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Using HBIM for Energy Efficiency Analysis of Historical Buildings: An Example as a Case Study from Ermenek / Karaman

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1. Introduction

In today's construction industry, Building Information Modeling (BIM) can be seen as the next step beyond computer-aided design (CAD) systems (Eastman et al., 2008). BIM platform emerged with the development of parametric modeling in computer-aided design. Unlike simple 3D representations, the models used in BIM are data-rich and constitute a graphical representation linked to a database (Federman, 2017). Within the BIM environment, a project can contain all the information related to a building's construction and usage. BIM offers a systematic approach for managing all the data of a structure, from its concept to its usage and fostering organized collaboration (Feriel et al. 2018). Consequently, BIM can be utilized as a different source of information at each stage of the building's life cycle, eliminating incorrect data flow and redundancies (Bynum et al., 2013; Arayici, 2008). The structure is represented in the virtual environment with its object components and properties, which are then separated and defined semantically (Osello et al., 2018).

In a BIM environment, constructional information about building elements can include geometry related to the project, geographic positioning coordinates, material quantities, cost estimates, material details, project schedules, energy, and structural information. The relationship between resources and properties of various elements related to the building can be observed even before its construction by allowing performance evaluation (Smith & Tardif, 2009). BIM facilitates swift and accurate updates to changes, reducing the effort required to create spatial programs (Linderoth, 2010). The advantages of BIM extend to designers, constructors, contractors, and subcontractors, including benefits such as automated assembly, improved design, controlled costs, environmental data, quality production, and enhanced customer service (Dossick & Neff, 2010; Alshawi & Faraj, 2002).

Applications in the construction sector for cultural heritage require interdisciplinary collaboration between spatial, geometrical, historical, thematic, and temporal disciplines. While architectural cultural heritage shares fundamental construction techniques, its historical construction stages are diverse due to the evolution of architectural typologies (Green & Dixon, 2016). Managing and storing this multi-input information is significantly facilitated by information systems. HBIM can be defined as a valuable information system to enrich data about an existing building and allow data management.

This study aims to develop an information management approach that encourages the preservation and evaluation of Traditional Turkish Houses through Historical Building Information Modeling (HBIM). A sustainable analysis of a traditional Turkish house has been conducted using HBIM as an illustrative case study. During its sustainability analysis, results from various local and international analysis methods have been compared. The analysis covers different assessments, such as sunlight exposure, location, orientation, heating and cooling loads, thermal properties of materials, ventilation, and daylight analysis. The study establishes an exemplary use of digital documentation techniques for the shared use of HBIM and introduces a novel approach to popularize this usage.

2. Material and Method

In the study, an innovative approach has been introduced through the comprehensive utilization of required analysis methods using modern documentation techniques within the HBIM platform. In the study's methodology, high accuracy building documentation was initially achieved using modern documentation techniques. Data obtained through the Terrestrial Laser Scanner (TLS) (Faro S120 Laser Scanner) were transferred to the HBIM platform (Revit 2020) after the post-processing stage using point-cloud processing software (Recap Pro). The UNDET Plugin in Revit 2020 platform was used to generate 2D images from the 3D point cloud, and the inputs were combined over different sheets based on raster images, resulting in the creation of the HBIM model (Figure 1).

I. Point Cloud II. 3D Model III. Analysis

Figure 1. Building workflow

Thanks to the plugin, the accuracy of the parametric model obtained from the point cloud data can be analyzed, and differences between the model and the point cloud can be observed, ensuring the achievement of a highly accurate model. Within this platform, the 3D model required for analysis is prepared at Level of Detail (LOD) 350 based on the point cloud.

Different sheets (plans, sections, elevations, and 3D perspectives) can be obtained from these 3D models as needed.

In the scope of the study, the parametric model obtained was used to conduct a building energy performance analysis based on parameters that can be modified within a single scenario, considering that historical buildings' locations remain fixed. In addition to this software, an energy performance simulation of the historical building was obtained through Autodesk Green Building Studio. The obtained simulations and results were compared with the online Building Energy Performance - Turkish Regulations (BEP-TR 2) software, which is mandatory for applications in Turkey and checks the building's energy requirements. The results from both platforms were compared, and recommendations for new conservation practices were obtained.

3. Importance of HBIM

HBIM system, in addition to being a part of the BIM platform, can be viewed as a repository focused on information management for special issues related to historical buildings, encompassing all information related to cultural heritage (Tapponi et al. 2015). Furthermore, it represents an effective tool for conservation and monitoring to prevent damage (Malinverni et al, 2019). HBIM applications can be described as new modeling systems that represent parametric object libraries representing architectural elements created from historical data and their mapping (Murphy et al., 2013). After the study by Murphy et al., research on building information modeling for cultural heritage modeling for cultural heritage has rapidly increased worldwide (Fai & Sydor, 2013; Oreni et al., 2014; Boeykens et al., 2012; Baik et al. 2015; Bruno & Roncella, 2018). However, in Turkey, which is rich in cultural heritage, there are limited studies on HBIM (Saygi & Remondino, 2013). In these applications, the parametric components available in BIM tools can be used similarly, recording materials and details related to historical objects to create an accurate and easily accessible database for future similar projects. The HBIM model can be used for the maintenance and management of the building even after restoration (Wu et al. 2013).

Collaborating teams in the conservation process utilize the knowledge they gain for their design and implementation purposes. HBIM helps manage the preservation process, including rebuilding the building in case of damage or disappearance, as well as the end of the preservation life cycle during the operation and maintenance stages (Osello et al., 2018). The difference between BIM and HBIM mainly stems from their respective purposes. HBIM is expected to be an informative system that defines the conservation and planning status for future applications throughout the entire life cycle of architectural heritage. Thus, the conceptual framework and variables specific to cultural heritage differentiate HBIM from the general BIM platform. Overall, in terms of process content and conceptual schema, HBIM differs from the BIM platform (Valk et al., 2012).

4. Sustainability and Building Condition Improvement

Sustainable architecture refers to buildings that balance social, environmental, and economic concerns (Brown et al., 2009). BIM enables the estimation of energy consumption in the conceptual phase of sustainable building projects. It facilitates sustainable practices in the planning, design, construction, operation, maintenance, and decommissioning of buildings (Khan & Ghandge, 2019; Alwan et al., 2015). BIM is crucial for sustainable designs as it allows building form analysis, energy cost analysis, structural deterioration analysis, energy management, sustainable material use, interdisciplinary communication, and management (Kriegel & Nies, 2008). When dealing with a historical building, it becomes essential to bring the building's comfort conditions up to contemporary standards within the context of reuse. Enhancing the existing features of historical structures is directly related to the concept of "retrofit." This term refers to any intervention that adjusts, reuses, or upgrades a building to fit new conditions or requirements (Wilkinson, 2011). These interventions can encompass a wide range of aspects, from structural reinforcement to efficient use of natural light, insulation properties, and reduction of energy expenses (Douglas, 2006).

Sustainability has been a prevalent concept worldwide since 1987 and is now considered an essential aspect in various aspects of life (Saieg et al., 2018). Increasing energy efficiency in the production and use of buildings is a crucial part of sustainable architecture, aiming to utilize natural resources efficiently (Li et al., 2012). Using the existing building stock through appropriate renovations is generally seen as a sustainable approach (Khodeir & Soliman, 2017; Krygiel & Nies, 2008). Regarding energy efficiency, improving the structural conditions of architectural heritage to continue their use is a technically and culturally sustainable approach (Ovali & Delibaş, 2016). Reducing the energy consumption of historical buildings to lower CO_2 emissions, enhancing indoor quality and comfort, and managing economic expenses through qualified planning are all part of a sustainable approach (Khodeir et al., 2016). The HBIM platform provides the knowledge to manage this planning. Through the HBIM platform, the thermal performance of historical buildings can be optimized, various alternative solutions can be explored to question the economic gains throughout the building's life cycle, and alternative simulations can be prepared to achieve contemporary comfort conditions. Thanks to this knowledge, historical buildings continue to be active elements in sustainable urban development. Otherwise, Protection practices that fail to meet expectations cannot be efficiently and actively utilized over time due to their inability to deliver the expected performance.

5. Case Study- Energy Efficiency analysis of Historical Timber Structure, Traditional House

Traditional Turkish houses reflect the physical-functional needs, cultural-social structure, and family composition of the people living inside them. The Turks have created a housing culture that integrates local construction techniques with a nomadic lifestyle in Anatolia (Eldem, 1984). Traditional Turkish houses are examples of vernacular architecture that harmoniously blend with their environment and the people, incorporating experience-based logical solutions, efficient use of topography and local materials, and respect for natural values (Paköz, 2016). As such, they encompass a wealth of data relevant to contemporary applications (Aytis & Polatkan, 2010). Their open and semi-open spaces, microclimatic features, courtyard solutions, and passive ventilation systems serve as an inspiration for modern architecture (Eyüce, 2005). Within the borders of Turkey, the Balkans, and the Middle East, a significant number of region-specific Turkish houses can be found.

In this study, analyses were conducted on strengthening the thermal performance of a traditional house in Ermenek, a settlement located in the high-altitude region of the Toros Mountains, which separates the Mediterranean and Central Anatolia (Figure 2). This region houses numerous well-preserved traditional architectural structures, especially dating back to the early 20th century (Figure 3). Traditional architecture typically features rubble stone on the ground floor and wooden-framed upper floors, often filled with stone materials. Thermal efficiency is of great importance in this region, particularly during the cold winter months. The subject of this study is a house constructed with rubble stone on the ground floor and wooden-framed stone material on the upper floor, following a "karnıyarık" plan type. The basement walls occasionally incorporate wooden lintels within the stone masonry system.

Figure 2. Location of Ermenek

Figure 3. Some examples of Ermenek historical dwellings

The main objective of the field study is to strengthen the historical structure to adapt it to modern conditions, as it is one of the most crucial factors in preserving cultural heritage. The examined historical building in this study has been subjected to significant deformations over the years, with observed deteriorations and damages in its architectural details. There is peeling on the exterior plaster and considerable damage to the roof. Deteriorations in the window frames are also noticeable. The field study focuses on how to enhance the thermal performance of the building after restoration by improving insulation details and increasing the insulation value of the building materials. In this regard, the HBIM environment allowed for simulations of these thermal enhancements before implementation and observation of their results. Additionally, an analysis was conducted to understand how the building's location and orientation affect its required energy.

The field study started by documenting the building using modern techniques. The obtained data underwent alignment and cleaning in the point cloud post-processing software. Due to the cumbersome nature of very dense point clouds in existing software, decimation was applied to the point cloud as per the intended purpose. The point cloud was then imported into the Revit 2020 platform, and thus the modeling process commenced. Creating a BIM model from the point cloud starts with recognizing parametric objects and architectural components. Through this software, HBIM point cloud-based building and building detail models were created, enabling the development of an essential digital, parametric, and highly accurate library specifically for Cultural Heritage. This library serves as a database, providing detail and building element alternatives for future works. This parametric library facilitates easy access to post-restoration building details and accelerates production during the implementation phase.

After creating precise architectural components and building details, a conceptual and parametric model of the historical structure was developed by the historical building factor, paying attention to the fact that unlimited strengthening and interventions cannot be performed, and the original facade character must be respected to preserve the values of the historical building. The restoration project prepared within this framework was submitted to the Conservation Board, and the following applications were approved by the board:

Plaster: All the deteriorated plaster covering of the historical building was removed, and high-insulation hydraulic lime plaster (Thermal Conductivity 0.73 W/m.k) will be used. The existing traditional plaster of the historical building is a 3 cm thick mixture of earth, straw, and water with very low resistance. This type of plaster is known for its low thermal insulation value of 0.73 W/m.k. It is not resistant to external weather conditions and is typically renewed every two years in the local culture. Replacing this plaster with high-insulation, weather-resistant hydraulic lime plaster will enhance the building's insulation value while preserving its original facade character.

Insulation work in unusable attic spaces: There is currently no insulation material in the attic, and when necessary, removable Stone Wool (Thermal Conductivity range of 0.035 W/m.k) will be installed in the attic.

Renewal of the window glasses and frames: The existing window glasses and frames with a low insulation value have been replaced. The current thermal conductivity value for single glass and frame is 5.7 (W/m^2K), while the application uses wood material with a thermal conductivity value of 1.9 (W/m^2K) for double glazing.

For analyzing the energy efficiency of the prepared model, the Revit 2020 plugin called Insight 360, which allows for the modification of various parameters, was used. As on-site measurements and evaluations of the building's elements (plaster, glass, frames, etc.) were input into the conceptual model in Revit 2020, the complexity and accuracy of the analysis increased. The Revit 2020 Energy Analytical Model enabled automatic generation and integrated simulation of the model, allowing changes to be observed simultaneously.

In addition to energy conservation, the analysis was conducted for daylight levels, which also significantly affect energy consumption. Daylight analyses were performed in the same software by adding real material properties such as transparency and glass color to the windows. Illumination maps were automatically generated in the working plane.

Different time-based illumination and average illumination values were obtained, and the illuminations during the summer and winter periods were compared. This allowed for a more conscious selection of lighting elements to be used (Figure 4).

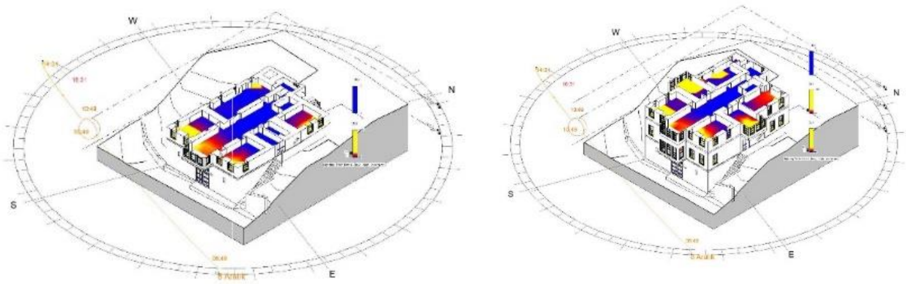


Figure 4. HBIM Model Daylight Analysis thematic maps

The annual energy requirements of the historical building were calculated based on the existing building details without insulation materials using Insight 360 software, and the HBIM Energy Use Intensity (EUI) was determined to be 246 kWh/m²/year. After the approved reinforcements were implemented, the Energy Use Intensity (EUI) was calculated to be 196 kWh/m²/year. These reinforcements included the changes in wall details, the improvements in window glass properties, renewal of plaster materials, and the modifications in interior lighting requirements (such as using high-power single lamps instead of multiple low-power lamps in areas that require lighter, selecting lamps based on the highest lumen/Watt ratio).

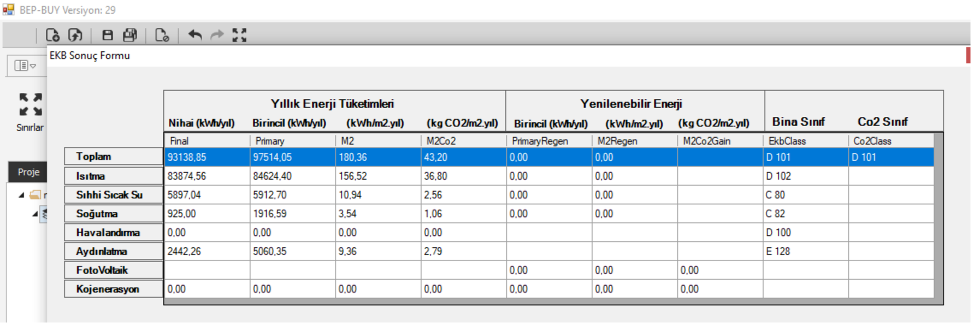
Alongside the internationally based calculations, local analyses were performed in accordance with local laws and regulations. For this purpose, the Beb-Buy software, provided by the Ministry of Environment and

Urbanization, was used to calculate the thermal performance of existing and new buildings. Similar building details were input into this software as well. Without any reinforcement, the total annual energy consumption was found to be 215 kWh/m²/year. After restoration, the total annual energy consumption was determined to be 181 kWh/m²/year based on the calculations from this software. The most significant energy consumption was for heating, hot water, lighting, and ventilation, respectively (Figure 5).

When comparing the two sets of data, it was observed that the results obtained from both national and international software were in close agreement with each other, showing an average correlation (Table 1). The findings from the used and similar software were deemed valid for historical buildings in terms of energy use intensity and quantity. Consequently, the results of the restoration application remained within acceptable national and international consumption limits, demonstrating energy efficiency. This restoration approach can be applicable to other similar houses as well (Figure 6).

Table 1. Benchmark table of different plugins for one-year energy consumption.

Beb-Buy Before Thermal Insulation	215 kWh /m2 / yıl
Beb-Buy-(Plaster+Roof Insulation+Changed Window's Glasses)	181 kWh/ m2 / yıl
Insight 360 Before Thermal Insulation	246 kWh/ m2 / yıl
Insıght 360 (Plaster+Roof Insulation+Changed Window's Glasses)	196 kWh/ m2 / yıl



BEP-BUY Versiyon: 29

EKB Sonuç Formu

	Yıllık Enerji Tüketimleri				Yenilenebilir Enerji				
	Nihai (kWh/yıl)	Birincil (kWh/yıl)	(kWh/m2.yıl)	(kg CO2/m2.yıl)	Birincil (kWh/yıl)	(kWh/m2.yıl)	(kg CO2/m2.yıl)	Bina Sınıf	Co2 Sınıf
	Final	Primary	M2	M2Co2	PrimaryRegen	M2Regen	M2Co2Gain	EkbClass	Co2Class
Toplam	93138,85	97514,05	180,36	43,20	0,00	0,00		D 101	D 101
Isıtma	83874,56	84624,40	156,52	36,80	0,00	0,00		D 102	
Sıhhi Sıcak Su	5897,04	5912,70	10,94	2,56	0,00	0,00		C 80	
Soğutma	925,00	1916,59	3,54	1,06	0,00	0,00		C 82	
Havalandırma	0,00	0,00	0,00	0,00				D 100	
Aydınlatma	2442,26	5060,35	9,36	2,79				E 128	
FotoVoltaik					0,00	0,00	0,00		
Kojenerasyon	0,00	0,00	0,00	0,00	0,00	0,00	0,00		

Figure 5. Beb-Buy result

Figure 6. Photos of historical building after the insulation retrofitting.

6. Conclusions

This study utilized different digital platforms with a semantic perspective to conduct energy analyses before restoring the building. By considering the obtained values during the building reinforcement process, the thermal performance of the buildings' thermal performance was improved. BIM-based software allows various energy calculations to during the field study on the historic building, 5 cm stone wool was added to suitable locations within the interior walls. In the result of the model simulation, the energy consumption was found to be 125 kWh/m²/year.

HBIM platforms provide opportunities for such analyses and scenarios, enabling historic buildings to achieve enhanced energy performance with minimal intervention. This ensures the sustainability of historic buildings and allows for more effective planning of the transformation of the existing building stock. The approach in this study serves as a significant example of semantic and planned design and implementation processes for historic buildings, emphasizing on-site solutions. Moreover, the integration of digital scanning and on-site measurements from the initial decision-making phase, along with pre-simulated digital environments for each decision stage, and interdisciplinary coordination, highlight the importance and ease of using HBIM models.

As a result of the thermal performance analyses, the selected building materials were changed to ones with higher thermal values within the limits allowed by the building physical properties. The choice of lighting analysis resulted in the selection of lighting elements that would not harm the building's texture, considering parameters such as the surface form, material, color, ultraviolet, infrared light components, and energy efficiency of the system.

The created smart object libraries can be used in different periodization studies and various projects, contributing to the formation of a local and national library that harmonizes with each other and compares energy performance values to ensure the building's presence at an urban scale. HBIM plays a significant role in raising awareness and increasing recognition at the national level.

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The article complies with national and international research and publication ethics. Ethics Committee approval was not required for the study.

Author Contribution and Conflict of Interest Declaration Information

All authors contributed equally to the article.

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