

BIM Based Design Optimization Framework for the Energy Efficient Buildings Design in Turkey

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Abstract: Buildings in Turkey consume a great amount of energy to supply comfort conditions. This is due to the ineffective design decisions by designers with no consideration of the environmental impact and energy efficiency. Thus, building design parameters should be studied and examined during the design stage considering the environment that is a crucial factor for the energy efficient building design, which may lead to better energy performance and fewer CO₂ emission.

BIM as a new way of working methodology enables energy efficient design solutions considering design parameters for the improved high building performance in Turkey. Therefore, this research aims to develop a strategic BIM framework encapsulating the optimized design process, technology implementation, building design rules considering the local values and energy performance assessment of the concept building design.

Research adopts multi case studies methodology that helps to gain qualitative and quantitative insights and understand the current practices. Revit based BIM modelling is used with Design Builder for energy performance simulation in relation to the building design parameters.

The outcome will be a design guide for the energy optimised building design in Turkey. This design guide will help designers to successful use of BIM for design optimization process, effective technology implementation, rules-based design development and energy assessment scheme reflecting local values for sustainable building design.

Keywords: Building information modelling, Design Optimisation for Energy Efficiency, Energy Performance Simulation, BIM based Design framework, Performance parameter.

1. INTRODUCTION

Buildings are the most energy user sector, making 40% of the total energy consumption (Chwieduk, 2016). To achieve significant energy saving, buildings should be designed and operated properly (Cao et al., 2016). In this regard, energy efficiency can be as a solution to energy shortage and CO₂ carbon emissions. In Turkey, the energy consumption of buildings is significantly high. According to energy statistics in Turkey, the average energy used by buildings is 175 KWh/m². While in European countries, the total energy consumed including heating cooling and ventilation is around 100 KWh/m², as a result the energy used in Turkey is two times higher than the energy used in European countries (Kazanasmaz, 2014). Nowadays, buildings are designed without taking account of environment situation. For example, new buildings in Turkey consume a great amount of energy to supply comfort conditions. This is due to inefficient design (Kocagil and Oral, 2015). Moreover, new building design in Turkey does not take into consideration the environmental impacts and energy assessment (Mangan and Oral, 2016).

Therefore, continuing the current practices of designing buildings and systems in which all the segments of the building – architecture, HVAC, and electrical system, etc. – are designed independently from each other, will keep us from achieving our energy saving goal. Current design, construction, and operation practices are classically too

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fragmented to allow the timely and effective implementation and integration of energy efficiency methods and technologies on construction of new building or renovation projects (Cho et al., 2012). That's why there is a need for efficient energy usage in Turkey because building are responsible for a great amount energy use making around half at present of total energy consumption, which will result in the increased CO₂ emission to the atmosphere (Eskin & Türkmen, 2008). To do that, design parameters should be studied and considered during the design stage about environment, which is a crucial factor that suggests enough information to develop well-suited building design.

2. LITERATURE REVIEW

There are many factors that can impact the energy use in buildings, many of them can be fixed and managed to obtain better energy efficiency. The energy performance of the building envelope materials including (external walls, roofs, windows etc.) can help in calculating the amount of energy needed inside the building (Abanda and Byers, 2016). Envelope materials can work as a suitable and promising solution for not only enhancing indoor comfort but also decreasing the energy used by buildings (Han & Taylor, 2016). The ability that a building must naturally heat or light its internal may significantly influence energy efficiency and reduces energy use. This is often measured by building orientation (Abanda and Byers, 2016). (Pacheco et al, 2012) declared that building orientation is one of the most crucial factors, which have a real impact on the energy use of building.

Building performance simulation allows the engineers and architects to investigate various design alternatives and choose the most energy efficient alternatives (Aksamija, 2013). In order to optimize and evaluate the building design and performance, various analysis and simulation should be part of an integrated building design process. This is the base of performance based design strategy. However, as mentioned by (Aksamija and Mallasi, 2010), this is challenging paradigm when compared to a traditional design method:

- Traditional design method has insufficiencies. This is due to the fact that it may include simplified assumptions based on rules of thumb which can be inaccurate, it may force an aesthetic features without considering the performance impacts, and it may not offer performance evaluation of a certain design solution.
- Building Performance based design method has an ability to determine the impact of any design solution since the building performance are investigated with actual and quantifiable data and not rules of thumb. It also uses a detailed building models to analyze, simulate, and predict the behavior of the building.

The use of emerging BIM in building energy simulations has deeply enhanced the process of building energy analysis allowing for better decision making and appropriate prediction of building performance. (Pacheco et al., 2012) defined BIM as a set of policies, processes and technologies combined to manage building design and project information digitally during building's life cycle. (Abanda and Byers, 2016) mentioned that BIM can help in optimizing building envelope by assessing the heat transferred through envelope materials to reduce energy loads. Furthermore, it can be used to decrease the energy needs and analyse renewable energy options of buildings before being constructed. BIM can be used to study the effect of the building orientation on energy use during the early design stages of a project. (Bahar et al., 2013) claimed that nowadays there is an emphasis on high-performance buildings. Therefore, BIM- based energy analysis during early design is highly needed, because BIM include the construction and use of unified and reliable information about a building. Moreover, it leads to better decision-making and appropriate forecast about the building performance.

3. BIM BASED DESIGN OPTIMIZATION FRAMEWORK

In order to achieve sustainable and efficient building design performance, critical design decisions should be made by the stakeholders during the early design stage of the building. Building Information Modelling (BIM) can be used for energy and performance simulations, where the analysis process can be integrated with the design process. The lack of integration into the design process will lead to an inefficient design process (Cho et al, 2012). Therefore the use of BIM during building energy simulation will greatly improve the energy analysis process, this is due to fact that the uptake of the Building Information Modelling (BIM) paradigm have intensified the need for collaboration between different stakeholders (Jeong and Kim, 2016). The method or approach for data and information exchange between BIM and energy analysis software are mainly depend on the purpose of the analysis and what type of information is needed. Therefore there is also a need to develop an approach which ensure transferring data and information properly and correctly between BIM model and energy software analysis.

Sustainability in architectural design looks for lower energy consumption as it leads to eliminate the negative impacts on environment as well as ensures comfort of building occupants (Abdelhameed, 2017). In order to reduce these effects, passive and ecological building design criteria should be adopted in designing the buildings. These design criteria are capable in achieving the lowest energy requirements by optimizing heat losses and gains through the building envelope (Omran and Marsono, 2016). Renewable energy can ensure the sustainability of electricity

supply while reducing carbon dioxide emissions (Sulaiman et al., 2013). It will not only lead to further modernization of the energy sector, but also achieve national economic and sustainable development goals (Inglesi-Lotz, 2013). All these issues drive to investigate the using of solar, wind and other type of renewable resources in order to generate energy (Kazem and Chaichan, 2012).

With the increasing awareness of sustainable development in the construction industry, implementation of an energy rating procedure to assess buildings is becoming more important. There are different building assessment certificates such as (LEED), (BREEAM) and Green Star. (Roderick et al, 2008). However, there is a consensus that global certification of green building is not possible due regional differences in environment conditions, supply of energy, raw material, water, availability of green materials, and economic conditions (Ilter and Ilter, 2011). That's why developing an energy performance assessment scheme for buildings considering the local design criteria and conditions is highly needed. That's why based on the facts mentioned above, a conceptual BIM based design framework is formulated see figure 1. This is to develop a guide or approach for how BIM can be adopted successfully for the purpose of design optimization and energy efficient building at the early design stages.

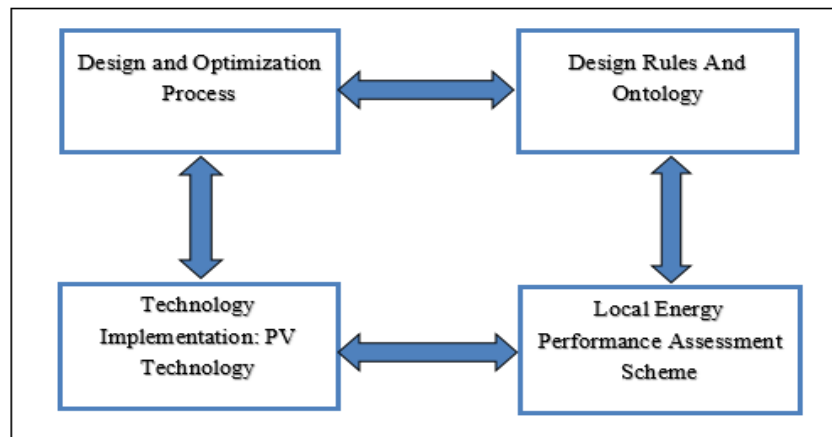


Figure 1. The conceptual BIM based design optimization framework.

As shown in the figure 1, the framework is consist of four main components which are a design and optimization process, design rules and ontology, technology implementation (PV technology), and energy performance assessment scheme. However in this study the first component which is about design and optimization process will be undertaken and discussed.

4. RESEARCH METHODOLOGY

In this study, a case study methodology that helps to gain qualitative and quantitative insights and understand the current practices is adopted. Figure 2 illustrates the methodology which is followed in this study.

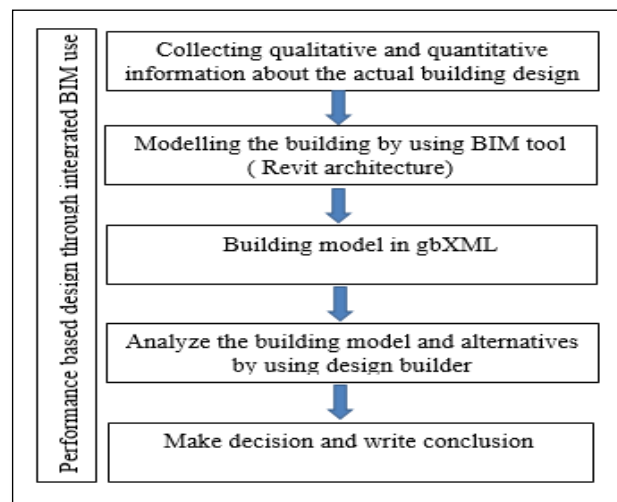


Figure 2. Case study procedure

In this study, both qualitative and quantitative information were collected about the building case study for the purpose of designing and preparing it for analysis. First, the building is modelled by using BIM tool Revit Architecture. Then the created model is imported to design builder (one of the energy simulation tools for the purpose of analysis). This is done through (gbXML), as a way of exchanging data between BIM and energy analysis tools. Design builder software is used to carry out the energy analysis and simulation of three main parameters which are building orientation, wall insulation, and glazing. It was chosen due to its ability to carry out the detailed energy simulation and analysis, calculating heating and cooling load (bahar et al., 2013).

5. CASE STUDY APPLICATION : ARBIM BUILDING

In order to illustrate the relationship between design decisions and building performance analysis by using BIM, a case study building is conducted examining different design parameters, modelling and data exchange, analysis process and results. The building is a two story university construction and it's located in Gaziantep_ Turkey. First, a 3D building geometry is created by using Revit architecture. Topography was added to the building model, as well as site elements such as car parking, street, trees and shrubs. Figure 3 shows the 3D geometry of ARBIM building and its topography modelled by using Revit 2016.

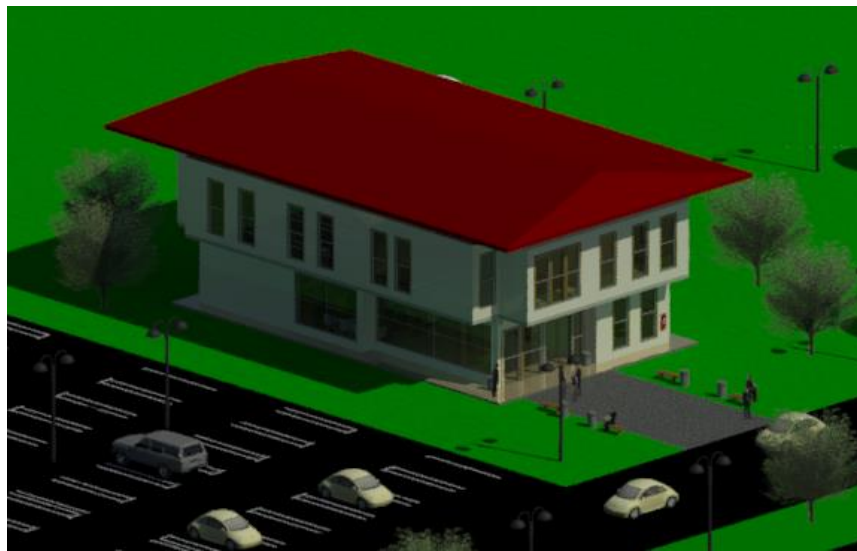


Figure 3. 3D model of ARBIM building.

To run the energy simulation, the building model was exported from Revit using gbXML imported into design builder for the purpose of performance analysis and simulation the final results of the building importing process are shown in figure 4.

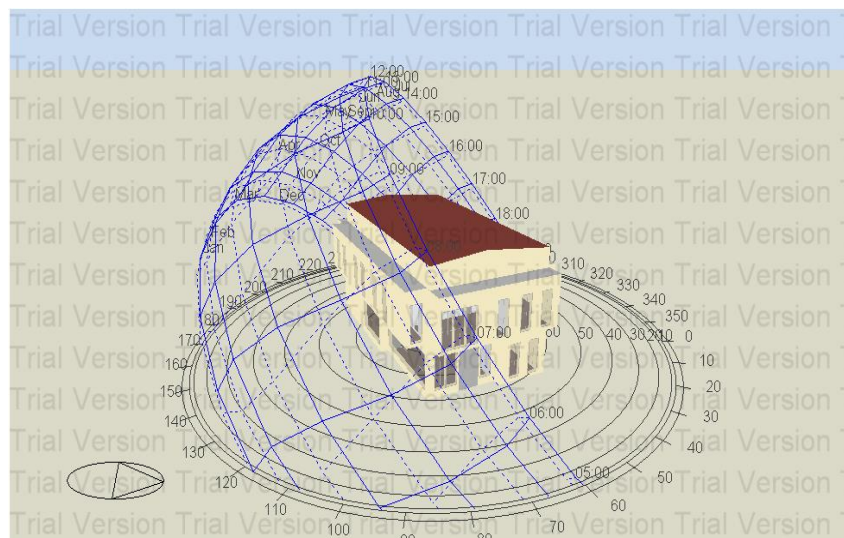


Figure 4. ARBIM building model in Design builder.

6. ANALYSIS AND RESULTS

Since the goal of this study is to identify ways of design optimization for energy efficient buildings. Three design parameters were considered in the energy simulation, building orientation, wall insulation, and building glazing.

6.1 The Impact of Building Orientation on Building Energy Performance

The actual orientation of the building is at 330 degree, where the front side of the building is facing east-north direction. To determine the optimum orientation, 12 other tests were performed and simulated, by rotating the building 30 degree at each test. The simulation results are shown in [table 1](#).

Table 1. The impact of building orientation on building energy consumption

Orientation	Annual cooling load (KWh)	Annual heating load (KWh)	Annual energy load (KWh)	Co2 Emission (Kg)
(330) actual	34903.88	13221.09	48124.97	25992.13
(0) optimum	33594.34	12577.04	46171.38	25334.10
30	35588.92	12913.98	48502.9	26152.28
60	37957.7	13184.42	51142.12	27084.9
90	38551.1	13144.7	51695.8	27286.26
120	38539.01	13447.72	51986.73	27369.56
150	36590.23	13297.95	49888.18	26622.25
180	34357.25	13067.00	47424.25	25748.56
210	35472.36	13631.00	49103.36	26313.65
240	36978.67	13933.47	50912.14	26943.82
270	37102.86	13671.95	50774.81	26912.54
300	36801.23	13690.12	50491.35	26810.73

As shown in table 1, the energy use of building at its actual direction will make an annual energy consumption equal to 48124.97 KWh and annual CO₂ production equal to 25992.13 kg, while when the building is at (0) degree direction will perform the best in term of energy efficiency, making an annual energy use equal to 46171.38 KWh and annual CO₂ production equal to 25334.10 kg. The implementation of the optimized building orientation will lead to energy saving equal to 1309.54 KWh and 644.05 KWh for cooling and heating respectively, and reduction in CO₂ emission equal to 658.03 Kg.

6.2 The Impact of Glazing on Building Energy Performance

The type of glazing used for the actual building design is clear double glazed 4mm with air gap equal to 12 mm. To study the impact of glazing on building energy consumption different glaze thicknesses and types are simulated and analyzed. The simulation results are shown in [table 2](#).

Table 2. The impact of glazing type and thickness on building energy consumption

Glazing type	U value (w/m2.k)	Heating energy load (Kwh)	Cooling energy load (Kwh)	Annual energy load (Kwh)	Co2 emission (Kg)
4mm clear-12 air gap- 4mm clear (actual)	2.866	13221.09	34903.88	48124.97	28328.99
4mm clear-12 air gap-4mm low e	1.771	13069.39	29563.33	42632.72	24015.58
6 mm clear- 12 mm- 6 mm clear	2.823	13568.49	33655.08	47218.57	25641.56
6 mm clear- 12 mm- 6 mm low e (optimum)	1.754	13346.00	28695.30	42041.30	23781.77
6 mm clear- 12 mm- 6 mm tinted	2.828	16665.60	25646.70	42312.30	23659.33

As shown in figure 2, the use (6mm double low e) glazing will perform the best and lead to the lowest energy consumption when compared to the other types, making an annual energy consumption equal to 42041.30 Kwh and annual Co2 production equal to 23781.77 Kg. This is due to its low U value of 1.754 which describes the flow of heat from warmer place to cooler place. The less U value the less energy loss achieved. A significant amount of energy will be saved as well as less CO2 production will be achieved. The use of 6 mm low e glazing will lead to annual energy saving equal to 6083.67 Kwh and the annual reduction in CO2 emission is equal to 4547.22 kg when compared to the actual glazing used in the building.

6.3 The Impact of Wall Insulation on Building Energy Performance

To decide on which insulation materials to be used for buildings, three types of insulation materials are considered and simulated. The simulation results are shown in table 3.

Table 3. The impact of wall insulation on building energy performance

Insulation type (4 cm)	U-value (w/m2.k)	Heating load (Kwh)	Cooling load (Kwh)	Annual energy load (Kwh)	Co2 emission (Kg)
No insulation (actual)	0.897	13221.09	34903.88	48124.97	25992.13
Rock wool	0.509	10628.14	35290.85	45918.99	25278.80
Extruded polystyrene (optimum)	0.408	10074.89	35304.96	45379.85	25124.36
Expanded polystyrene	0.473	10433.73	35290.46	45724.19	25222.61

As shown in table 3, all the insulation materials have an impact on the building energy performance. The rank of their effectiveness from best to less impact are as follows: extruded polystyrene (XPS), expanded polystyrene (EPS) and finally rock wool (RW). The use of (XPS) has the best impact on the heating energy use compared to the other types, making an annual energy consumption equal to 45379.85 Kwh and annual Co2 emission equal to 25124.36 Kg which are the lowest. This is greatly due to its low u-value, which determine the flow of energy from warmer places to cooler places. In other words, the less U value will lead to less energy consumption.

6.4 The Design and Optimization Process

6.4.1 Stakeholders, Process Stages and Tasks

In order to optimize the building performance, an early collaboration is highly needed between the actors at the early design stage. For instance, designers and engineer need to know what type of materials to use for a specific design, this can be done through reviewing the available materials with clients who will decide on which one to be used based on different aspects such as energy performance, economy, and aesthetic needs. Based on the performance based design applied for ARBIM building case study, the process stages for optimizing building design which identify the stakeholders involved in the process, as well as the stages and tasks required to achieve best design alternatives are illustrated in figure 5. These process stages and activities are explained below:

Stage 1: Review building design and alternatives: clients at the first stage will receive the energy performance results for the actual building design and suggest some alternatives in a collaborative manner with architects and engineers based on the materials availability, economic and aesthetic needs.

Stage 2: Prepare and check the selected alternatives for energy analysis: at this stage, the architects will create 3D building model by using Revit architecture. They also will prepare the building materials alternatives chosen previously, and then the building design model and alternatives will be transferred to the energy experts for energy performance analysis.

Stage 3: Analyzing actual building energy performance and alternatives: in this stage the energy expert will analyze the actual building model as well as the alternatives provided by the architectures and calculate the energy performance for each one. In this regard, Design builder energy software was used to calculate the amount of energy

consumed for each design alternatives. Once the energy performance is determined, then the total energy cost for each design alternatives will be calculated.

Stage 4: Review design alternatives with energy performance and cost results: The engineers and architects will receive the simulated and analyzed building models with their calculated energy performance and energy cost. Similarly, they will calculate the cost of material alternatives. Then, they will make some changes and optimize the design model based on the energy performance, energy cost and materials cost of each design alternatives.

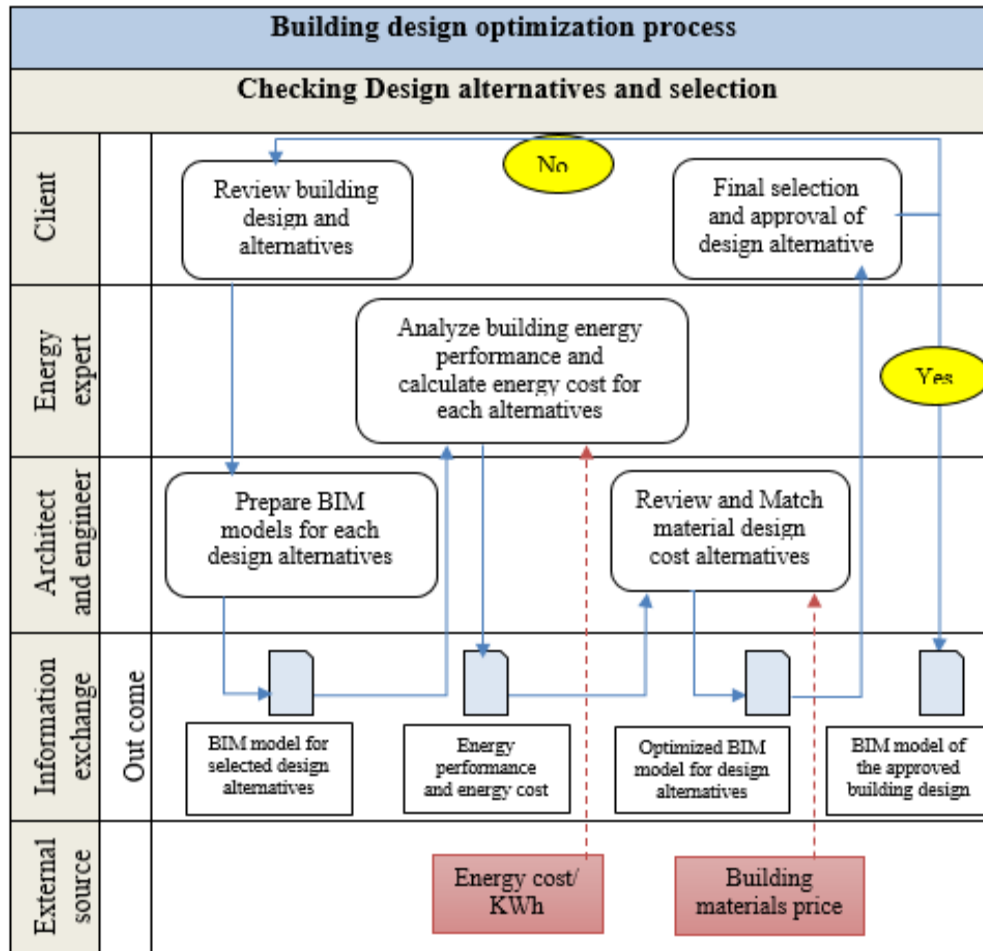


Figure 5. The stakeholders and design process stages and tasks.

Stage 5: Final selection and approval of a design alternative: in this stage the clients will receive all the information related to the proposed design alternatives, they will compare and analyze the BIM models being developed previously, and select the most appropriate alternatives based on economical, energy efficient, and aesthetic needs. The selected alternative is shared via the virtual collaborative workspace.

6.4.2 Data and Information Exchange Requirements

The next step is to specify the information exchange and its contents with the information exchange requirements which represent the link between process and data. It contains the relevant data to ensure the correct exchange of data between two actors and their corresponding tasks in the integrated process and (Belsky et al, 2014). Figure 6 shows the information exchange requirements between actors involved in the design optimization process.

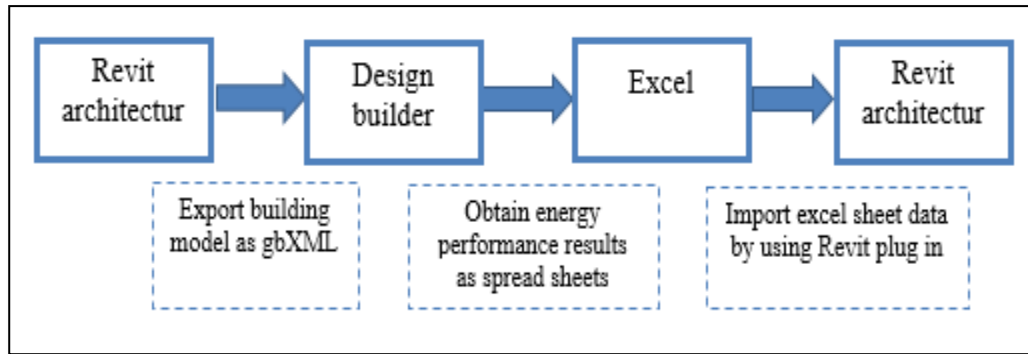


Figure 6. Data and information exchange requirements.

Typical workflow and information exchange between BIM and energy analysis software requires exporting building model geometry from BIM to analysis applications. Appropriate method for data and information exchange between BIM and energy software depends on the analysis goal and what type of information is needed. As shown in the figure above, the data and information exchange from Revit architecture to design builder accomplished by using gbXML file. Once the model is imported in design builder, the results of the simulation can be obtained in different forms such as tables, figures and spreadsheet. Hence, importing the results of the analysis back into the BIM is challenging. Therefore, a custom-built plug-in for the Revit platform was developed, that allows importing the analytical results, such as building orientation and envelope materials energy performance results, into BIM design model. It enables importing of data via Excel spreadsheets based on the numeric values obtain from design builder (see figure 7).

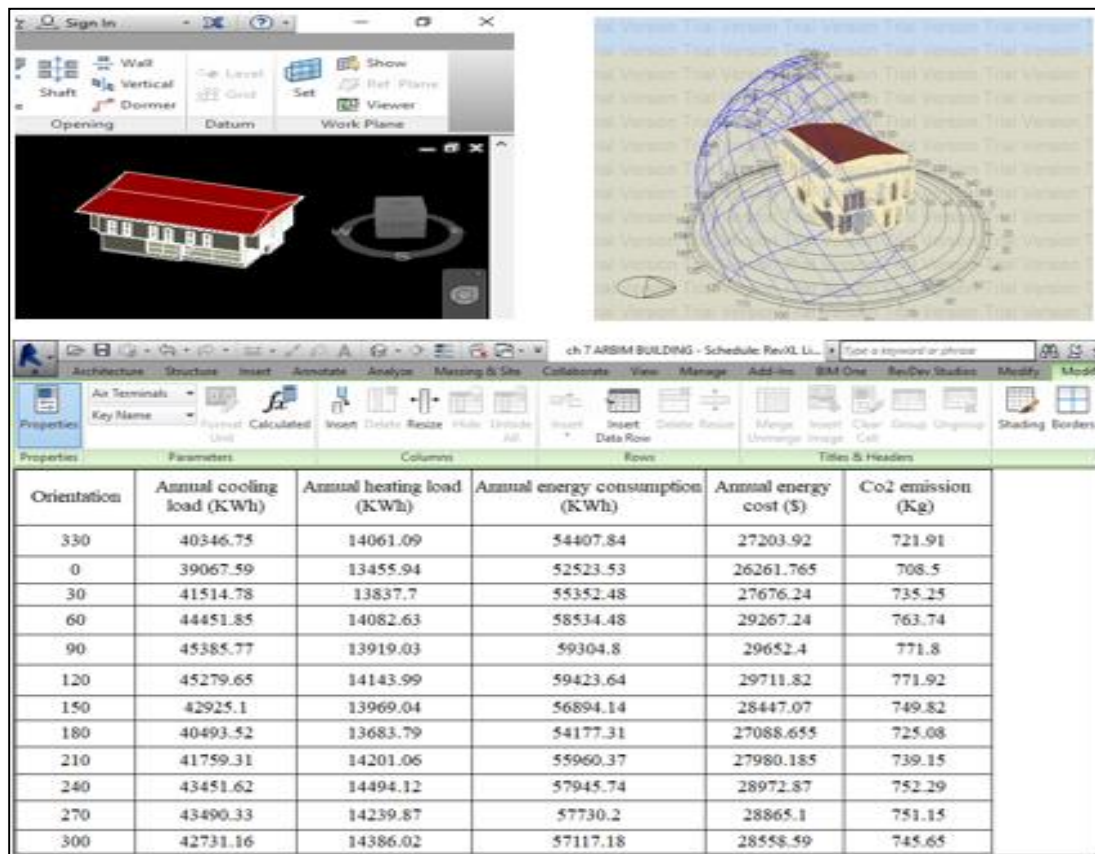


Figure 7. Exporting data results into excel sheet and importing it into Revit by using Revit excel importer.

As shown in figure 7, the process of information exchange was tested for building orientation, where the building first is exported as gbXML from Revit to design builder to analyze different orientations and calculate the building energy performance at each test, then the calculated results were exported from design builder to excel sheet. Once

the data is imported into excel sheet, then the total energy cost were calculated and finally imported into Revit by using Revit-excel importer, which it has been downloaded from application store of Revit.

7. CONCLUSION

In this study, an attempt was made to identify and explore the first component of the hypothetical framework: a design and optimization process. Based on the analysis and simulation results of ARBIM building case study, the relationship between building energy performance simulations and design process, and how performance predictions can help in identifying strategies to reduce energy consumption and enhance building performance were discussed. Furthermore, the design process components including, the stakeholders involved in the process as well as their roles and responsibilities during the design stage were identified, this was followed by identifying the process tasks and stages needed in order to achieve better decision during the design stage.

The methods and ways needed for information exchange between BIM and energy analysis software (Design builder) were also identified, ensuring the importance of differentiating between “design” BIM models and “analysis” models. Interoperability between BIM-based design and simulation tools can enhance the workflow between design documents and analysis applications, where data and information contained in the models can be used for analysis process as well.

However, BIM-design model and the BIM-analysis model need to be managed and properly developed considering the stakeholders involved, process stages and the information exchange during the process. It is important to know what type of data and information is necessary for a particular analysis, and how effectively to use BIM to simulate design decisions. Although, recent studies show a steady increase in energy consumption of buildings in Turkey. The knowledge and technologies exist could be used to produce better performance buildings. Energy saving can be achieved if:

- Energy efficiency parameters and measures combined with efficient integration, are incorporated in the early design stage.
- Effective design decisions based on the collaboration of all stakeholders are made in the preconstruction stage.
- The analysis of energy efficiency incorporated as part of the building design process.
- BIM, energy modelling and intensive coordination among the design team members through appropriate and effective ways for information exchange between the stakeholders involved in the design process are in place.

REFERENCES

- [1] Chwieduk, D. A. (2016). Some aspects of energy efficient building envelope in high latitude countries. *Solar Energy*, 133, 194-206.
- [2] Cao, X., Dai, X., Liu, J. (2016). Building energy-consumption status worldwide and the state-of-the-art technologies for zero-energy buildings during the past decade. *Energy and buildings*, 128, 198-213.
- [3] Kazanasmaz, T., Uygun, I. E., Akkurt, G. G., Turhan, C., Ekmen, K. E. (2014). On the relation between architectural considerations and heating energy performance of Turkish residential buildings in Izmir. *Energy and Buildings*, 72, 38-50.
- [4] Kocagil, I.E. Oral, G.K., 2015. The effect of building form and settlement texture on energy efficiency for hot dry climate zone in turkey. *Energy Procedia*, 78, pp.1835-1840.
- [5] Mangan, S. D., Oral, G. K. (2016). Assessment of residential building performances for the different climate zones of Turkey in terms of life cycle energy and cost efficiency. *Energy and Buildings*, 110, 362-376.
- [6] Cho, C. S., Chen, D., Woo, S. (2012). Building information modeling (BIM)-Based design of energy efficient buildings. *Journal of KIBIM*, 2(1), 1-6.
- [7] Eskin, N., Türkmen, H. (2008). Analysis of annual heating and cooling energy requirements for office buildings in different climates in Turkey. *Energy and Buildings*, 40(5), 763-773.
- [8] Abanda, F. H., Byers, L. (2016). An investigation of the impact of building orientation on energy consumption in a domestic building using emerging BIM (Building Information Modelling). *Energy*, 97, 517-527.

- [9] Han, Y., Taylor, J. E. (2016). Simulating the Inter-Building Effect on energy consumption from embedding phase change materials in building envelopes. *Sustainable Cities and Society*, 27, 287-295.
- [10] Pacheco, R., Ordóñez, J., Martínez, G. (2012). Energy efficient design of building: A review. *Renewable and Sustainable Energy Reviews*, 16(6), 3559-3573.
- [11] Aksamija, A. (2013). Building simulations and high performance buildings research: use of building information modeling (BIM) for integrated design and analysis. *Perkins+ Will Res. J*, 5(01), 20-34.
- [12] Aksamija, A., Mallasi, Z. (2010). Building Performance Predictions: How Simulations Can Improve Design Decisions. *Perkins+ Will Research Journal*, 2(2), 7-32.
- [13] Bahar, Y. N., Pere, C., Landrieu, J., Nicolle, C. (2013). A thermal simulation tool for building and its interoperability through the building information modeling (BIM) platform. *Buildings*, 3(2), 380-398.
- [14] Jeong, W., Kim, K. H. (2016). A Performance Evaluation of the BIM-Based Object-Oriented Physical Modeling Technique for Building Thermal Simulations: A Comparative Case Study. *Sustainability*, 8(7), 648.
- [15] Almahmoud, E., Doloi, H. K. (2015). Assessment of social sustainability in construction projects using social network analysis. *Facilities*, 33(3/4), 152-176.
- Omran, H., Marsono, A. K. (2016). Optimization of building energy performance through passive design strategies. *British Journal of Applied Science & Technology*, 13(6), 1-16.
- [16] Sulaiman, J., Azman, A., Saboori, B. (2013). The potential of renewable energy: using the environmental Kuznets curve model. *American Journal of Environmental Sciences*, 9(2), 103.
- [17] Inglesi-Lotz, R. (2013). The impact of renewable energy consumption to economic welfare: a panel data application. University of Pretoria.
- [18] Kazem, H. A., & Chaichan, M. T. (2012). Status and future prospects of renewable energy in Iraq. *Renewable and Sustainable Energy Reviews*, 16(8), 6007-6012.
- [19] Roderick, Y., McEwan, D., Wheatley, C., Alonso, C. (2008). A comparative study of building energy performance assessment between LEED, BREEAM and Green Star schemes, Integrated Environmental Solutions Limited, Kelvin Campus, West of Scotland Science Park, Glasgow, G20 0SP, UK.
- [20] Ilter, D. E. N. I. Z., Ilter, A. T. (2011). An overview of green building practice in Turkey. In *Management and Innovation for a Sustainable Built Environment MISBE 2011*, Amsterdam, The Netherlands, June 20-23, 2011. CIB, Working Commissions W55, W65, W89, W112; ENHR and AESP.
- [21] Belsky, M., Eastman, C., Sacks, R., Venugopal, M., Aram, S., Yang, D. (2014). for precast concrete building models. *PCI Journal*.