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Research Article

Using Semi-Automated Parametric Methods in Calculation of Thermal Performance in Historic Buildings

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Keywords

HBIM,
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Energy retrofit,
Parametric design,
Traditional Turkish house.

Abstract

Although the global energy demand is increasing daily, different policies are being implemented to reduce energy demand. The policies developed since buildings are responsible for about a quarter of energy consumption also cover buildings. Heritage buildings, which have a large proportion worldwide, especially in Europe, will be important in achieving future energy targets with energy performance retrofits. It is hoped that climate change can be prevented by reducing carbon emissions. In order to provide energy efficiency in buildings, heat losses in the building envelope are being minimized. In traditional structures, reinforcement is usually carried out within the building envelope. However, energy retrofitting in historic buildings is a very challenging process. Since any intervention requires the protection of existing building materials, problems and solutions must be realized by considering heritage values. The use of BIM-based systems with the developing technology makes the process easier. With the HBIM model obtained from point clouds, all possible interventions can be observed and planned in advance. This study proposes a semi-parametric performance calculation system based on BIM-based TS 825, using Revit and its add-on Dynamo, considering the insulation material type and thickness over the HBIM model. The system allows data visualization and isolation changes in the HBIM environment to occur simultaneously on the HBIM model. The study was carried out as a case study on a representation of traditional Turkish houses located in the Tire district of Izmir province in Turkey. According to the study's results, an average of 54% of energy efficiency has increased.

1. Introduction

The construction industry is responsible for a large part of energy consumption. It is responsible for 35% of total energy consumption and 38% of all carbon emissions in CO_2 emissions in 2019 [1]. Increasing energy efficiency is an essential step towards reducing global energy consumption as buildings consume more energy during their construction processes and lifetimes. While increasing energy efficiency in buildings, it aims to strengthen buildings and reduce energy consumption through building materials [2]. Residences built before 1945 make up a large part of the total building stock in many countries. In Europe, this rate is 23% on average [3]. Therefore, increasing the energy efficiency of existing historical buildings is necessary to achieve global energy efficiency targets. The primary purpose of this study is to evaluate how the thermal performance of historical buildings can be made without damaging the value of the

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building. Therefore, the article presents an innovative approach to building performance improvements in the building envelope (roof, exterior walls, and floor) of heritage buildings. Apart from traditional methods, it has proposed a BIM-based semi-parametric system. In the study, it is believed that utilizing insulation, which is a very important design criterion for the building envelope, is an effective approach to mitigating the negative environmental effects [4-5]. But heritage structures are quite special structures. For this reason, special attention and experience are required for the operations to be performed on the building envelope [6]. Possible interventions may damage the building's identity [7]. For this purpose, the use of the HBIM system allows the detection and resolution of problems with a semantic perspective, especially in these structures, apart from on-site intervention decisions. In the study, the interventions in the building shell can be calculated in advance with a parametric system proposal. For this, it is necessary to have the HBIM model. A sequential set of operations is required before HBIM model generation and building performance calculation; The structure discussed in the case study is scanned with the help of a laser scanner. The resulting point cloud is transferred to BIM software through different software. HBIM model is created from point cloud data. Then, the system created in Dynamo is matched with the TS 825 [8] calculation method, and the performance of the building envelope is calculated. In addition, since the types and thickness of insulation materials used in buildings affect the energy and thermal performance of the building, the changes made in the model are reflected in the result simultaneously [9]. When the studies in the literature review are examined, it has been seen that there has been an increase in the use of historical buildings and BIM in academia in recent years, especially in Europe. Various analyses are carried out after creating a point cloud by historically scanning buildings with a laser scanner and using the HBIM modeling process. At the same time, parametric energy calculation and optimization studies have been carried out within the scope of new structures recently. Strengthening works are carried out in historical buildings using various energy-related tools. When the studies on historical buildings and building energy performance are examined, the commonality is in using different software in both. Using different software makes the process quite challenging. When the scenarios foreseen in the calculation tools are changed, or different design alternatives are tried, the whole system returns to the beginning. In addition, the foreseen changes do not show any change in the model, and the necessary technical drawings are realized due to assumptions. Therefore, this study proposes a unified system in which all studies are carried out in one place by addressing this critical problem in a single framework.

2. Parametric Design / HBIM

In parametric design, variables are defined instead of creating geometries with traditional drawing methods. The variables included in the model determine the geometries and properties of the model [10]. When the parameters change, different interdependent variables of the model vary within specific rules [11]. Therefore, it is possible to produce different variations of a model in parametric design [12]. The use of BIM systems for parametric design and their integration with the design contribute positively to the design process [13]. A single model-centered, parametric design process used in BIM provides cost, implementation, etc., to the model and develops a multi-faceted perspective. [14]. Heritage Building Information Modeling (HBIM) has developed a new modeling system proposal by Murphy (2009) [15] for parametric object libraries representing architectural elements created from historical data and mapping these objects. Afterward, studies in this field gradually increased. Some studies within the scope of the subject are given in Table 1. Unlike BIM, the creation of HBIM for existing buildings follows a reverse process of new construction processes, starting from the existing structure and coming to the digital model through research, modeling, and information enrichment [16].

2.1. Thermal Performance in Architectural Protection

While the regulations mainly apply to new buildings, in 2017, the European Committee for Standardization defined appropriate standards across Europe to improve the energy performance of historic buildings. The standards cover registered and unregistered buildings of all types and ages perceived as heritage [31]. With this standard, it has been ensured that traditional buildings, construction techniques, materials used, and energy performance can be increased with certain limitations.

In historic buildings, building elements (wall, roof, door, and window) are important values related to energy performance that show the physical properties of the building [32-33]. Since these values change over time, the building's performance varies according to the periods [34]. In addition, indiscriminate repairs have damaged the importance of historical buildings or increased the risks they carry [35]. However, despite the changes made, it was observed that the thermal permeability (U-values) of the walls of traditional buildings was below the default values because of on-site measurements [36]. For this reason, protecting the built heritage also reduces energy consumption. According to BPIE, small and medium-sized interventions should be possible in historical buildings to reduce CO2 and obtain energy by 2050 [37]. Improvement studies have shown that the current performance of traditional structures can be made more efficient [38]. However, when planning the improvement works for the energy efficiency of a historical building, it is necessary to investigate in detail not only the possible effects on the importance of the building but also the performance of the building and its possible effects on the building. Table 1 shows the literature review on HBIM.

3. Methodology

First, high accuracy building documentation was carried out using modern documentation techniques. The data obtained with Terrestrial Laser Scanner (TLS) (Faro S120 Laser Scanner) were transferred from point-cloud processing software (Recap Pro) to the HBIM platform (Revit 2020, Academic version) after the post-processing stage. The 3D model LOD 350 (Level of Detail) required for performance calculation within this platform has been prepared as a model at the detail level. After the HBIM model is defined in Dynamo, it is combined with the TS 825 calculation method prepared in Dynamo. With the calculation created in Dynamo, the values can be changed automatically, the current heat loss of the building can be calculated, and the effects of possible thermal insulation materials to be added in the HBIM model on the thermal performance of the building can be monitored. In the calculation method created in Dynamo, the values in the calculation of the thermal performance of the buildings according to TS 825 (region, monthly solar energy intensity, function, etc.) are required for the calculation from the formulas and the HBIM model; building shell material properties (type, thickness, thermal conductivity value, area), windows and doors (material, area, directions), volume and area ready codes nodes in Dynamo, different codes in different Dynamo packages (Orchid, Rhythm, Arci-lab) nodes, and new code nodes are obtained by writing. Figure 1 shows the workflow of present study

Table 1. Literature review on HBIM

Author	***Date***	***Working Scope***	***Building Typology***	***Tools Used***
Baik [17]	2017	Concepts such as HBIM, Object library creation, level of development (LoD), and project delivery time (PDT) are the subjects of study..	Historical Traditional Residence	Revit
Barazzetti et al.[18]	2015	It describes the use of HBIM models derived from point clouds for structural simulation based on Finite Element Analysis.	Historic Castle	Revit+ Autodesk Robot Structure
Oreni et al. [19]	2014	HBIM restoration proposals, NURBS modeling, Finite element analysis were carried out within the scope of the study.	Basilica	Rhino+Revit+Midas
Barazzetti et. Al[20]	2016	A new concept such as HBIM parametric design, NURBS modeling, BIMonitoring realized in the study has been proposed.	Historical Bridge	Revit
Quattrini et al.[21]	2015	Quality HBIM modeling and Parametric design proposals have been introduced in complex structures.	Historic Church	Revit
Tommasi [22]	2016	Comparison of the software used in the HBIM modeling process was carried out.	Historic Cathedral	Revit,Rhino, Grasshopper, Archicad
Tapponi et al. [23]	2015	HBIM restoration recommendations, Digital Documentation performed.	Historic Cathedral	Revit
Maisarah et. al[24]	2018	New recommendations have been made on HBIM developmental levels (LOD).	Historical Traditional Residence	Revit
Murphy et al. [25]	2017	The transfer of HBIM to WEB-based games has been studied.	Historic Court Building	Revit
Chiabrando et al.[26]	2016	Interoperability of LIDAR and VR with HBIM and semi-automatic optimization of HBIM are aimed in the study.	Historic Castle	Revit
Prizeman [27]	2016	Within the scope of HBIM Period studies, 19th and 20th centuries. The changes made to the historical structure were examined.	Historical Library	Revit
Capone and Lanzara [28]	2019	The production of dome models with parametric modeling in historical buildings is discussed.	Historic Churches	Revit,Rhino, Grasshopper,
Yang et al. [29]	2018	A new methodology has been proposed, such as HBIM parametric modeling, model sequential modeling and semi-automatic Lod level arrangement.	Historical Monastery	Revit+Dynamo
Agnello [30]	2019	A virtual tour was carried out in conjunction with HBIM VR.	Historical Monastery	Revit

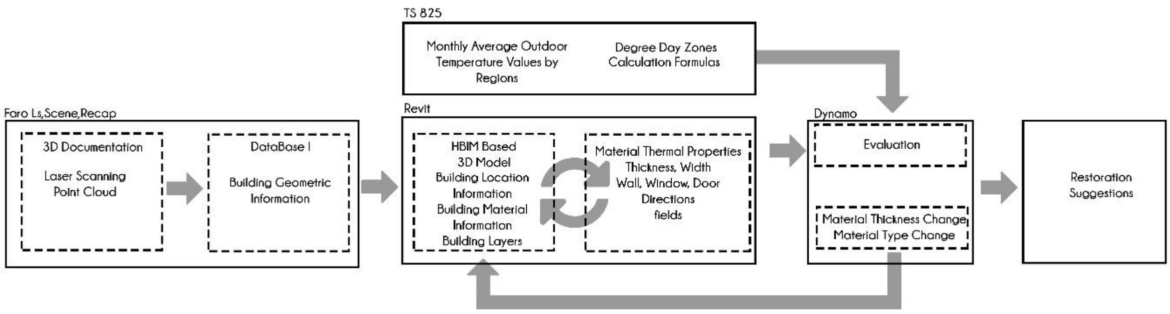

Figure 1. Workflow of study

3.1.Case Study

Traditional Turkish houses are examples of vernacular architecture that integrates with the environment and people in which they are built; contains logical solutions based on experience, uses topography and local materials efficiently; and respects natural values [39]. For this aspect, they contain a lot of data for current practices [40]. Open and semi-open spaces, courtyard solutions with prominent micro-climatic features, and passive ventilation systems are a source of inspiration for modern architecture. Located in Izmir

Province, Tire District (Figure 2, Figure 3), the building consists of two floors, a basement, and a ground floor. We do not have exact information about the date of its construction. The house can be dated to the end of the 19th century and the first half of the 20th century, according to our typological research and similar houses examined in the center of Tire. The building, which was built as a residence, has not lost its function and is used as a residence. The building is in the I. Climate region according to the TS 825 Rules for Thermal Insulation in Buildings.

Figure 2. Location of İzmir

Figure 3. Location of Tire

The traditional house was built with two floors, a basement, and a ground floor (Figure 4). There is a courtyard in the east direction. Direct entrance to the building is provided by the double-wing metal door on the west facade. On the eastern axis of this opening, which provides direct access to the ground floor hall, there is a double-winged wooden door used as a courtyard door and a second entrance to the building.

Figure 4. Western Front

Figure 5. Northern Front

The south and west facades of the building face the road. There are no windows on the south façade (Figure 5). The eastern façade of the building, whose northern façade is adjacent to the residence on the side plot, opens to the courtyard. The entrance to the courtyard of the house is provided by a double-winged wooden door on the south façade. The basement, which consists of a single space, has a square plan. Access to the venue is provided from the courtyard. There are two rubble stone columns in the middle of the place. There are two ruined open windows and three closed windows in the space. The ground floor plan, designed in the plan type with an interior sofa, consists of 4 rooms and a sofa. There is a passage from the west side of the sofa to the street and from the east side to the courtyard.

3.2.HBIM Model and Thermal Performance Parametric Calculation

In the field study, first of all, the building was documented with modern techniques. Alignment and cleaning were performed in the Recap software of the point cloud post-processing process of the obtained data. Modeling (Figure 6, Figure 7) has started with reference to the point cloud imported to the Revit 2020 platform. Thanks to this software, HBIM point cloud-based building and building detail models (LOD 350) were created [41].

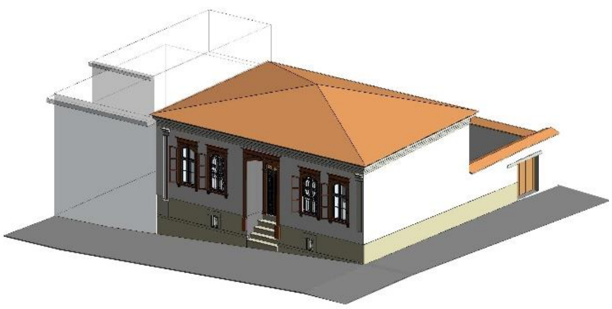

Figure 6. HBIM model 3D View

Figure 7. HBIM model 3D View

In the system developed in Revit plugin Dynamo, the necessary values (wall, floor) for TS 825 building energy performance calculation were made by selecting the model. After the selection is made, after the values in the variables are selected in accordance with the project, the calculation process is performed automatically, and the annual energy consumption of the building is obtained. In the second stage, insulation materials are added by the decision-makers to the appropriate places on the HBIM model. After the insulation materials are added, the system simultaneously gives the calculation results. In the developed system, when the types and thicknesses of insulation materials are changed in Dynamo, changes occur simultaneously in both the calculation results and the model. In this way, different design alternatives can be produced simultaneously on the model (Figure 8).

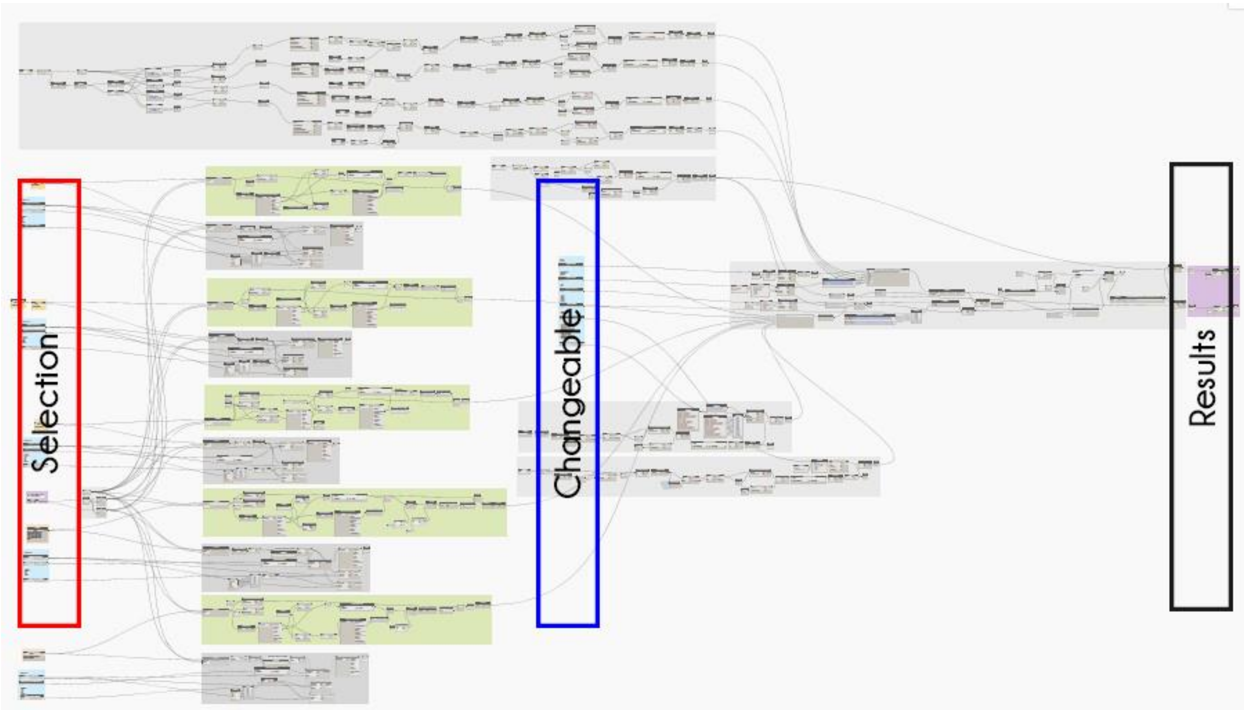

Figure 8. Dynamo of study

In historical buildings, insulation is usually carried out indoors. Indoor insulation: It is carried out as a flexible cover that can be fixed mechanically by spraying it in the form of a spray attached to a rigid board or an existing wall [42]. As the thermal conductivity value decreases in insulation materials, the insulation performance increases (Table 2). In the study, the materials with the following characteristics, which are among the traditional insulation materials, were used in the case study. In the developed system, the user can use insulating materials with different properties according to his wishes (Figure 9).

Table 2. Thermal insulation performance [43]

Material	Weight (kg)	Thermal Conductivity (W/m K)	Intensity (kg/m³)
Rock Wool	1.20	0.033	100
Glass Wool	1.00	0.038	50
EPS	1.30	0.035	23
PUR	1.4	0.028	30
XPS	1.7	0.040	10
Cellulose	2.34	0,042	43

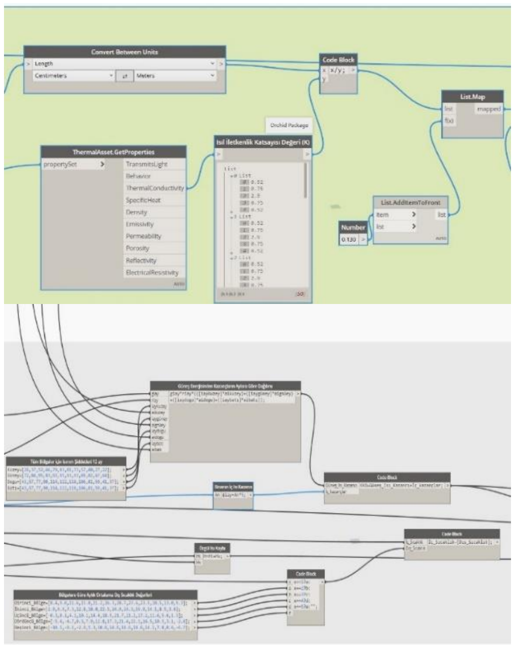

Figure 9. Walls Thermal e conductivity and KKO

4. Result and Discussion

This study presents a semi-parametric approach to the improvement options within the building envelope with a case study of a traditional Turkish house based on HBIM and TS 825. The proposed system integrates the modeling of the point cloud obtained from laser scanning in Revit, the BIM platform, and the TS 825 calculation method developed in the Revit plugin Dynamo. In the historical building, the exterior walls, roof, and floor coverings of the retrofit building envelope were modified on the model and then at Dynamo. According to the findings obtained in the study, the annual heat energy requirement of the building in its current state is 197.88 KW h / m2. As a result of the application of 5 cm thick insulation materials to the walls on the ground floor in the HBIM model, the annual energy consumption of the building according to the applied materials; Rock wool is 91.04 kWh/m², Glass Wool is 94.96 kWh/m², EPS is 92.78 kWh/m², PUR is 87.79 kWh/m², XPS is 96.26 kWh/m², Cellulose is 97.53 kWh/m². In this case, the best thermal performance enhancement was obtained when Polyurethane Rigid Foam (PUR) was applied. Polyurethane Rigid Foam, EPS, Glass Wool, Rock Wool, and cellulose materials gave the best results, respectively.

As a result of the reinforcement, it was observed that the insulation materials provided an average of 54% improvement in thermal performance. The sustainability of historic buildings will be ensured, and the transformation of existing building stocks will be planned more effectively.

This study constitutes an important example in historical buildings not for on-site solutions but for semantic and planned design and implementation stages. In addition, from the first moment of the decision to renovate the building, it is essential in terms of the importance and ease of use of the HBIM model of different parameters such as digital scanning and bringing together the values measured on-site, simulating each decision stage in digital environment beforehand, and ensuring interdisciplinary coordination.

5. Conclusions

The subject is at the intersection of architectural preservation, BIM technologies, and solution proposals. As a result of the study, material renewals and insulation details required with BIM technologies are directly related to the protection principles at a single building scale. Proposed during the study process and the insulation details were prepared concerning the sample projects of the relevant boards. According to the results obtained:

- It has been seen that the thermal performance of a historical building can be increased without harming its cultural, aesthetic, and originality qualities.
- It was found that the insulation materials improved thermal performance by, on average, 54%.
- The retrofitting of the existing building stock will be planned more skillfully, and the sustainability of historic buildings will be guaranteed.
- In this context, it is also among the study results that BIM technologies should develop the information infrastructure that will facilitate the modeling of historical building details and material types.
- Each historical building contains different features. Therefore, the selection of insulation material is an important parameter.
- As the thickness of the insulation materials decreases, the efficiency difference of the materials between the climatic regions decreases.

In parallel with the developing technologies, using these technologies in cultural heritage studies is becoming increasingly crucial for qualified conservation practices. With the efficient use of these technologies, facilities are observed in all kinds of works related to our cultural heritage, and these facilities will ensure that cultural heritage is included in current life. It will make significant contributions to the production of more qualified protection practices.

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