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Investigating Building Information Model (BIM) to Building Energy Simulation (BES): Interoperability and Simulation Results

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Abstract. Buildings are a main contributor to energy consumption, it accounts for approximately one-third of global energy use; therefore, 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 low energy buildings including the building energy simulation (BES). However, there exist challenges for exchanging data and interoperability has caused barriers to utilize the information from BIM for BES. This paper explored the energy model accuracy of two different software including Autodesk Revit and DesignBuilder. The annual electricity consumption of the two programs were analyzed and compared to the actual measured consumption data of three typical residential building on different three locations including Cairo, Alexandria and Asyut. The outcomes suggest that comparisons may be made between building energy performance simulated data and measured data, nevertheless the outcomes might vary based on the human behavior patterns within the model. Additionally, the results show that DesignBuilder simulated data was close to actual data for the electricity consumption than the Revit however both programs were very close to the actual measured data.

Keywords: BIM, BES, Interoperability

1. Introduction

Over 60% of the total electricity consumption in Egypt is attributed to residential, commercial and Governmental buildings[1], with residential buildings account for approximately 43% of total electricity consumption in the country [2], The increased population, housing stockin addition to better living standards, leads to an expected energy supply deficit between 30 and 50 m.t.o.e between 2020 and 2050, which is 24–35% of demand[2]. This increase in the energy consumption can be avoided by a well designed building envelope at the initial design stage based upon the climate type of the building location. Itwas estimated that between 20% and 50% reduction in total energy consumption could be achieved by implementing appropriate building envelope design.The relation between the building envelope design and energy consumption data can be identified through iteration by changing



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the variables. Through creating and calibrating the right the numerical method[3]. As it enables designers and clients to foresee the problems in the final product and facilitates the parametric analysis among a broad range of design scenarios. Therefore, it helps in solving the time consuming dilemma and save cost as it can simulate the subject within a short time frame with minimum cost if compared with the mathematical or experimental approaches. However, previous studies confirm that most of the available performance simulation tools (BPS) are not compatible or friendly with architects' needs or working procedures [4, 5, 6]. As for many architects, most of the building energy simulation tools (BES) are moreover complicated and not a design supportive tool [6]. Until recent years, as more attention has been focusing on the collaboration promoted by the Building Information Modelling (BIM) between the different disciplines by affording a single 3D CAD model containing all relevant data and can be easily exported to various function-specific software [7]. BIM can help to increase the efficiency of BPS by facilitating the data input for simulation and therefore allowing more scenarios to be investigated. [8]. The information provided through the BIM model can perform as an input for BPS and therefore can reduce the amount of complexity and time consuming of drawing the model again or setting up the simulation manually on the BPS [9].

This paper aims to assess and compare the transfer of building geometry data via BIMformat into BPS and order to investigate the accuracy of their outcomes. the For this purpose, two simulations software including REVIT as BIM and DesignBuilder as BPS were carried out in within three different locations within the Arab Republic of Egypt, including Cairo (hot arid climate), Alexandria (hot humid climate) and Asyut. Analyses of the results generated by two simulations software were tested with the actual measurements for the validity and efficiency of the outcomes.

Selection of Software

Autodesk Revit is commercially available Computer Aided Design (CAD) software that enables the user to follow a Building Information Model (BIM) workflow for any Architectural, Engineering and/or Construction (AEC) project. This includes, among other features, producing 3D geometry and an energy analysis of the building. The energy simulation is conducted using Autodesk Insight 360 as a Revit Plug-in. Autodesk Insight provides whole building energy, heating, cooling, day lighting and solar radiation simulation by utilizing the EnergyPlus[9] simulation engine. The BIM practice using Autodesk Revit 2017 confirmed that is one of the best procedures for addressing the energy analysis of buildings [10].

DesignBuilder is also a commercially available CAD software for 3D modelling of buildings for the purpose of energy efficient design and building operation. DesignBuilderis developed allowing the import of BIM data from another computing environment presumably, so that only energy relevant BIM parameters are used [11]. Again, EnergyPlus is the simulation engine used utilizing thermal zones and component-based HVAC systems. Autodesk Revit, which is a BIM-based design tool, is among the leading BIM software platforms [12]. Therefore, it was chosen as the BIM authoring tool. DesignBuilder, which is non-BIM based, is the selected pre-processing tool for gbXML. It supports importing BIM through gbXML and allows for IDF export, which is the format needed to be imported into EnergyPlus[13].

2. Methodology

The methodology implemented in this paper includes two aspects as follows:

- testing the information exchange accuracy from BIM (Autodesk Revit) to BES tool (DesignBuilder)
- determining the accuracy of the two programs including REVIT and DesignBuilder on conducting an energy modeling in estimating the energy consumption of air-conditioned residential buildings

The first step was to identify typical residential building typology and characteristics through literature review including a description of a comprehensive set of building construction, equipment and dimensions. The second step was to build the building geometry and all information needed in REVIT before exporting the 3D model and the attached data to DesignBuilder. The third step was to conduct the same numerical simulations using the REVIT and DesignBuilder for the representative case

studies. For the final step, results analysis was carried out for both programs in comparison with the actual data obtained from the literature review

2.1. Case Study Selection criteria

According to the 2006 census report [14] almost 90% of the air-conditioned dwellings are located in the residential sector in three main cities known as Cairo, Alexandria and Asyut [15]. Accordingly, these three cities were selected Cairo (30.13°N and 31.0°E) Alexandria (31.2°N, 29.95°E), and Asyut (31.18°N and 27.18°E) where the outdoor design temperature are 38.5°C, 32°C and 41.2°C, respectively.

The apartments size are varies yet according to census 2006 [14], apartments in Egypt are categorized based on four classes as follows:

- A: 7 percent have gross areas greater than 130 m²
- B: 47 percent have gross areas between 110 and 130m²
- C: 23 percent have areas between 90 and 110 m²
- D: 11 percent have areas between 60 and 90 m²

Based on this classification, the majority of air conditioned residential apartments are in class B. Attia and Evrard, [15] conducted a survey on three middle class neighborhoods that fall in class B with high penetration values of air-conditioning units on these three major cities based on the local electricity utility companies and from on-site observation in the three cases. Therefore, the study aimed at:

- selecting the same cases that was performed by Attia and Evrard, [15]
- performing numerical simulation for each representative case using REVIT and DesignBuilder
- using the local electricity utility for validation the modelling outcomes
- The selection resulted in three neighborhoods, namely Mohandessin in Cairo, SidiGaber in Alexandria, and Firiyal in Asyut. According to by Attia and Evrard, [15] site observations showed that those residential neighborhoods have buildings with minimalist and replicated modular architecture. Apartment blocks and concrete walk-up buildings are dominant.

2.2. Building Description

The case study building as shown in figure 2 is of total area 122 m² with a net conditioned area of 60 m², representing three rooms per apartment. The basic building construction is a reinforced-concrete post and beam structure with 0.15 m thick brick infill walls without insulation. Windows are single glazed, transparent and have a 0.003 m thick glass pane. The total amount of glass in the North and South facades is estimated to be between 45% and 35% of the total wall area. There is no solar protection for the facades and most wooden windows are draughty. Table 1, lists the general description of the sample building and some properties for the construction materials used.

Table 1. Building description

Building description.	
Shape	Rectangular (25 m x 11 m x18m)
No of floors	6 and 2.8 m height per floor
Aspect ratio	2.3/1
Apartment description	
volume	366 m ³
External wall area	110 m ²
Roof area	122 m ²
Floor area	122 m ²
Windows area	60 m ²
Glazing U-Value	6.25 W/m ² K

Exterior wall UValue	2.5 W/m ² K
Roof U-value	1.39 W/m ² K
Floor U-value	1.58 W/m ² K
Single clear glazing	$T_v = 0.88$
Solar Heat Gain Coefficient (SHGC)	0.75

2.3. Annual electricity usage

Based upon the analysis of the local electricity utility companies billing history, the average consumption for a typical apartment was 26.6 kWh/m²/year in Cairo, 22.4 kWh/m²/year in Alexandria, and 31 kWh/m²/year in Asyut based upon the analysis of the local electricity utility companies billing history [16].

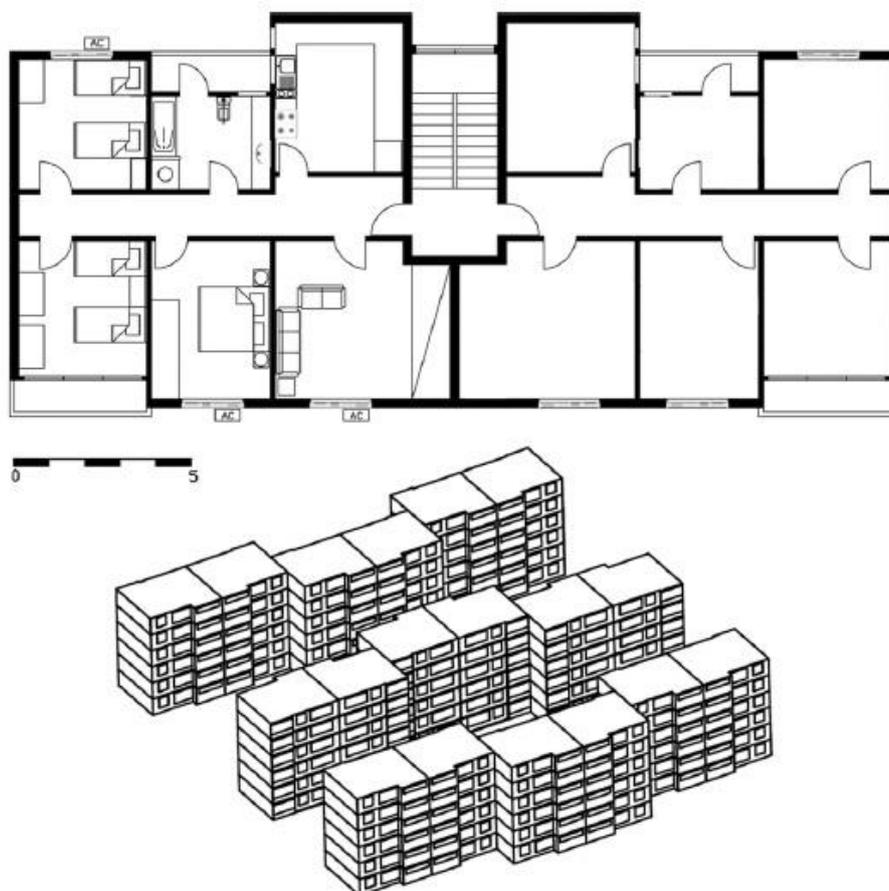


Figure 1. The case study classified as class B and its urban context.

2.4. Modelling approach and settings

The second step according to the methodology is to use building information modeling (BIM) tools (Revit) in order to create the physical building geometry with envelope construction, occupation, HVAC system, and other building load related information incorporated. All this information was obtained from the literature review including table 1 for the building construction and building envelope and based on Attia and Evrard, [15] survey all other information was extracted such as the Occupancy rates, density and schedule. As seen in Figure2, the architectural model was simplified and the interior spaces and zones were defined in BIM. The location and weather file were all defined in

Revit in addition to all other necessary information such as operation schedule, internal loads, and HVAC system. Then comes the Revit to DesignBuilder transition process, which is according to the DesignBuilder manual there are currently two ways to transfer Revit BIM data to DesignBuilder (Figure 3) either to use the DesignBuilder Revit Plugin which is the case in this research or using the built-in Revit gbXML export menu option to create a gbXML file which is then imported into DesignBuilder. According to Salmon [17] exporting gbXML files may have some errors that need to be sorted out before modelling where 6 out of 10 gbXML files were successfully exported to BES. This was confirmed with previous studies which have reported to have problems with geometry during export of either gbXML or IFC [11; 18]. For both ways an intermediate Analytical Model have to be generated by either place rooms to create an Analytical Model (AM). This can be done either manually or for, closed and bounded areas, it can be done automatically or automatically create the Energy Analytical Model (EAM). In the current research the first approach was applied by doing it manually. The most important of these steps is to accurately identify the “rooms” or “spaces” in the model.

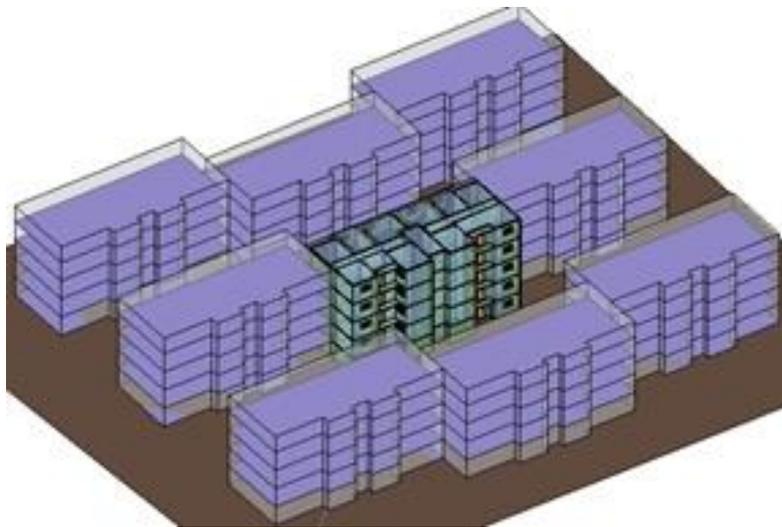


Figure 2. the model in Revit with surrounding buildings

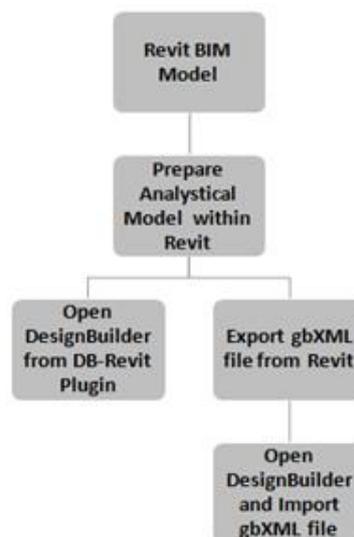


Figure 3. Exporting Revit (BIM) model and data to DesignBuilder (BES)

3. Analysis and Discussion

The model simulations have been carried out using the two programs including the Autodesk Revit (BIM) and DesignBuilder (BES) for the same building in three different locations known as Cairo, Alexandria and Asyut. Regarding the first simulation performed with Revit was straight forward, the architectural model was simplified and the spaces and zones were defined as shown in figure (4). All locations were easily adjusted for Cairo and Alexandria, as both cities were already stored within the program including their weather profile based on the nearest weather station. However, when it came to Asyut, the internet mapping services have been activated and the city was identified manually and the software automatically generates the weather profile of the location then the Revit exported all data including model geometry and settings to the cloud, where the simulations are run through EnergyPlus. On the other hand, DesignBuilder already has the three cities locations stored on the software including the weather profile for each city. The software was able to import correct geometric information from BIM model but non-geometric information was misrepresented or overwritten by template, the same error was reported in previous study conducted by Chen et al. [19]. The rooms or spaces names and numbers were all imported correctly however the function for each room has to be identified again in addition to the construction materials and the activities and occupancy patterns (Figure 5). All objects such as windows, doors, and walls which were either created or used from the Autodesk Revit families, were not treated as the same material after being transformed into a BES tool which is confirmed with previous research [19]. Therefore they were all identified again in DesignBuilder.

As shown in figure 6, the actual annual electricity consumption data was compare with Autodesk Revit and DesignBuilder analysis data. In general, both simulation results show positive and viable results since the discrepancy of the results is within the range of 15%, which means the percentage differences for both simulation software and field measurement results were acceptable according to literature review [20;21;22]. Yet the simulations outcomes compared to the reported ones are on yearly basis which makes the validation accuracy still need further investigation for its accuracy, accordingly, the validity has been further checked on monthly basis for only one case study through a calibration between the model outcomes and the utility monthly bills over one year (figure 7). However one of Revit limitation is related to the type of information and report generated where the building information outcomes from calculations only came on two file types namely as portable document file (.pdf), and extensible markup language (.xml) file. The PDF files shows only graphs and printable images including general data. Instead the XML-based file includes all information from building design data and all results obtained from simulations, yet, all data is saved in code data and text formatting, which implies that the data isn't legitimately perceived by Excel or other number based programs. Consequently, the issue was illuminated by the change of information downloaded from text to numbers using Excel documents. Still, it could turn into shortcoming for further research including large amount of data to analyze.



Figure 4. Spaces and zones identification in BIM (Revit)

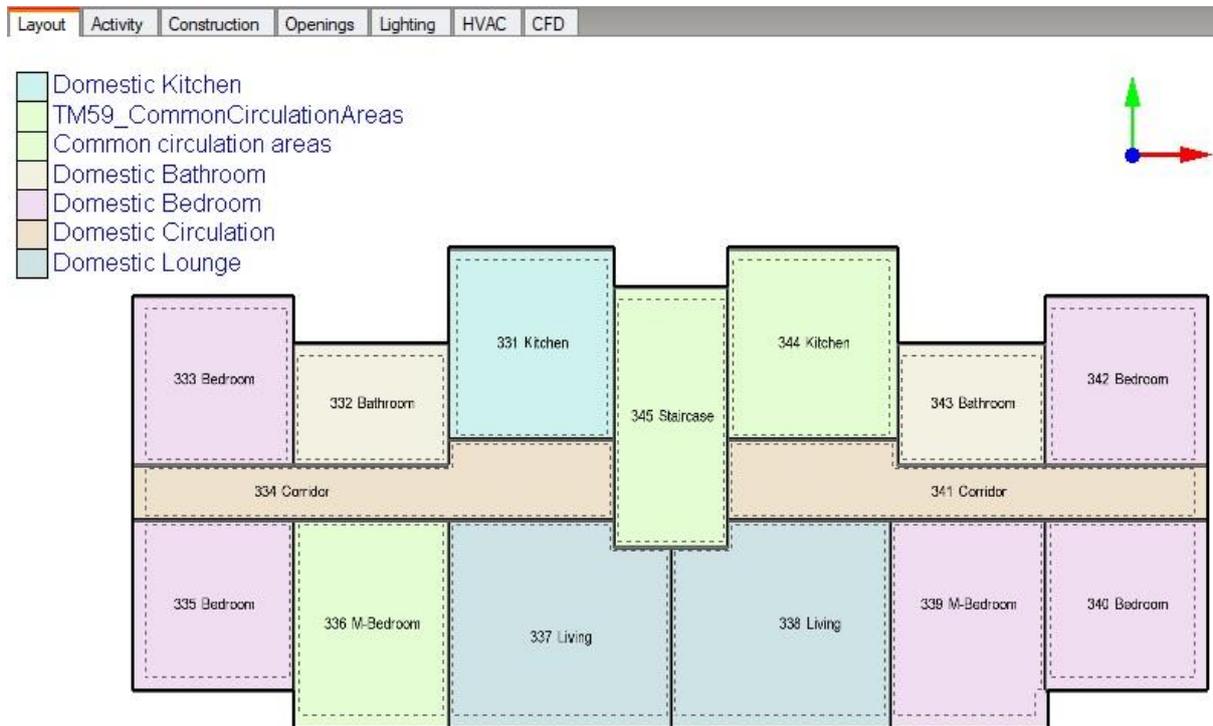


Figure 5. Spaces and zones identification in BES (DesignBuilder)

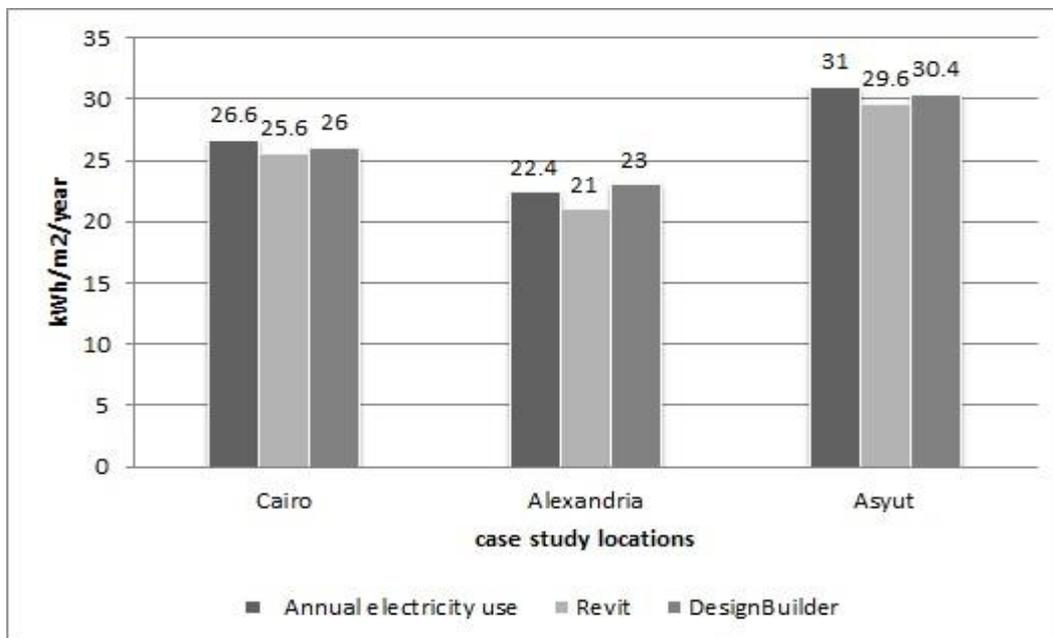


Figure 6. Annual Energy consumption for each building according to official bills and simulated results

Figure 7 presents the comparison between the estimated averages monthly electricity usage and the corresponding energy modeling for Cairo Case study. Revit and DesignBuilder outcomes are plotted against the data obtained from the monthly electricity bills over one year. The two simulations outcomes were in a good approximation with the obtained ones. The Revit and DesignBuilder estimated energy plotted curve shapes showed a good

approximation with the observed data. The results show that DesignBuilder simulated data was close to actual data for the electricity consumption than the Revit however both programs were very close to the actual measured data. Yet, the both shaped were slightly shifted towards lower limits than the reported data in the electricity bills.

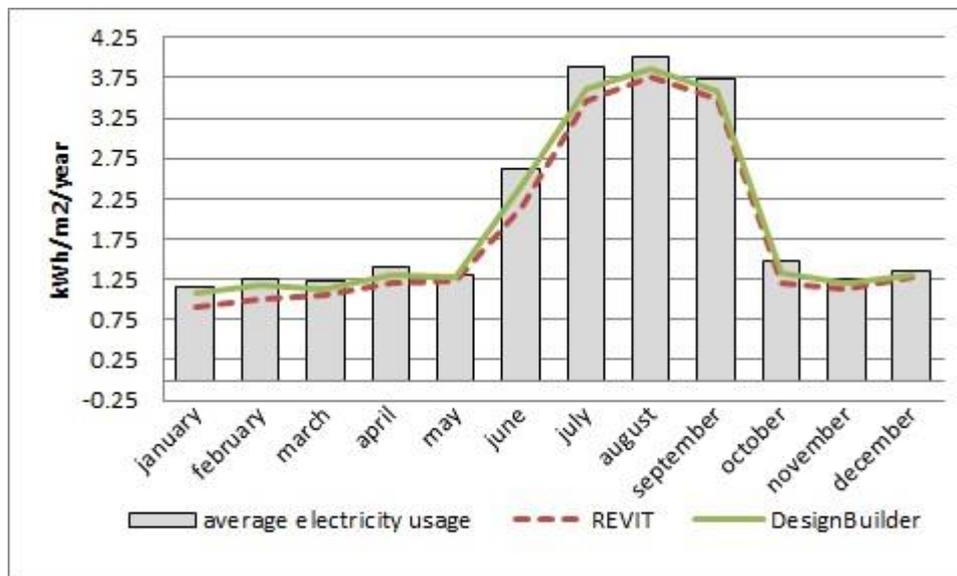


Figure 7. Surveyed and simulated monthly electricity usage for Cairo typical residential building

4. Conclusion

The objective of this paper was to investigate the information exchange accuracy from BIM to BES tool, in addition to determine the accuracy of the two programs including REVIT and DesignBuilder on estimating the energy consumption of air-conditioned residential buildings. The process of generating, extracting, transforming and simulating building geometry for the purpose of BPS is defined by an array of actions, necessary for a successful workflow. These operations are done in consecutive steps to outline a workflow, which facilitates data exporting between the two programs. Figure 8 gives a detailed outline of the steps taken. First a case study model is created in Revit. The definitions for the building elements and the spaces are identified. Next, the data is exported using the DesignBuilder plug-in within the analysis ribbon in Revit. Based on the energy annually consumption data obtained from the utility bills a typical residential building located in three different cities in Egypt was used to examine the accuracy of the workflow, interoperability, modeling strategies and results. For additional validity the case study for the residential building of Cairo was further checked on monthly basis over one year. The conclusion of the analysis presented herein is summarized as follows:

- It becomes clear that both data formats are capable of extracting and transferring spatial and geometrical information from BIM models as the geometry is exported with a high degree of accuracy from the BIM model.
- The non-geometric information was misrepresented or overwritten during the process of exchanging data from BIM to BES. The rooms or spaces names and numbers were all imported correctly however the function for each room has to be identified again in addition to the construction materials and the activities and occupancy patterns
- BIM and BES are proved to be reliable tool for sustainable and low energy building design
- The 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.

- Although the both programs outputs were very close to the actual measured data, still, the acceptable range stated is too general and the accuracy by day and hour should be analyzed in order to investigate the accuracy and preference of the software for future research
- Occupant behavior was very crucial in developing the modeling calibration, as there is almost no study that identifies the user thermal behavior in the Egyptian context [16]. Therefore, it was necessary during the calibration process of comparing simulation results with the annual electricity bills to conduct an occupant behavior pattern based on field survey and on site observation.

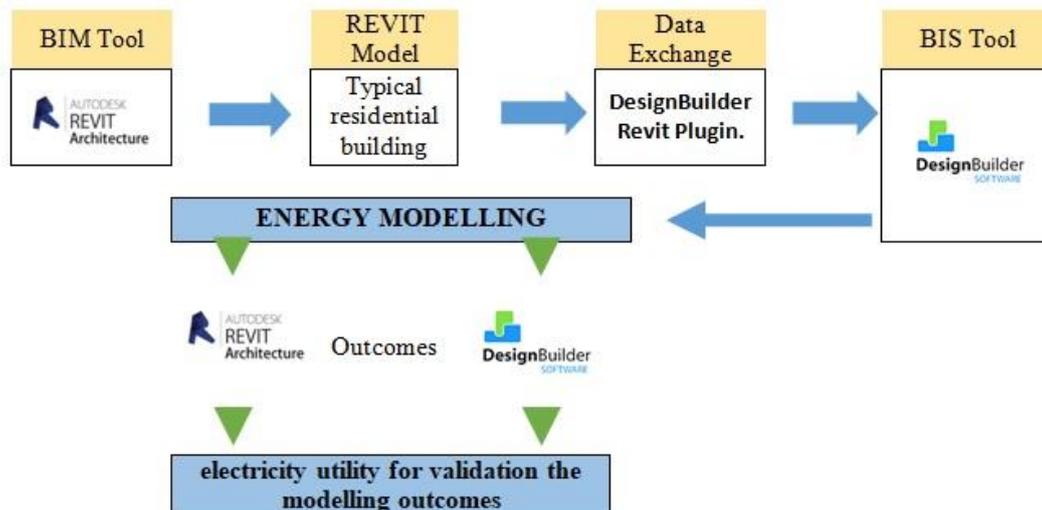


Figure 8. Methodology workflow

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