Design for Sustainability: An approach based on the integration of BIM and Building Performance Analysis

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ABSTRACT

BIM has emerged as a modern method for the design and management of construction throughout the lifecycle of a project. BIM has been widely used in various activities such as architectural and structural design, scheduling, resolving clashes, data sharing, monitoring projects, and various applications during the construction phase of a project. Nowadays, most countries are motivated in building great infrastructures thereby causing increased carbon emissions and energy consumption. This leads to a rise in the greenhouse effect. To overcome this crisis the AEC industry has given more importance to sustainable design and construction. Different private organizations have introduced various advanced technologies which have capable in analyse the building performance for sustainable outcomes. In construction, the industry has followed innovative methods through a collaboration of BIM with the Building performance analysis (BPA)tools to enhance the sustainable design workflow. This research paper brings an overview of the importance of sustainable design in the AEC industry. The importance of the BPA tools which are used along with BIM for the analysis of energy consumption and carbon emission. The hypothetical case study has demonstrated the step-by-step procedure for fully integrating BIM and BPA by using the Revit application and IES VE (Integrated Environment Solution and Virtual environment). This producer can be able to understand the relationship between BIM and BPA tools. Mainly about the challenges faced during the interoperability process which will be affected the sustainable analysis. Through the integration of BIM and BPA tools can be able to understand the current level of limitations and benefits of the sustainable design workflow.

1 INTRODUCTION

Building information modelling (BIM) widely used technology in architecture, engineering, and construction (AEC) have a prominent role in developing 3D geometry, object-oriented, parametric, quantity estimation and clash detection [1]. The BIM as well as data-rich enables the coordination to achieve a suitable platform for the data exchange [2]. In the construction sector, sustainable development is a new path for the reduction of carbon emissions and energy consumption from infrastructure and construction activities. An ecologically friendly building or environment must be the ultimate result of sustainable construction projects [3]. BIM gives significant flexibility to integrate supportable measures

through all the various phases of the project life cycle so the collaboration of BIM with sustainability is considered a major area in the AEC industry [1], [4].

The BIM applications and BPA tools are two different software which has been used by different teams for their specific discipline. For example, BIM authoring tools like Revit and ArchiCAD are used to create models, on the other hand, the BPA application like IES VE, and Ecotect were used for the energy simulation [4]. Using BIM can significantly aid in the creation of the model and sharing information with the BPA tool for the energy analysis which helps to make the decision process and works effectively to achieve a sustainable goal during the design stage [6]But during the integration of BIM and BPA applications, some common issues arise regarding interoperability [6], [7].

This research study talks about BIM aid for sustainable design and BIM-based BPA tools which are used to evaluate the building energy and carbon emission. This research investigates the relationship between BIM and BPA tool and their drawback during the interoperability process which affects the building energy analysis during the design stage. The benefits and limitations of integration of BIM and BPA tools.

1.1 Aim and Objectives of the research study

The purpose of the research is to address BIM for sustainable development in the construction industry through the collaboration of BIM and the BPA tool. The key to achieving sustainability in the AEC industry by the integration of BIM and BPA tools for the analysing of building performance

- To investigate the need for building information modelling (BIM) in sustainable development in the AEC industry.
- To investigate the different BPA tools used along with the BIM.
- To investigate the integration of BIM and BPA tools to address both the design phase and interoperability towards sustainable analysis through a hypothetical case study (by using Autodesk Revit and IES VE).
- To know the limitations and benefits of the integration of BIM and BPA.

2 BUILDING INFORMATION MODELLING IN THE INDUSTRY

2.1 Awareness of sustainability in the Construction Industry

The building environment sector plays a significant role in carbon emission and energy consumption which causes an increasing greenhouse effect globally. From the data on global energy consumption for the period of 2015 - 2021, the worldwide carbon-di-oxide emission went up by 2% to 3.5 % every year [8]. China is known for the largest CO_2 emission and energy consumption which accounts for around 41% directly and indirectly from construction activities [9]. The United States accounts for 22% of the overall energy consumed by the greenhouse gases produced. European Union contributes around 18% of carbon emissions only by building the environment [10]. There is no sign of a decline in energy consumption and carbon emission from the building operation sector as the consumption remained constant over the years [10]. Due to this effect, the known impacts and consequences are as follows:

- Due to CO_2 emissions, the atmosphere is covered by a layer of warm temperature which prevents cooling and thus causes a rise in global temperature. Also, there will be an increase in sea level and a significant rise in ocean temperature [11]. According to a report from the "National Oceanic and Atmospheric Administration", in the year 2017, both the land and ocean temperatures were at an average rate of 0.63°C, but in the year 2021, it has increased to an average rate of 0.85°C.
- This effect causes acid rain which is harmful to nature and built exteriors also. This rise in global temperature affects the whole ecosystem [12].

The construction industry considered this issue seriously to reduce the overall greenhouse gas effect. To overcome this crisis, the government and researchers have come up with many environmental guidelines, policies, and innovative methods to minimise energy consumption [5].

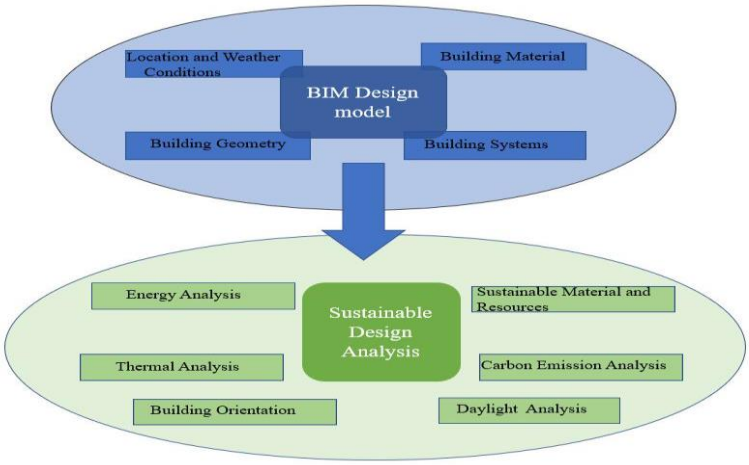
2.3 BIM in Sustainability Design

the construction industry has developed distinct software or tools like Ectotect, DesignBuilder, and IES VE which can simultaneously create a model and simulate to address sustainability challenges. However, these digital project model design applications lack some features for sustainability analysis like building construction material and parameter details which will be insufficient for evaluating building energy performance [13]. In this case, BIM software helps by providing rich data to the existing model. Hence the implementation of BIM for sustainable building design flagged as an innovative method for the AEC industry [14].

The functions of Building information modelling for sustainable analysis are:

- BIM digital model has integrated all the information like architecture and structural materials, internal loads, HVAC systems, building parameters like locations, and weather conditions. The BIM digital model integrates all necessary information. The geometry model can be utilised for energy simulation as well as for sharing information with different other software tools in the project development [16].

- From the Management perspective, throughout the building life cycle, BIM creates a collaborative working environment by combining work and management processes [17]. It also facilitates information sharing and connecting stakeholders on the same project. It helps in arriving at accurate decisions and the improvement of management efficiency. It also offers the client intrinsically improved capabilities for continuous facilities management throughout building occupancy [17].



Information flow for sustainable design analysis from BIM (Adapted from [4],[18]).

As from the above figure, the model which are designed by using BIM will have rich data about the design components and project information. where it not only designs geometry models moreover, can store the model information like parameter details, topology, building mechanical and electrical systems and constriction details. BIM aids significant optional for interoperability which allows the collaboration with different sustainable tools for analysis of the building energy consumption and carbon emission within an environmentally sustainable design framework [15].

2.4 BIM Integrated BPA for Sustainable Design

Building performance analysis tools (BPA) are also known as Building energy simulation tools which will help analyse the amount of energy consumption and carbon emission and provide a baseline to construct sustainable buildings on-site [19]. Building performance simulation can be used to evaluate the energy in many alternative ways, which helps by providing clarification and making a decision by the professional's design team and technical team [20] [21].

Interoperability is known as a communication product which means the ability to transfer the data with different software [22]. Typically, the architecturally developed model by using the BIM tool is imported into the BPA tool by using one of the standard file formats either IFC or gbXML, which supports carrying out energy analysis [23].

3 METHODOLOGY

The data has been gathered for this research through primary and secondary sources. Firstly, secondary sources have been collected through research papers that have been published in other research journals, and articles. The information is gathered to learn about the importance of sustainable design in the AEC industry. Also, to know BIM plays a prominent role in sustainability in construction design and management. The primary data was collected and analysed by performing a hypothetical case study or sample case study. It is done by designing a residential 3D model using the Autodesk Revit software tool which has been imported to one of the BPA tools (IES VE). the data is collected and analysed to know about the difference in the building performance results, so carbon emission analysis is carried out for both default model and the modified model. Overall this case study can collect data to know about the relationship between BIM and BPA tools through the interoperability process. It also reveals the benefits and limitations of the 'Integration of the BIM and BPA tool'.

3.1 Preface for the hypothetical case study analysis.

This case study has the vision to understand the relationship between BIM and BPA tools by using Autodesk Revit software and the IES VE tool respectively. This paper has explained the integration of the BIM and BPA process which takes place in three parts were known as firstly by designing an analytical model in Revit software, secondly transferring data from Revit to IES VE and verification of the model data then finally simulation in the BPA tool**.**

3.2 Designing the analytical model

A simple residential 3D model has been designed for this research study by using the Autodesk Revit 2021 software tool which is shown in the figure below.

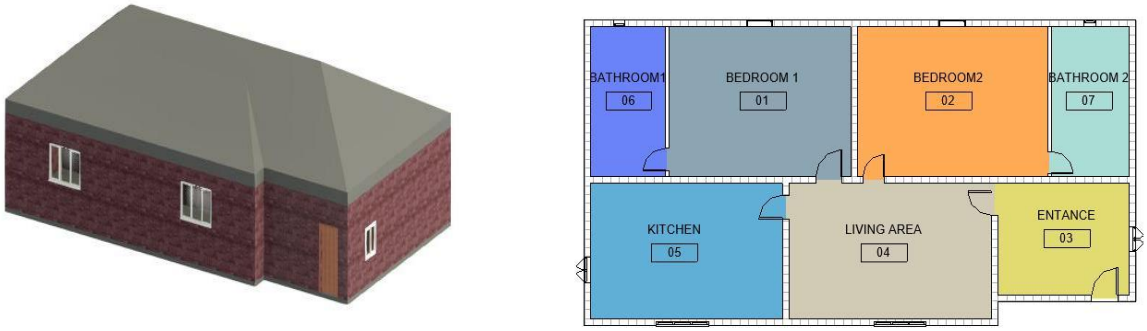


Figure 7: 3D Model and its room areas created from Autodesk Revit

Information of model elements used in Revit

Structure	**Construction details**	**U-value** [W/(m^2K)]
Exterior wall	The basic wall contians with Standard materials	0.344
Interior wall	Brick and both sides covered with light plaster	0.258
Floor	Concrete floor	1.211
Ceiling	Gypsum wallboard	1.087
Roof	Sloping roof	0.163
Doors	Wooden door	3.244
External windows	Large, double-glazed windows	3.689
External windows	Single glazed exterior windows	3.144

The imported report can be checked in the IES VE tool during the interoperability process which provides detailed information about the specification and dimensions of the BIM model [24], all the thermal zones were exported from Revit to IES VE normally.

3.3 Investigation of data transfer from Revit to IES VE

There is one difference between these two applications, where the geometry zones of the Revit model were represented as thermal zones in IES VE for energy analysis [7]. As shown in figure (11), But there are some errors identified in the IES VE application that, there was unbonded or a gap created between the roof and model level. Due to the compatibility of the Revit model in IES VE, as a result, one of the exterior walls was mismatched, as presented in figure (9). Apart from this the building location, building type, orientation, and construction details like building envelope elements and U- values data were exported successfully, but IES VE has failed to import the Schedules detail.

3.4 Modification of the Model

The data is transferred from Revit to IES VE through the gbXML then an imported statistic report needs to check the errors and warnings, meanwhile, the geometry model needs to be verified then the model needs to be modified before evaluating the building performance for the effective result [25]. In this case study, the model is transferred again back to the Revit tool to modify the model's area and volume. To correct all the mismatched edges of the external wall and modified the roof error. Then, followed with the same procedure to export the Revit model through the gbXML tool to IES VE and run for analysis. The overall

workflow of this hypothetical case study concerning the interoperability process is explained in the above figure (12).

The continuity part of importing the Revit model to IESVE is to learn about the interoperability process and how the errors in the model will affect the overall building simulation results. In this case study, the building performance analysis is carried out on carbon emissions. So, firstly the total CO_2 emission analysis was carried out on the error model then again same analysis was carried out on the modified model and the results were compared. This difference between the two types of total carbon emission analysis performed with both the error and modified data model is explained in the results and discussion section.

4. Results and Discussion

Sustainability analysis of a building needs to be carried out during the design phase to avoid rework, mitigate errors, and reduce the time and cost during the construction phase. Comparatively, 2D drawings have limited information about the model details but the BIM-based 3D models are enriched in data including building elements, components, schedules, and parameter details, BIM is also efficient for sharing information with other tools. So, for this reason, BIM is widely used along with the BPA tools for sustainable analysis during the design stage. Collaboration between the architectural team and technical team for evaluating the building energy performance gives room for immediate alterations and corrections where needed.

Through published research papers, it is understood that there some BIM-based BPA tools are used for sustainable analysis such as Ecotect, GBS (Green Building Studio) DesignBuilder, and IES VE tool (Integrated Energy Solution and Virtual Environment). These BPA tools cannot be able to import data from the BIM application directly, so it needs a supporting file format like gbXML or IFC which is commonly used. During the integration of the BIM and BPA, some errors or issues might arise through the interoperability process which will impact the overall energy analysis results. There is a lack of research conducted on this interoperability issue during the integration of BIM and the BPA tool. So, a hypothetical case study has been carried out in this research project by using Revit and IES VE tools.

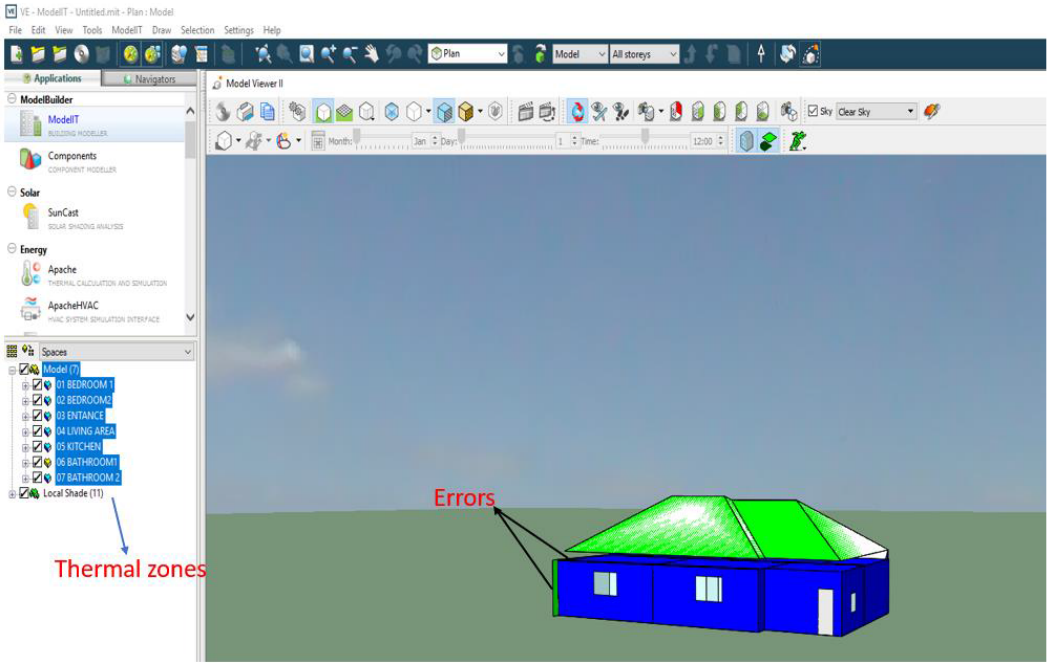
By using one of the BIM-authorised tools, the Revit model has been created for a small residential building with all components like an external wall, interior wall, roof, floor, door, and window. Through the gbXML, data has been imported successfully to the IES VE.

Summary of the data transfer from Revit to IES VE

Parameter	**Description**
Location details and Building type	Location details and Building type were successfully imported to IESVE.
Orientation	Building orientation imported accurately.
Geometry model	Model elements import successfully but an error was found in the elevation.
Construction details and material details	The U-value was imported but construction materials details were missing.

Rooms zones	All geometry zones were imported but changes in area and volume
Schedules	IES VE tool has failed to import the schedule details.

During the interoperability process, there are some errors and default values found in the model. It was observed that there was a gap created between the roof and ceiling. Due to the partial compatibility of the Revit model in the IES VE tool, the external walls are mismatched as shown in the figure below.



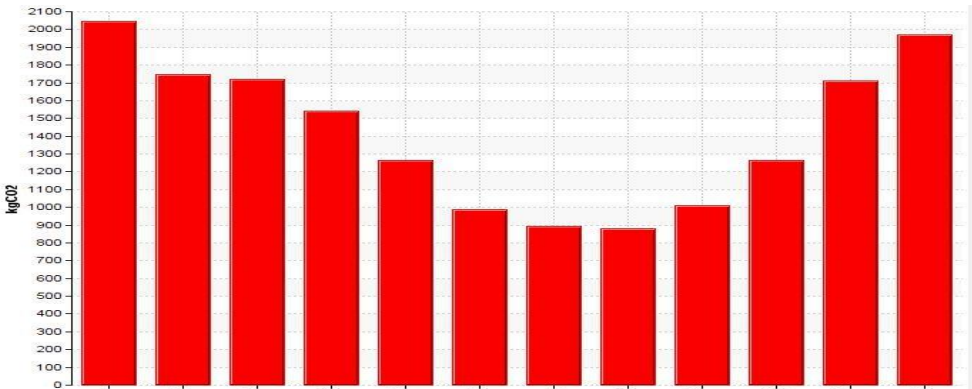
Model imported in IES VE indicates "thermal zone" and "errors".

There are some other default values where the area and volume were changed during the interoperability process. The changes in area and volumes are mentioned in the table below.

Comparison of the area and volume

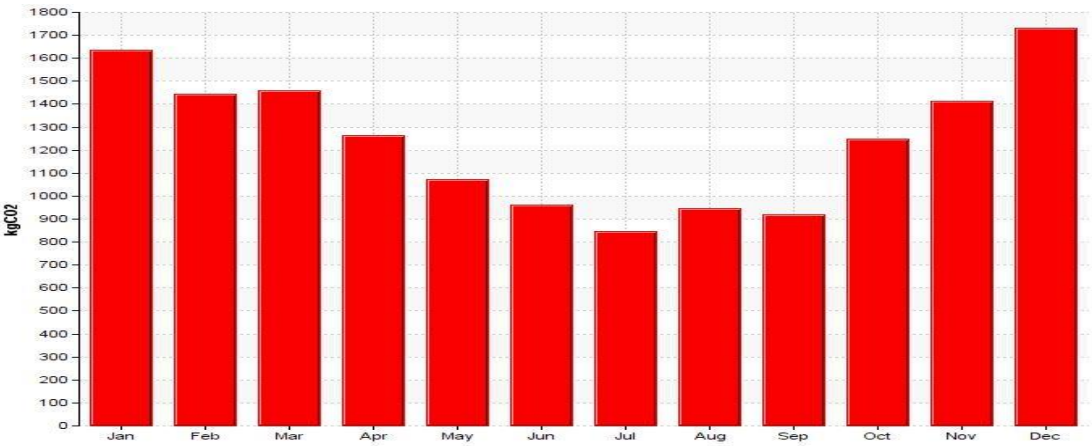
Zones	Room Area (m^2)		Volume (m^3)	
	Revit	IES VE	Revit	IES VE
01	35.74	35.74	105.98	106.36
02	36.91	38.01	92.34	109.18

Again, back to the Revit application which could be able to modify the model manually with respective the errors found in the IES VE tool. To know how the default values will be affected for the building simulation result. So as a continuity part of the interoperability process between the BIM and IES VE was carried out to evaluate the total carbon emission (CE) of this residential model on an annual based.



Snapshot of the total carbon emission analysis with the error model in IES VE.

Through the IES VE can able to analyse the carbon emission which results will be represented through the graphs as shown in figure (13). This graph represents the analysis of the total carbon emission (CE) from the model which has errors and default values. In the graph, X-axis which is representing the months, and the y-axis which is representing the total carbon emission value in kilograms.



Snapshot of the total carbon emission analysis with a modified model in IESVE.

Again, the same residential model was corrected with the unmatched edges, roof, error of area and volumes and it was again imported to IES VE. Then the model was analysed for the total carbon emission for the annual which can be observed in the above figure (14). The overall total carbon emission per year is calculated and the difference between these two kinds of carbon emission analysis is summarised in the below table (4).

Comparison of total carbon emission results

Types of models	Annual Total Carbon emission (Kg CO2).	The average value of the annual Total Carbon emission (Kg CO2).
A model with default value and errors	17034	1419.5
modified model	14944	1245.3

During the interoperability process, there will be existing errors in the model that will form inaccuracy in the building performance results. Through this case study, it is shown that the model has some errors and variations in dimensions which shows the difference in the simulation results. This impact was demonstrated by analysing the total carbon emissions. As a result, there is a difference in the total carbon emission value which is shown in the table above. Furthermore, the difference between these values of the total carbon emission is an average of 174.2 $kgCO_2$ per year (1419.5 -1245.3 = 174.2 $kgCO_2$) which is an overall 2% of the variation in these two different kinds of analysis.

Due to the contrast in results, it is evident that in this small model there are variations. So, for complex or large building models there is a much chance for an increase in default values and errors through the interoperability process. This will create a huge variation in the simulation values to achieve a sustainable target. Therefore, the architecture team

and technical team need to give more importance to interoperability during the integration of BIM and BPA tools.

This hypothetical case study proves that during the design stage, the BIM integrated BPA tool will successfully achieve the simulation of building performance. The model imported report which will be generated in IES VE provided more detailed information about the building standards and specifications which will be more convenient to understand for professionals. The integrated BIM will provide an actual model and information about the building which helps in better visualisation and have capable of monitoring for the sustainable simulation. It is, therefore, necessary that before carrying out any building performance like energy simulation or carbon emission analysis, designers need to be more cautious on the information exchange and need to rectify errors for an effective sustainable analysis outcome.

Apart from the above issues, there are some other limitations to the integration of BIM and BPA tools which came to be known from this research study that the integration of BIM and IES VE is semi-automated which requires manual setting from both tools during exchanging the data. Manual clean-up is required during the modification of the model from the errors.
On the other hand, there are some benefits from this integration of the BIM and BPA are:

- During the design phase, in Revit parameter information can be added and that will help effectively during sustainable analysis. These parameters can be modified easily.
- The data exchange is bidirectional between Revit and IES VE through gbXML.
- Moreover, through this case study, it is shown that the integration of BIM and BPA tools will act as a single platform for exchanging data and helps to update the model where the design team, technical team, operation, and maintenance team can work parallel toward a project to achieve the sustainable target.

5 CONCLUSIONS AND RECOMMENDATIONS.

5.1 Conclusion

This research is based on a hypothetical case study that shows a clear picture of the interoperability process and the overall benefits and limitations of the integration of BIM and BPA tools. This study process is carried out in three phases. Firstly, designing an analytical model by using BIM authorised REVIT tool. Secondly, data export and import via gbXML format and finally, the simulation from the IES VE tool. It was observed that a semi-automated workflow exists during this integration of BIM and the BPA tool. This is because, during data export, some parameters must be activated in Revit manually. Also, while importing to IES VE it is necessary to align the settings manually. The settings include the building details like location and weather file through gbXML. For example, it is not possible to import all the data by the IES VE tool. To analyse the interoperability effects in the simulation output, carbon emission analysis is carried out in the IES VE tool for the imported residential model in two different approaches. In the first approach, the carbon emission analysis is carried out successfully with the model which has default

values and errors. In the latter approach, the same model is modified and again imported to IES VE and then the test is carried out.

5.2 Limitations of the research study

This research paper has explored all possible extents of the topic. However, there are a few local constraints concerning the research. This paper mentions four BPA tools namely Ecotect, GBS, IES VE and DesignBuilder. But this paper focuses on the IES VE tool due to its nature. As mentioned, the other tools can be explored in future studies. The other constraint is that this paper has mentioned two supporting file formats namely gbXML and IFC for the integration of BIM and BPA. Since the gbXML format has the best suitability for this research, the other format is used in a limited manner. Further research based on this topic can involve the other file format to overcome this limitation.

5.3 Recommendations

The following recommendation is based on the hypothetical case study by using Revit and IES VE.

- In the future, research needs to develop more on the interoperability process to overcome the issues or find any alternative methods for the seamless data exchange between BIM and BPA tools.
- While the integration of BIM and BPA tools, the researchers can utilise the model viewer tool for the data exchange process and visual errors in models before carrying out any building performance simulation of the model in future research.
- The automation process needs to be developed during interoperability settings and to avoid manual clean-up during the modification process.

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