
INVESTIGATION OF INTEROPERABILITY BETWEEN BUILDING INFORMATION MODELLING (BIM) AND BUILDING ENERGY SIMULATION (BES)

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Building Information Modelling (BIM) has become an emerging digital technology in the architecture, engineering and construction (AEC) industry. There is a growing demand on applying BIM for sustainable design including the building energy simulation (BES). Lack of sufficient interoperability has caused barriers to utilize the information from BIM for BES. In this study, the interoperability between BIM and four different BES tools (i.e., Ecotect, EQUEST, Design Builder and IES-VE) was explored by using a case study of a residential building in the design stage. The misrepresented information from BIM to multiple BES tools were identified based on six different categories of building information parameters. The research proposed an approach of creating gbXML file with an improved integrity of information in BIM. Overall, this study would lead to further work in developing platforms for improving the information transformation from BIM to BES.

Keywords: Building Information Modelling (BIM), building energy simulation (BES), interoperability, sustainable design, op Green Building XML schema (gbXML)

1. Introduction

Building information modelling (BIM), as a revolutionary technology of Architecture, Engineering, and Construction (AEC) industry, enables the coordination of information including 3D geometries, materials, building structures, Mechanical, Electrical, and Plumbing (MEP) systems, and schedules for different disciplines during the building lifecycle [1]. BIM allows the assessment of building performance in the earlier design stages so that the design parameters such as location, orientation, glazing ratio and fabric properties could be optimized [2]. There are multiple building energy simulation (BES) software tools (e.g. Ecotect) for professionals to evaluate the building performance. However, preparation of input parameters (e.g., building geometry and material properties) for simulation is usually error-prone and expensive [3]. BIM-based BES model could reduce the effort to input these building parameters, and the information or data

consistency from BIM to BES could be maintained [4]. Productivity in the BIM world will suffer from lack of incompatible software programs or platforms, and improved interoperability between software applications is the top industry improvement to increase BIM value [5]. Currently, the interoperability between BIM and BES tools are mainly processed with data-exchange scheme such as Drawing Interchange Format (DXF), Industry Foundation Classes (IFC) and Green Building XML schema (gbXML) [1]. Existing BIM tools such as Revit, Bentley and ArchiCAD, and BES programs (e.g., Green Building Studio, Ecotect, eQUEST and IES-VE) are supporting both IFC and gbXML schemas [6]. BIM-based energy simulation can be performed by importing the extracted information from BIM models with the defined data exchange scheme. Moon et al. [3] stated that there were variations of the level of interoperability between existing BES programs and BIM, and additional input and modification were inevitable when extracting the information from

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BIM to BES. Steel et al. [7] described four interoperability levels between IFC and BIM including file, syntactic, visualisation and semantic level. Among them, the semantic level has the most difficulties in information exchange such as issue of representation difference between architectural and energy simulation models. Previous research has indicated six areas of interoperability between BIM and BES: 1) location; 2) geometry, construction and space; 3) thermal zones; 4) occupancy, equipment and lighting loads; 5) HVAC systems; 6) energy simulation [8]. There are some developments on information exchange between BIM and BES tools from BES software vendors and research institutions which primarily focus on the transfer of geometric information (e.g. walls, shading surface and windows) into BES tools [8–11]. Currently there is insufficient definition or standard of interoperability level between BIM and BES. Utilizing BIM for BES purpose is therefore highly depending on several factors such as user experience of BES tools or programs, and collaboration level between BIM staff and energy modellers.

This study aimed to identify some existing problems between BIM and BES tools by adopting a case study of residential project, and to propose an approach to achieve the improved interoperability to perform building energy analysis. The study was divided into three objectives: 1) to evaluate the influence of irregular-shaped building envelope on interoperability; 2) to identify the misrepresented building information between BIM and different BES tools; and 3) to use a more interoperable workflow to run BES using the same case study.

2. Methodology and background

The interoperability issue was investigated following the workflow described in Fig. 1. Autodesk Revit 2015™ [12] was adopted as the BIM authoring tool in this study. A case study building was adopted for testing the information exchange from BIM to multiple BES tools including Autodesk Ecotect 2011™ [13], eQUEST™ [14], DesignBuilder™ [15] and IES-VE 2015™ [16].

It is a one storey 162 m² residential building consisting of two building blocks (i.e., a round house and a rectangular house shown in Fig. 1, respectively). The building was a custom design at the location of St. Lucia, a tropical island in the eastern Caribbean Sea. The orientation of the building is north east faced with the unique curved walls and slope roof. The gbXML was applied as the BIM exchanged scheme. The gbXML is an open source language developed to facilitate information transfer between CAD-based building design files and building energy analysis software [17]. It is officially supported by 16 BIM authoring and CAD software tools and 30 building energy analysis tools including four BES tools in this study [18]. The gbXML specifically targets on thermal and energy related properties. Compared to IFC which includes information from building construction to building operation [19, 20], gbXML could generate simple implementation and improved interoperability with BES tools. The evaluation for interoperability in this study was carried out under the six categories of criteria, namely building geometry, space composition, building construction, internal loads, operation schedule, and HVAC system.

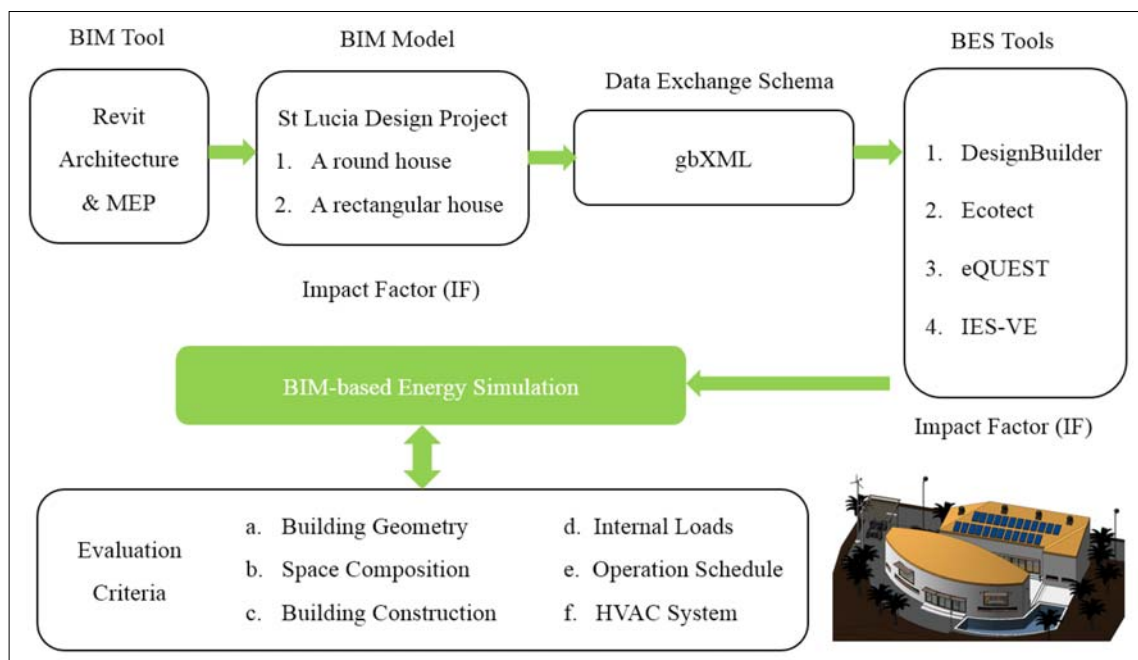


Fig. 1. Workflow of interoperability investigation

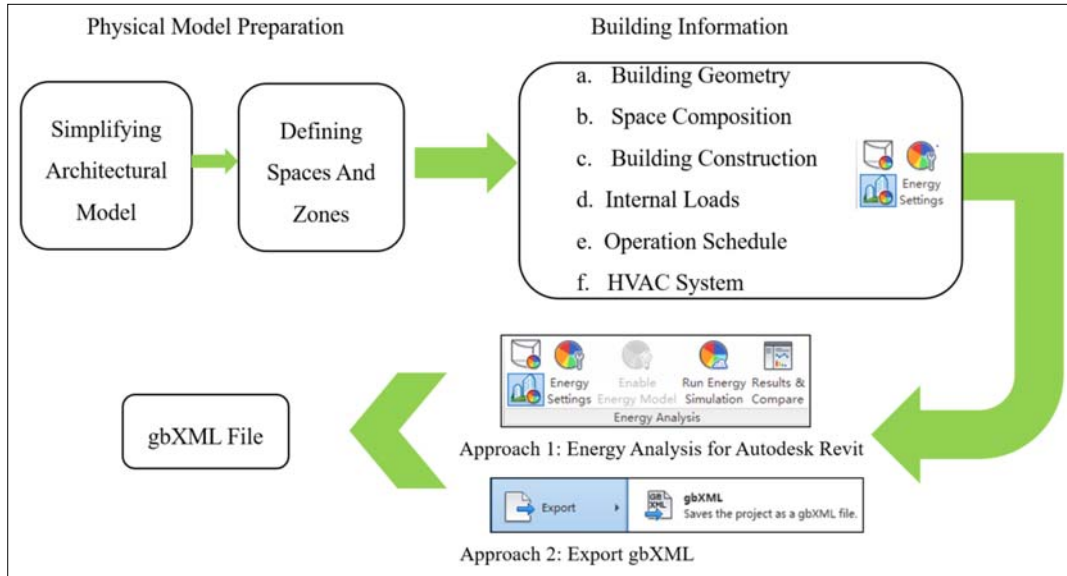


Fig. 2. The process of exporting BIM-based information

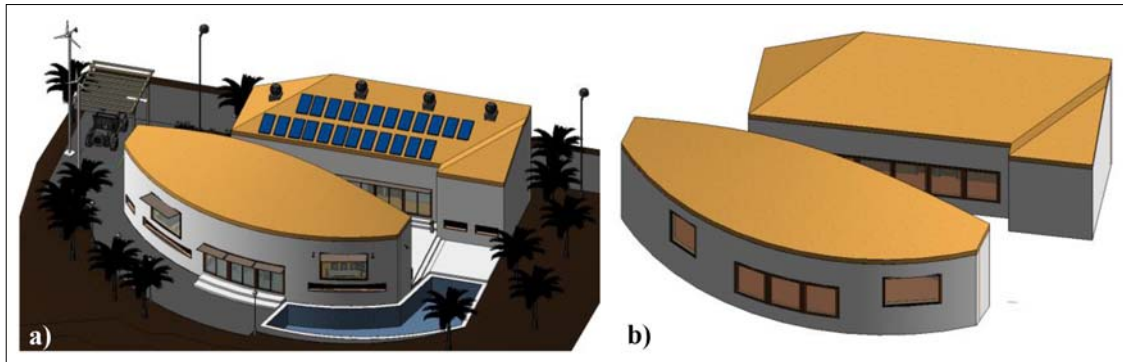


Fig. 3. Model simplification. a) Detailed, b) Simplified architectural model

tion, internal loads, operation schedule, and HVAC system.

Based on the six categories, the three-step workflow of exporting information from BIM in the gbXML scheme is illustrated in Fig. 2.

The steps of exporting gbXML files included preparing physical model, defining building information, and converting the information from BIM model into gbXML scheme.

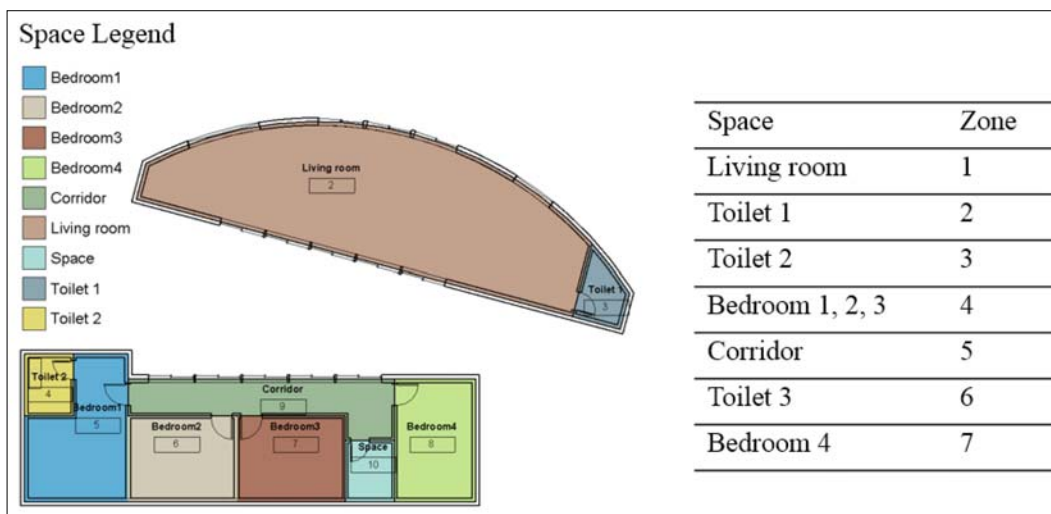


Fig. 4. Spaces and zones information in BIM

Table 1. Building construction information set in Autodesk Revit

Category	Analytic construction	U value [W/(m ² K)]
Exterior walls	Standard wall construction	0.3495
Roofs	Sloping roof including loft	0.1589
Floors	Wilton carpet on concrete	1.2908
Interior walls	Light plaster, brick, light plaster	1.6896
Doors	Wooden	2.1944
Exterior windows	Low-E double glazing (1/4 in + 1/4in)	1.6743

2.1. Physical model preparation

The first step focused on creating the physical model in Autodesk Revit as shown in Fig. 3.

As seen in Fig. 3, the architectural model was simplified and the spaces and zones were defined. Figure 4 shows the interior spaces and zones defined in BIM.

2.2. Building Information

Besides the location and weather information defined in Revit, Table 1 displays an example of the building information parameters set in Revit.

Other building information including operation schedule, internal loads, and HVAC system were all defined in Revit. For example, air changes per hour was set at 0.35.

2.3. Converting BIM model into gbXML file

There are two typical approaches to generate gbXML file from Autodesk Revit. The first approach is to utilize the Energy Analysis function in Revit to automatically generate the energy simulation model in the gbXML format and then to upload the model to Autodesk Green Building Studio (GBS). Afterwards,

the gbXML file can be exported from GBS cloud service and be imported into a BES software tool that is compatible with gbXML. The advantages of this Energy Analysis approach lie in the correct extraction of non-geometric information including occupancy, equipment, lighting and thermostat, weather of cooling and heating design day, types and values of HVAC system, and outside air information. However, disconnected building geometric elements were found from the model in GBS as shown in Fig. 5.

Compared to the first approach based on Energy Analysis, a second approach could preserve the building geometric information. However, the non-geometric information extracted in the gbXML format was largely misrepresented. For example, information related to HVAC and outside air condition was largely missing. In addition, the operation schedule information was also misrepresented.

3. Results and discussion

Before running the interoperability evaluation between Autodesk Revit and different BES tools, a combined solution was proposed as displayed in Fig. 6.

According to the combined approach, a Create New function recommended by Autodesk Knowledge Network [21] was adopted to extract the information



Fig. 5. Disconnected building elements in 3D VRML view in GBS

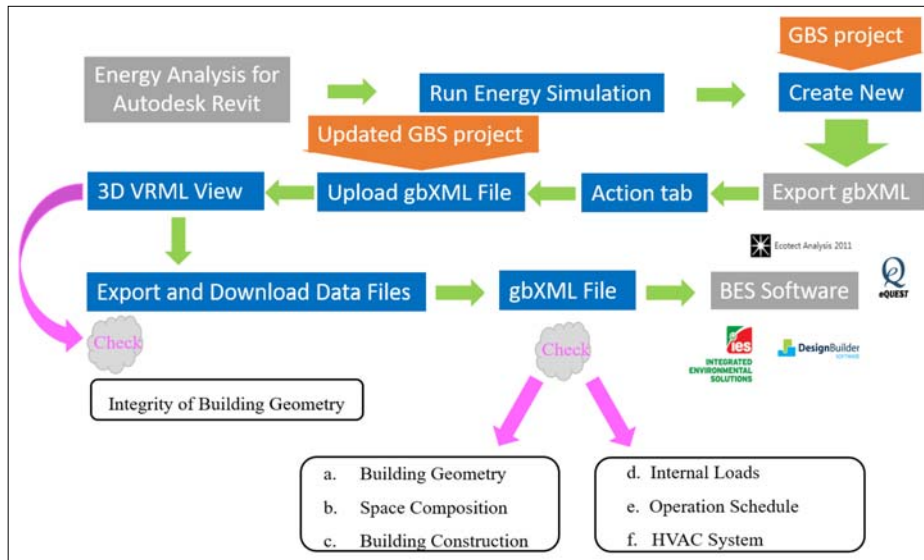


Fig. 6. Process of creating gbXML file from Revit model

from Autodesk Revit. It yielded an opportunity to create gbXML format with fully integrated building geometric information. According to Fig. 6, a GBS project was firstly created by incorporating the non-geometric information (e.g., locations, internal loads, operation schedules, HVAC systems, and outside air information) from Energy Analysis. By using the Export gbXML method, the GBS project would be updated [21]. Continuing following the steps illustrated in Fig. 6, the building model updated in GBS was improved as seen in Fig. 7.

An improved GBS project model displayed in Fig. 7 was then ready to be transformed to BES tools. By trials of the four different BES tools in terms of their interoperability with Autodesk Revit, multiple information gaps were identified as shown in Table 2. Overall, eQUEST was most compatible with BIM model from Revit due to the fact that Green Building Studio utilizes industry standard DOE-2.2 same

as eQUEST. Ecotect was most incompatible with BIM model as it only identified the building geometry of regular shape. DesignBuilder was able to import correct geometric information from BIM model but non-geometric information was misrepresented or overwritten by template. Although space composition and building construction were successfully transferred in IES-VE, it was incompatible with irregular shape and overwrote information of internal loads, operation schedules and HVAC systems.

According to Fig. 8, the round or irregular-shaped building envelope was more likely to be misrepresented in BES tools compared with regular-shaped buildings. Four BES tools experienced different levels of geometric interoperability problems which confirmed the findings from previous research [22, 23]. Despite that some BES tools may display certain superior interoperability performance with BIM than others, several general interoperability problems were

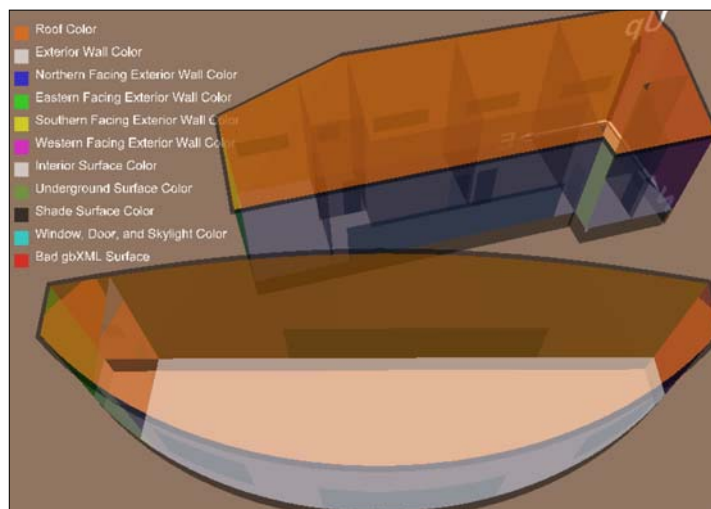


Fig. 7. Full integrity of building geometry of updated GBS project

Table 2. Summary of interoperability between BIM model and BES tools

	BIM model	Ecotect	eQUEST	DesignBuilder	IES-VE
Building geometry	Regular shape	√	√	√	√
	Irregular shape	×	×	√	×
Space composition	Name	×	×	×	√
	Thermal zone	×	√	×	√
Building construction	Category	×	√	O	√
	<i>U</i> value	×	√	O	√
Internal loads	Number of people	×	√	×	O
	Sensible heat gain	×	√	×	O
	Latent heat gain	×	√	×	O
	Lighting power density	×	√	×	O
	Equipment power density	×	√	×	O
Operation schedules	Occupancy schedule	×	√	O	O
	Lighting schedule	×	√	O	O
	Equipment schedule	×	O	O	O
	Hourly value	×	√	O	O
HVAC systems	Type of systems	×	√	O	O
	Conditioned zones	×	√	O	O
	Cooling and heating set points	×	√	O	O

Note: √ = Identified; × = Misrepresented; O = Information overwritten by software template

identified. Misrepresentation of geometric information imported from BIM was not uncommon. For example, separated windows on curved walls in BIM could not be recognized in BES. In some cases, a single larger window with the same glazing area might be needed to replace the separated windows for energy simulation. Irregular-shaped houses might not be saved of its envelope when the geometric information is transformed from BIM to BES.

Interoperability at the semantic level mentioned by various studies [24, 25] is another major challenge. In this case study, lack of platform for transforming

HVAC parameters was found because of different sizing options of HVAC systems in BES tools. For instance, Ecotect oversimplified the options of few default systems and thermostat settings while IES-VE [26] offered highly parametric HVAC configurations with system components and control strategies. Because internal loads and operation schedules were associated with HVAC settings, the difference in HVAC module further led to false transition of information on them. Missing schedules of heating, activity level and infiltration in gbXML file were also found during the EnergyPlus simulation [27]. Other non-geometric

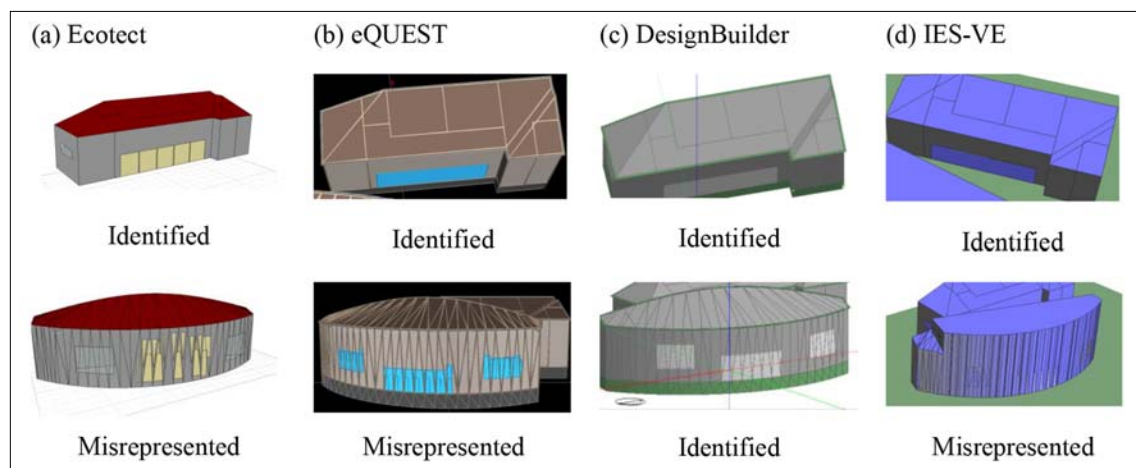


Fig. 8. Building geometry of BIM model in BES tools: (a) Ecotect; (b) eQUEST; (c) DesignBuilder; (d) IES-VE

information which could not be correctly transformed from BIM to BES included building construction materials and thermal zones. For example, the glass door in BIM was not treated as the same material after being transformed into a BES tool. Integrated Environmental Solutions published white papers about BIM and building performance analysis using Revit 2014 with lots of description about geometric information transfer but seldom about non-geometric information [11].

It remains a challenge to optimize different categories of building parameters when linking BIM into BES, including but not limited to building geometry, space composition, construction materials, internal loads, operation schedules, and HVAC system. These existing BES tools tested in this study could not interpret correctly all the six categories of information defined in Figs 1 and 2. In addition, current translation between BIM and BES tools tends to be one-directional meaning that any alteration of gbXML in BES tools could not be updated back to the BIM model. The shared information among architects, MEP engineers and civil engineers through BIM has limited inclusion of information related to environmental sustainability, because existing BES tools have limited connection with BIM ecosystems. More work is needed in bridging the information gap between BIM and existing BES programs to improve the interoperability. It would also be necessary to compare the work efficiency or time effort between BIM-driven BES and remodelling the information in BES programs.

4. Conclusion

This study aimed to investigate the level of interoperability between BIM and four different Building Energy Simulation (BES) tools by adopting a residential building as the case study. A round-shaped house was adopted to test the interoperability level between BIM and BES in terms of irregular envelopes. The study started by proposing a combined workflow to enhance the information exchange of both geometric and semantic data when extracting the model from BIM. These existing BES tools all yielded certain lack of interoperability when connected to BIM, such as incorrect geometric information (e.g., window numbers and round-shaped building envelope) and disconnected semantic information sharing such as HVAC parameters. The study contributed to the knowledge in interoperability in BIM and BES by identifying commonly encountered problems. More future work can be performed to improve the interoperability based on the problems identified, either in geometric aspects or the semantic level. The study may serve as a general guideline to professionals to determine how much information should be created for building energy simu-

lation. For instance, the initial energy simulation could be conducted right after architects finish the conceptual design in BIM before further details related to interior rendering, structural design, or building services engineering design are ready.

The limitations of the current study lie in that it just revealed several interoperability issues between BIM and several existing BES tools. It has not provided corresponding solutions to handle these issues. Moreover, only one simplified small-sized residential building was adopted as the case study. It is expected that more interoperability would be found as the project becomes more sophisticated. The combined approach adopted in this study is still simple and unable to solve more interoperability problems. Future work could apply more effective methods, such as programming, development of interface, and algorithm, etc.

References

- [1] Kim S., Woo, J. H. (2011 December), Analysis of the differences in energy simulation results between building information modeling (BIM)-based simulation method and the detailed simulation method. In: Proceedings of the Winter Simulation Conference, pp. 3550–3561.
- [2] Azhar S., Brown J., Sattineni A. (2010, June), A case study of building performance analyses using building information modeling. In: Proceedings of the 27th international symposium on automation and robotics in construction (ISARC-27), Bratislava, Slovakia, pp. 25–27.
- [3] Moon H. J., Choi M. S., Kim S. K., Ryu S. H. (2011, November), Case studies for the evaluation of interoperability between a BIM based architectural model and building performance analysis programs. In: Proceedings of 12th Conference of International Building Performance Simulation Association, Vol. 2011.
- [4] Ham Y., Golparvar-Fard M. (2015), Mapping actual thermal properties to building elements in gbXML-based BIM for reliable building energy performance modeling. *Automation in Construction*, 49, 214–224.
- [5] Young N. W., Jones S. A., Bernstein H. M., Gudgeon J. (2009), The business value of BIM-getting building information modeling to the bottom line. Bedford, MA: McGraw-Hill Construction, 51.
- [6] Kim J. B., Jeong W., Clayton M. J., Haberl J. S., Yan W. (2015), Developing a physical BIM library for building thermal energy simulation. *Automation in Construction*, 50, 16–28.
- [7] Steel J., Drogemuller R., Toth B. (2012), Model interoperability in building information modelling. *Software & Systems Modelling*, 11(1), 99–109.
- [8] Cemesova A., Hopfe C. J., Mcleod R. S. (2015), Passiv-BIM: Enhancing interoperability between BIM and low energy design software. *Automation in Construction*, 57, 17–32.
- [9] O'Donnell J. T., Maile T., Rose C. (2013), Transforming BIM to BEM: Generation of building geometry for the NASA Ames sustainability base BIM. Simulation Research Group.

- [10] DesignBuilder Software Ltd. (2016), DesignBuilder Revit – gbXML Tutorial. Available at: http://www.designbuilder.co.uk/downloads/db_revit_tutorial_v1.pdf (Accessed: 5 July 2018).
- [11] Integrated Environmental Solutions Ltd. (2014), BIM + Building Performance Analysis Using Revit 2014 and IES <Virtual Environment>. Available at: <https://www.iesve.com/corporate/media-center/white-papers/general/revit-white-paper-2014.pdf> (Accessed on 5 July 2018).
- [12] Autodesk (2015), Autodesk Revit 2015. Available at: <https://www.autodesk.com/education/free-software/revit> (Accessed on 1 September 2015).
- [13] Autodesk (2011), Autodesk Ecotect Analysis. Available at: <http://usa.autodesk.com/ecotect-analysis/> (Accessed on 1 September 2015).
- [14] Hirsch J. (2009), The Quick Energy Simulation Tool. Available at: <http://doe2.com/equest/index.html> (Accessed on 1 September 2015).
- [15] DesignBuilder Software Ltd. (2014), DesignBuilder. Available at: <https://designbuilder.co.uk/> (Accessed on 1 September 2015).
- [16] Integrated Environmental Solutions Ltd. (2015), VE-For-Students. Available at: <https://www.iesve.com/software/download/ve-for-students> (Accessed on 1 September 2015).
- [17] Green Building XML (gbXML) Schema Inc. (2018), About gbXML: some background info and the organizations involved. Available at: http://www.gbxml.org/About_GreenBuildingXML_gbXML (Accessed on 5 July 2018).
- [18] Green Building XML (gbXML) Schema Inc. (2018), Software list: software tools that integrate with gbXML. Available at: http://www.gbxml.org/Software_Tools_that_Support_GreenBuildingXML_gbXML (Accessed on 5 July 2018).
- [19] Green Building XML (gbXML) Schema Inc. (2018), What is the difference between IFC and gbXML? Available at: <http://community.gbxml.org/forums/topic/what-is-the-difference-between-ifc-and-gbxml/> (Accessed on 5 July 2018).
- [20] Dong B., Lam K. P., Huang Y. C., Dobbs G. M. (2007, September), A comparative study of the IFC and gbXML informational infrastructures for data exchange in computational design support environments. In: Tenth International IBPSA Conference, pp. 1530–1537.
- [21] Autodesk Knowledge Network (2015), Specify the Green Building Studio Project for Energy Analysis. Available at: <http://help.autodesk.com/view/RVT/2015/ENU/?guid=GUID-2B7F5C32-1C33-4CE4-B763-BFED-6399C2D3> (Accessed on 27 Jun 2016).
- [22] Osello A., Cangialosi G., Dalmasso D., Di Paolo A., Turco M. L., Piumatti P., Vozzola M. (2011), Architecture data and energy efficiency simulations: BIM and interoperability standards. In: Proceedings of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association, Sydney, 14–16 November.
- [23] Hetherington R., Laney R., Peake S., Oldham D. (2011), Integrated building design, information and simulation modelling: the need for a new hierarchy. In: Building Simulation 2011, 14–16 Nov 2011, Sydney, Australia.
- [24] Pauwels P., Van Deursen D., Verstraeten R., De Roo J., De Meyer R., Van de Walle R., Van Campenhout J. (2011), A semantic rule checking environment for building performance checking. *Automation in Construction*, 20(5), 506–518.
- [25] Karan E. P., Irizarry J. (2015), Extending BIM interoperability to preconstruction operations using geospatial analyses and semantic web services. *Automation in Construction*, 53, 1–12.
- [26] Integrated Environmental Solutions Ltd. (2014), IES Virtual Environment & Compliance with ASHRAE 90.1 2004, 2007, and 2010 Appendix G Performance Rating Method. Available at: https://www.iesve.com/software/virtual_environment_prm_compliance.pdf (Accessed on 5 July 2018).
- [27] Dimitriou V., Firth S. K., Hassan T. M., Fouchal F. (2016), BIM enabled building energy modelling: development and verification of a GBXML to IDF conversion method. Proceedings of the 3rd IBPSA-England Conference BSO 2016, Newcastle, 12th–14th September 2016, p. 1126.