a given surface, which depend only on virtual boundaries immediately adjacent to the zone of interest without considering dividing parts. The second level depends on the invisible space behind the boundary, which is considered as the subdivision of the first level space boundary that represents a divided space with unique and consistent rate of heat flow or specific thermal performance. In terms of a floor plan of a building, when comparing the two levels of space boundaries, the second level of space boundaries require that the floor slab or wall of a space be broken along the centerline of the slab or wall adjacent to it. This allows some neighboring relations with adjacent spaces to be defined correctly. This is important for thermal energy analysis because a specific configuration of the space boundary determines the energy flow or airflow between neighboring surfaces.

The space boundaries include two categories of information to be used for the thermal energy analysis: the surface area and the material properties (Bazjanac 2010). The surface area, also called the building envelop, determines the thermal zoning and its corresponding thermal mass. The more surface area a building has, the more heat exchange will take place. For instance, in hotter climate, the taller ceiling, which results in more surface area and building volume, is appreciated because cooling takes place quickly under this condition. The direction of heat transfer is also important so that the vector information of space or surface should be distinguished. However, the information of surface area is often missing after exported from an architectural design software. Building components in a 3D architectural model should be recognized as interior or exterior surface areas in a TES model, and likewise, a room should automatically indicate a thermal zone. The material properties (i.e., the thermal abilities of a material), such as its specified thermal conductivity coefficient, also determine the building energy performance. The material properties influence the effects of solar radiation on window frames or wall surfaces; therefore, considering the solar radiation to which a building space is exposed to, is particularly important for reliable TES. Theoretically, the material properties closely related to thermal energy analysis should be consistent and comprehensive after they are exported from 3D architectural model, however, current practices are using and transferring insufficient information and most thermal properties of a material are not available to be assigned to building components in architectural design software. Obviously, due to a lack of information of surface area and material property provided by the architectural model, iteratively manual corrections of the model are required and unavoidable for TES.

3 MULTI AND SINGLE PLATFORM PROCESSES FOR TES

In an attempt to assess the efficiency of proposed processes, three buildings of different sizes and complexities have been considered. They have been obtained from an open IFC repository (Open IFC model Repository 2016). No comments will be made on the quality of IFC files and thermal performance since this work focuses on the process itself. This also implies that the IFC files will be used as-is and no manual corrections will be made to overcome any importing/simulation problem to fit the thermal analysis. Buildings considered within this study are presented in Figure 1. Since this paper only investigates the interoperable process, the impact on the experiments from the volumes and types of selected buildings will not be considered.



Building #1
Floor Area: 154 m2
External Wall Area: 215 m2
External Window Ratio: 0.29

Building #2
Floor Area: 918 m2
External Wall Area: 746 m2
External Window Ratio: 0.03

Building #3
Floor Area: 1744 m2
External Wall Area: 814 m2
External Window Ratio: 0.38

Figure 1. Buildings considered with floor, external wall, and external window information.

3.1 Multi-platform Processes

The current application of standard exchange format can be described as a multi-platform process, where a 3D architectural model is created and subsequently imported and analyzed in some dedicated TES software. For this study, Simergy (Simergy 2013), Energy Plus (Energy Plus) and CYPETHERM Eplus (CYPETHERM 2016) were used. The TES may be conducted either by an engineer or an architect in the early-design phases (Bambardekar and Poerschke 2009). As described earlier, interoperability problems are common with the IFC-file standard and require manual corrections on the architectural model for further accurate energy simulation. Moreover, particular modification of the model may be required back and forth for TES relevant parameters, such as reassigning of thermal zones and extra addition of material properties. Lastly, in order to have a comprehensive and an accurate simulation that translates well to the actual thermal energy performance, a number of simulation parameters (e.g., weather conditions, building orientation, internal occupational loads, HVAC attributes, etc.) are required as an input. A flowchart summarizing the main steps of the multi-platform process is shown in Figure 2.

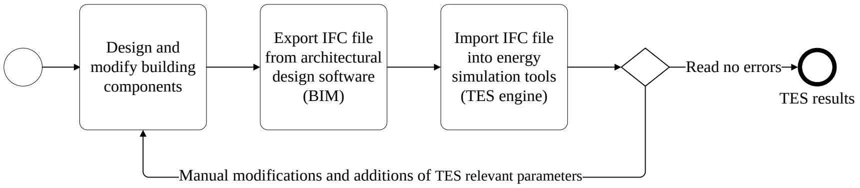


Figure 2. Multi-platform process explained via a flowchart.

All three buildings used as an example to test this process (see Figure 2) encountered problems within different phases of simulation and thus it was not possible to come up with a conclusion on the efficiency of this multi-platform process. Simergy had errors in importing the geometry correctly; existence of windows and roofs/slabs was the main problem. Energy Plus (Energy Plus) was able to import the files (converted to IDF) with no warnings or errors, yet it was revealed after simulation that windows were not recognized. Lastly, CYPETHERM Eplus was not able to open the IFC files at all. The difficulty in importing the geometry correctly, especially first try without the need for manual modification was deemed not possible.

3.2 Single-platform Processes

The efficiency of employing a single-platform process, i.e. the use of single software both for architectural design as well as TES, was investigated as an alternative to the conventional multi-platform process. For this purpose, the IFC (IFC1) files of the same buildings presented in Figure 1 were imported into the 3D-CAD software Revit. As an initial observation, no difficulties arose during the importing process. They were then analyzed with the built-in energy simulation tool of this software. The procedure was quite straightforward and required only a minimal number of operations. No manual corrections of geometry as well as setting of other parameters (e.g. glazing material type of a window, conductivity coefficient of a wall etc.) were required. The results were presented in the end in an electronic report format. This shows that a single-platform process can potentially eliminate interoperability issues. Additionally, professionals would require experience in a less amount of tools. However, the software dependency created by this process should not be neglected.

In order to further optimize this process, Space Boundary Tool (Berkeley Lab 2014) was incorporated in an attempt of automating the cumbersome task of defining space boundaries, enhancing the precision of surface areas of a building and exporting an enhanced IFC (IFC2) file for further analysis. Automatic handling of space-boundaries could drastically reduce manual labor for energy simulations. The workflow of a single-platform process with the inclusion of Space Boundary Tool is shown in Figure 3. Results from TES, both with and without the use of Space Boundary Tool, is compared and presented in the next section and its impact on the simulation results discussed.

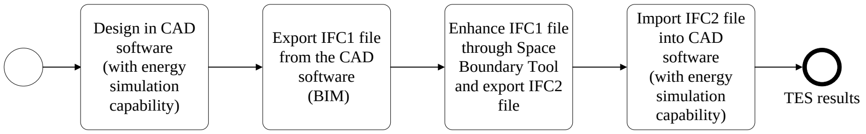


Figure 3. Single-platform process explained via a flowchart.

4 IMPLICATIONS FOR ROBUST IFC FILES: EFFECT OF SPACE BOUNDARY

According to the comparative simulation results of TES with and without Space Boundary Tool conditions in Table 1, an increase in the values of energy simulation metrics (e.g., electricity use, fuel use, energy cost, etc.) were observed under the condition that the space boundaries in a building were optimized using the Space Boundary Tool. It is assumed that the building energy consumption will increase when more precise room or thermal zone definitions are detected for a simple building structure. A more correct assignment of surface area to a room and its building component's material property yielded an improvement of energy simulation accuracy. For example, all the three buildings generated increased energy costs due to a reliable validation of surface areas that determined the specific shape and functionality of each room. However, it is noted that the variations in the simulation results, to some extent, depended on the building masses themselves, for example, building #1 experienced a significant change in electricity use after it was experimented with Space Boundary Tool. Generally, it is revealed that the quality of building models in terms of the level of space boundary concretization influences the TES processes and results. However, usually there was missing information of space boundaries and boundary allocation rules in a raw IFC file directly exported from CAD design software. Also, a complex building geometry would cause the difficulty of defining proper building space boundaries, such as a curve-shaped geometry that is hard to define and calculate. Hence, in the perspective of an architect, his/her architectural model requires various evaluations to improve its quality due to the customized space boundary data in an IFC file needed for TES. On the other hand, TES engineers are recommended to consider the effect of space boundary optimization in order to ensure an acceptable level of energy model quality.

Table 1. Results from TES of the three buildings.

Building No.	Without Space Boundary Tool	With Space Boundary Tool	Change [%]
Building #1	Electricity use: 195 kWh/sm/yr	Electricity use: 370 kWh/sm/yr	89.7
	Fuel use: 964 MJ/sm/yr	Fuel use: 1402 MJ/sm/yr	45.4
	Energy Cost: 66,789 CHF	Energy Cost: 70,277 CHF	5.2
Building #2	Electricity use: 136 kWh/sm/yr	Electricity use: 137 kWh/sm/yr	0.7
	Fuel use: 271 MJ/sm/yr	Fuel use: 274 MJ/sm/yr	1.1
	Energy Cost: 131,310 CHF	Energy Cost: 130,560 CHF	-0.6
Building #3	Electricity use: 148 kWh/sm/yr	Electricity use: 151 kWh/sm/yr	2.0
	Fuel use: 514 MJ/sm/yr	Fuel use: 502 MJ/sm/yr	-2.3
	Energy Cost: 540,610 CHF	Energy Cost: 647,285 CHF	19.7

5 CONCLUSIONS AND FUTURE RESEARCH

This paper proposes two processes to handle building information exchange between an architectural model and a thermal energy simulation model in order to address current interoperability. The proposed processes were compared to evaluate their performance and efficacy. Three buildings were tested respectively using the multi-platform process and single-platform process, revealing that the single-platform process was preferred because no manual corrections of geometry were required to conduct a TES. Additionally, the Space Boundary Tool was applied to investigate the information reliability and robustness embedded into an IFC file using the single-platform process. Results show that the accuracy of TES simulation figures (e.g., electricity use, fuel use and energy cost) can be improved with the usage of Space Boundary Tool. Quick adaption of surface areas and material properties will enhance the quality of the energy model and yield reliable energy simulation results. Although the space boundary considerations can improve the performance of an IFC file in order to facilitate TES, the rules to conduct the space optimization for TES are still abstract and not well defined, especially for complex building structures. Future research focuses on the accuracy of geometry information transfer, especially the accuracy of reading coordinate system of the building geometry. Meanwhile, the Finite Element Method can be investigated to overcome the geometry translation problems with its well-defined coordinate system and naturally embedded material properties.

Acknowledgments

This paper resulted from elaboration on the initial work conducted during the Academia Industry Modelling (AIM) week organized by the Computational Science Zurich (CSZ), a joint initiative of ETHZ and UZH (http://www.zhcs.ch/education/academia-industry-modeling/). The authors would like to thank the organization committee and kindly acknowledge Ms. Dantong Yang and Dr. Stephan Huck from Siemens AG for providing the topic and their support.

References

Ahn, K., Kim, Y., Park, C., Kim, I., and Lee, K., BIM interface for Full vs. Semi-automated Building Energy Simulation, *Energy and Buildings*, 68, 671-678, 2014.

Bambardekar, S., and Poerschke, U.. The Architect as Performer of Energy Simulation in the Early Design Stage, *Building Simulation*, 1306-1313, 2009.

Bazjanac, V., Space Boundary Requirements for Modeling of Building Geometry for Energy and Other Performance Simulation, in *CIB W78: 27th International Conference*, 2010.

Berkeley Lab Simulation Research, U.S. Department of Energy, *Space Boundary Tool*, 2014. Retrieved from https://simulationresearch.lbl.gov/projects/space-boundary-tool on November 24, 2016.

BuildingSMART International Ltd. (BuildingSMART), *Summary of IFC Releases, IFC Release, Specifications*, BuildingSMART International home of openBIM, 2016. Retrieved from http://www.buildingsmart-tech.org/specifications/ifc-releases/summary on December 6, 2016.

CYPETHERM, Version 2016, CYPETHERM Suite: EPlus, CYPE Ingenieros, S.A. Retrieved from http://www.store.cype.com/en/cypetherm-suite/462-cypetherm-eplus.html on November 20, 2016.

Eastman, C. M., et al., BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors, John Wiley & Sons, 2011.

El Asmi, E., Robert, S., Haas, B., an Zreik, K., A Standardized Approach to BIM and Energy Simulation Connection, *International Journal of Design Sciences & Technology*, 21(1), 2015.

Energy Plus, Version 8.6.0., U.S. Department of Energy. Retrieved from https://energyplus.net/ on November 20, 2016.

Kim, J. B., Jeong, W., Clayton, M. J., Haberl, J. S., and Yan, W., Developing a Physical BIM Library for Building Thermal Energy Simulation, *Automation in Construction*, 50, 16-28, 2015.

Maile, T., O'Donnell, J., Bazjanac, V., and Rose, C., BIM–Geometry Modelling Guidelines for Building Energy Performance Simulation, in *Building Simulation Conference*, 2013.

Open IFC model Repository, Four storey office building, Four sto-001 (http://openifcmodel.cs.auckland.ac.nz/_models/20160414office_model_CV2_fordesign.ifc), ERDC: Duplex Apartment Model, ERDC - D-001 (http://openifcmodel.cs.auckland.ac.nz/_models/030811DuplexModel-IFC-2011-05-05.zip), and KIT: AC11-Institute-Var-2-IFC|KIT: AC1-001 (http://openifcmodel.cs.auckland.ac.nz/Model/Details/110), Department of Computer Science, The University of Auckland, 2016. Retrieved from http://openifcmodel.cs.auckland.ac.nz/Model on November 25, 2016.

Simergy, *Simergy: A Free, Comprehensive Graphical User Interface for Energy Modeling with EnergyPlus*, Version 1.3. U.S. Department of Energy, 2013. Retrieved from https://eetd.lbl.gov/news/article/56613/simergy-a-free-comprehensive-gr on November 20th, 2016.

Wimmer, R., Cao, J., Remmen, P., Maile, T., O'Donnell, J., Frisch, J., Streblow, R., Müller, D. and Van Treeck, C., Implementation of Advanced BIM-based Mapping Rules for Automated Conversion to Modelica, in *Proceedings of the 14th IBPSA Conference*, 2015.