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HYBRID REVIT AND A NEW MCDM APPROACH OF ENERGY EFFECTIVE NURSING-HOME DESIGNED BY NATURAL STONE AND GREEN INSULATION MATERIALS

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Abstract. The requisition for maintainable constructions has been greatly raising over the last several years. To fulfil the maintainability necessities of a construction, decisions or changes must be done to a construction in the course of the preconstruction and design steps. This can be plausible utilizing building information modelling. To indicate the utilize of building information modelling in maintainable planning, an example nursing-house is received for modelling research. The energy efficiency of nursing-home is analysed utilizing Autodesk Revit and Green Building Studio simulation which contained different characteristics such as annual heating and cooling loads, annual energy usage. Through using the utilize of different building, insulation and roof materials in the nursing-home modelling, the nursing-home modelling is changed into a greener construction modelling. In addition, the effects of using green walls on the facade of the building on the energy performance were analysed. Utilizing simulation, the utilize of non-natural sources can be dramatically decreased through substituting for them with the utilize of sustainable natural sources by that means energy saving. Building information modelling has substantiated to be effective in providing maintainability with alternative material's assessment and earlier decision-making. Furthermore, this study employed an integrated new MCDM model to evaluate the performance of four natural stones for utilize in a nursing home setting.

Keywords: building performance analysis, building information modelling, energy efficiency, green building, building envelope, energy saving, AROMAN-M.

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1. Introduction

The buildings' influence on the ecology has become a growing issue in recent decades (Cole, 2005; Wong & Kuan, 2014). The scientific community has proved and recognized the link between environmental issues and the building sector (Dong & Ng, 2015; Wen et al., 2015; Li et al., 2017). On an annual basis, the engineering, architecture, and construction business is liable for 0.32 of CO_2 emissions, 0.40 of overall power usage, and 0.25 of trash created in Europe. The building sector is liable for almost 0.33 of gases in atmosphere affecting and 0.40 of global power usage (Ramesh et al., 2010). Within the framework, society and public authorities have expressed a strong desire for more environmentally friendly, efficient, and sustainable structures and structure methods (Araújo et al., 2013).

One essential aspect or component in the construction of a structure is insulation, which guards against heat loss and helps buildings use less energy. The various characteristics are utilized to select an insulation material quality that strikes a balance between cost- and energy-savings. Buildings in cold-climates and in warm-climates are the two categories into which buildings fall in terms of thermal insulation location. Because of the high temperature and the sun-intensity disparities between the inside and external environments, the majority of the heat gained in hot regions enters the structure through its exterior. In comparison to the internal heat produced by the various activities, more heat is obtained from exterior sources. Increased thermal insulation in the building's outer shell will

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inevitably reduce the quantity of heat gained, which will minimize the energy required for cooling. Heat is transmitted from inside to outside in cold areas, so the insulation sheet should be placed on the superficies inner face the to minimize heat losses.

There are a variety of energy simulation software programs available, each with its own set of features for understanding the interplay between plan determinations and their influence on energy efficiency. By permitting a detailed analysis of complicated issues and design possibilities under actual settings, energy tool may meaningfully support the planning decision operation (Clarke, 2007). At each of the stages of the planning operation, adequate communication and data exchange amongst specialists is required. Building information modelling-sourced technics have acquired traction as important tools for boosting data interoperability and integration in building design and construction (Eastman et al., 2011; Summerfield & Lowe, 2012). Building information modelling is a digitized industry under a collaborative studying arena. BIM technology serves as a tool for estimating, managing and monitoring environmental impacts in construction projects, while at the same time bringing a new breath to sustainability studies around the world with its virtual prototyping and visualization features. BIM attracts a lot of carefulness from both industry and academia (Hamzakadı, 2019). Due to the advantages it provides to the project process, the number of countries with BIM directives is increasing day by day. A building information modelling may be built graphically and digitally through storing building attributes and multiple disciplinary data, making it a "richer warehouse" than a collection of computer-aided design drawings. Through exporting and sharing the data necessary to generate a "Building energy modelling", "Building information modelling" allows the utilization of information accessible from the architectural modelling, accelerating up the design planning, and reducing modelling re-formation time while permitting for additional planning repeats (Krygiel & Nies, 2008).

"Building energy modelling" – "Building information modelling" is a frequent moniker for this process. "Building energy modelling" using "Building information modelling" are a relatively new development in planning application. The effectiveness of these implementation is dependent on two key factors: technology and process (Staub-French et al., 2011; Succar, 2009). "Building information modelling" can also suggest other some advantages, which can be indirectly or directly related to maintainability as: water harvesting, building massing, building orientation, daylight analysis, energy modelling, renewable energy, sustainable materials (Gökgür, 2015). Several techniques and technologies have been created to meet the growing demand for sustainable buildings, with the goal of lowering power consumption, construction time, project costs, waste, CO_2 emissions, and other factors (Motawa & Carter, 2013; Solla et al., 2016). BIM is one of these methods that is gaining popularity. "Building information modelling" supplies a fantastic chance to include maintainable gauges across the numerous steps of a design through permitting interdisciplinary information to be layered and combined into a unified modelling (Azhar et al., 2011).

Krygiel and Nies (2008) outlined the major categories (renewable energy, sustainable materials, energy modelling) where BIM may be used to improve a project's sustainability level. Other skills that can be directly or indirectly connected to sustainability can be found in BIM methodology, such as; reduces resource utilization, accurate and automatic bill of cost estimations and materials, deconstruction-construction-rehabilitation waste management, facilitates the use of lean construction practices, automatic updating of project revisions (Balo & Ulutaş, 2023). Utilizing "Building information modelling", planners are supplied with precise data to determine the best maintainable options for the construction, based on the capabilities discussed before. The BIM technology's use has the ability to alter old processes, enabling for the more performance production of high-efficient and hence more maintainable buildings. On a university campus, research performed with "Building information modelling" to develop the project's maintainability level through Azhar et al. (2011). Over a 10-year period, the data revealed a 20% reduction in the overall project cost (about nine hundred thousand USD). The significant periods are the project phases and pre-construction according to Azhar et al. (2010), where choices for construction maintainability are meant to be taken. Because this is also when designs may gain the most from "Building information modelling", the impact it can have on construction maintainability becomes obvious. Wong and Kuan (2014) stated that "Building information modelling" should be employed from the initial plan phases onwards to make the sustainable design process cost-effective and more efficient, resulting in a bigger influence on the build design (Olawumi et al., 2018). Despite the fact that "Building information modelling" is highly advantageous in the course of the project stage, a few researches discuss that it should also be utilized in the course of the construction's subsequent life-cycle steps, such as repair, operation, demolition, and maintenance, to fully benefit from its use in promoting efficient and high-performance buildings (Eadie et al., 2013; Balo, 2011). Some BIM researches' summary in the building planning steps are given in Table 1.

The "Building information modelling" is well recognized as a platform that delivers a multiple-disciplinary plan detailed and "Architecture, Engineering, Construction" modelling (Barison & Santos, 2010). In a file, it manages overall of the design drawings. The paper discusses how "Building information modelling" may be utilized in the early steps of the planning procedure to accomplish some aspects of sustainable design. The article then goes on to discuss how "Building information modelling" may be used in particular fields like building orientation, wind velocity, and site selection in order to get the most maintainable resolution feasible. Construction elements and

Table 1. Some BIM researches' summary in the building planning step

Ref.	Research topic	Research Finding
Kumar and Mukherjee (2009)	Research focuses on BIM application status checks. A survey has been created to assess BIM adoption through 2009.	As determined in the researched literature, the ability to manage project information with capabilities for cost control and facility management is widely acknowledged in many nations.
Jadhav and Ghadge (2016)	This research offers a comparative evaluation of the BIM's benefits and effects on the horizontal building sector, including highways and bridges.	The research's conclusions provide a critical analysis of the numerous studies on BIM that have been published, highlighting issues with design complexity, labor shortages, and other issues. They also recommend future research directions.
Saundhrya and Uma (2016)	Because of its unique capabilities, BIM is frequently used in large-scale construction projects. The small-scale construction industry has also begun to employ BIM software. They aid in paperwork and offer thorough information about a facility.	In the structure sector, this essay provides information on the BIM application for all lifecycle of a construction.
Srimathi and Uma (2017)	In BIM, there are two methods for using 4-dimensional scheduling: using 4 dimensional tools in BIM, and using 4 dimensional BIM tools to connect the project schedule with the 3-dimensional BIM modelling.	The following methods are discussed: ▪ link BIM components to estimating software ▪ remove the amount take off document from the BIM simulation to the predicting program like Excel (MS).
Sarkar and Shah (2018)	Identified hazards related to building projects and the application of architectural, engineering, and construction.	Risks cause delays and overspending, which significantly lowers the likelihood that the project will be completed successfully.
Meganathan and Nandhini (2018)	▪ Offer advice on how construction firms might effectively incorporate BIM into their present operational processes. ▪ As part of the research approach, the BIM information state in the manufacturing sector is examined.	▪ A number of circumstances and variables, including high software costs, poor customer demand, and problems with management processes. ▪ In addition, a lack of commitment from upper management, ambiguous legal obligations, and a shortage of knowledgeable staff.
Nalawade et al. (2019)	In the building industry, collaboration is facilitated by a new and evolving software platform called BIM. BIM is used for preconstruction, construction, postconstruction, and bidding.	Had an important effect on the sector's improvements in productivity as well as product quality. This paper discusses the use, advantages, and specific restrictions of BIM.
Hire et al. (2021)	A range of functional aspects, technologies, and instruments of building projects were examined. An analysis for construction safety management was conducted.	Results aid in comprehending the potential of BIM for safety management and the requirements for safety.
Hire et al. (2022)	A bibliometric examination of the global construction innovation usage of BIM is presented in paper. Two stages of analysis were conducted with keywords in mind as the volume of materials and research quality.	Examines adoption worldwide, restricts findings to include BIM adoption in construction industry examines the BIM adoption for security. In international building and restricts the outputs to include adoption of BIM for security.
Dhopte and Daga (2022)	▪ The study's goal was to comprehend, examine, and gain knowledge of the past, present, and future of BIM adoption from an industry standpoint. ▪ With nearly two decades of expertise in the construction, engineering, and architectural industries, Excelize, a BIM service provider, has researched, compiled, analyzed, and presented the industry viewpoint on BIM deployment.	Conclusion that BIM offers a number of advantages for a project's overall performance and well-being over the course of the project. ▪ There are a lot of layers that project participants and BIM service providers need to investigate. ▪ BIM maturity is currently experiencing a rapid adoption phase, although continues to face a number of obstacles and adoption has experienced.
Sood and Laishram (2022)	Numerous important factors were mentioned. The level of maturity and its current state in the construction sector, as well as the various dimensions (3, 4, 5, 6, and 7 dimensional) were provided in along with potential future research agendas.	The findings may be very helpful to practitioners and policymakers if a BIM-based framework is made necessary for the Indian construction industry, as well as for those in other developing countries.
Salvi et al. (2022)	Provides an overview of the building lifecycle evaluation process using BIM. This approach aids in understanding the effects of the building environment.	The study's conclusions make BIM more useful in reducing the environmental impact of construction.
Chavan and Gorade (2022)	▪ A literature overview on the BIM use. ▪ BIM implementation for 3, 4, 5, 6, 7 and 8 dimensional.	▪ The article describes the characteristics and advantages of BIM, as well as its uses and the state of BIM adoption in different nations. ▪ This study also clarifies the extent of BIM and the difficulties encountered during implementation.
Kumar (2022)	BIM overview published as a book chapter. The notion of the BIM-ecosystem is explained by the author, along with client and service organizations in the architectural, engineering, and construction sectors.	Recommended and identified different BIM ecosystem components.
Singh et al. (2023)	This article focuses on the ergonomics of the construction sector, with a particular emphasis on how design modifications incorporating ergonomic interventions might optimize work conditions and instruments.	Demonstrates the use of a hybrid technique that combines the modeling of construction sites with a BIM-based ergonomic risk assessment.

material specifications aren't completely picked or specified in the early steps of project. Circulations, topology, zoning, and other project criteria are generally the emphasis of the design.

In order to have the examination and outcomes of each of resolutions or option projects, the technique proposed applies the policies and analyses of "Building information modelling" usage at those first planning stages. Stakeholders and designers would be able to make more informed decisions if the ramifications of each choice were fully understood. The architecture would calm down and go on with the finest sustainable alternative design. Using sustainable materials like cladding, insulation, and building elements like windows, doors, and other sustainable building components in later design stages would offer further improvements and additions in achieving higher values and metrics. By employing Autodesk software, Revit as "Green Building Studio" and a "Building information modelling simulation" as a simulation application and energy analysis, the suggested technique uses building information modelling, as the design's a sole arena to do the energy elements research.

The contribution of this study to the literature is as follows.

This paper fills an important gap in the literature by highlighting the positive impacts of building information modelling (BIM) technology on sustainable building design and energy efficiency. It also provides valuable information for future sustainable building projects by demonstrating the effects of sustainable material choices and green wall applications on energy performance with concrete examples.

In addition, the AROMAN-M method was developed in this study. Unlike the classical AROMAN method, the AROMAN-M method obtains more robust results by using separate normalization techniques for cost criteria.

In this study, a nursing-house is designed by using four different natural stones as building material, three different natural material as insulation material, two diverse natural material as roof material and green wall with Autodesk Revit 2021 and Green Building Studio simulations. To display how effective building information modelling is, the energy performance results of the nursing-home are analysed.

2. Data using in Autodesk Revit 2021 and Green Building Studio simulation

2.1. Climatic data for design nursing-house in Adana of Turkey

A wind rose depicts the direction and speed of the wind in a visual manner. It is a suitable tool for displaying anemometer data for analysis, such as wind speed and direction (Alamdari et al., 2012). The wind rose makes use of the 16 cardinal directions. The designers make selections about natural ventilation solutions for window placement and preservation of structures from chilly winter winds based on the local wind patterns. The wind rise in Figure 1 displays the frequency of winds at the project site in Adana, Turkey, circularly that are insufflation in particular ways.

When winds are coming from the northwest, they often have speeds between 9–11 and 7.5–6.5 knots (yellow and red are dominant).

Annual design conditions in Adana city, Turkey are displayed in Table 2. The threshold graphs display a thoroughly researched class of graphs with multiple motivations. The determination of the threshold temperatures acceptable for delivering climatic and thermal suitability is essential and crucial to the wellbeing of its inhabitants. The most prevalent degree-day measurement depends on thresholds for interior cooling and heating (Roshan et al., 2017).

Table 2. Annual design conditions in Adana city, Turkey

Cooling Degree Day		Heating Degree Day	
Threshold	Value	Threshold	Value
18.3 °C	847	18.3 °C	2627
21.1 °C	520	15.6 °C	2023
23.9 °C	262	12.8 °C	1507
26.7 °C	81	10 °C	1069

Annual Design Conditions				
Threshold	Dry Bulb (°C)	MCWB (°C)	Dry Bulb (°C)	MCWB (°C)
0.1%	41.3	17.8	–11.9	–12.9
0.2%	40.9	18.2	–11.2	–12.5
0.4%	39.7	17.5	–10.2	–11.3
0.5%	39.1	17.9	–9.7	–10.6
1%	37.9	17.8	–8.1	–9.4
2%	36.4	17.2	–6.3	–7.7
2.5%	35.7	16.9	–5.4	–6.9
5%	33.3	16.8	–3.4	–5.0

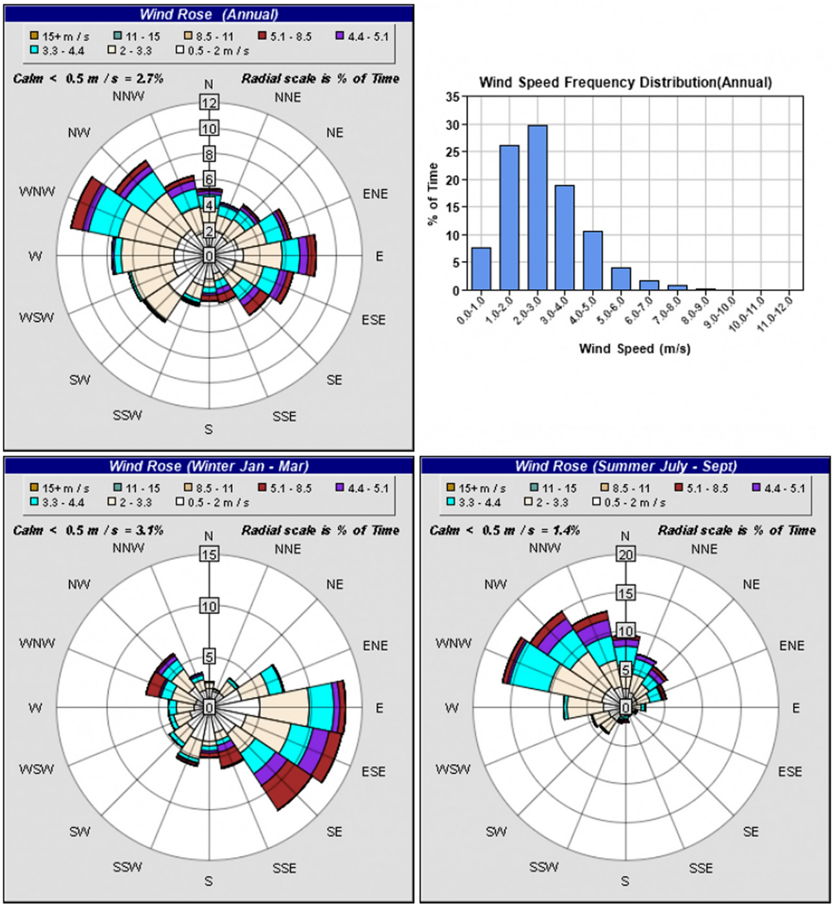

Figure 1. Annual wind rose in Adana city of Turkey

The number of cooling and heating degree days is a reliable and significant predictor in many ways. One of the most useful and straightforward indices is the degree-day index, which can be used to calculate the amount of required energy to sustain a comfortable climate. The daily temperature of the threshold level is defined as the highest mean deviation of the average temperature for human comfort. The atmosphere has to be cooled at temperatures above the minimum temperature, while the air needs to be heated at temperatures below the minimum.

The building, the area, and the city's thermal requirements can all be clearly and accurately depicted using the heating and cooling degree-day measurement. Additionally, it helps to improve patterns of energy usage and maintain thermal comfort. Energy consumption planning is a function of the measurement and estimation of the mean degree-day need for cooling and heating as the fundamental information for estimating the amount of required energy to cool and heat the construction in winter (Rahimikhoob et al., 2008).

2.2. Project stages in Autodesk Revit 2021

The floor plans of the nursing-house designed by Autodesk Revit 2021 are shown in Figure 2. 3D model of the exterior and interior views obtained by Lumion software of the nursing-house designed is illustrated in Figure 3. The building information of the nursing-house designed are given in Table 3. The wall structures analysed of the nursing-house designed are displayed in Figure 4.

The 208 alternative building envelopes were created by four different wall structures [Internally-externally insulated wall (Wall A), Sandwich wall (Wall B), Externally insulated wall (Wall C), Internally insulated wall (Wall D)], four different construction materials [Çol sarisi stone (CSS), Kizilotesi stone (KS), Erciyes karasi stone (EKS), Diyarbakir basalt stone (DBS)], three different insulation materials [Straw, Cellulose fiber, Hemp fiber] and two different roof types [Tile roof, Green roof].

Types created in different wall structures according to building, insulation and roof materials is given in Table 4. The thermo-physical properties of building envelope components are shown in Table 5. The building components' U values are given in Table 6. Thicknesses and layers of building components are displayed in Table 7.

2.3. Autodesk Revit and Green Buildings Studio analysis

Building information modelling is a connected technique for digitally investigating a planning's essential functional and physical aspects prior to construction, according to the Autodesk Committee. The operation of forming and utilizing a computer-produced modelling to repeat the

Figure 2. The floor plans of the nursing-house designed by Autodesk Revit 2021

Figure 3. 3D model of the exterior and interior views obtained by Lumion software of the nursing-house designed

Table 3. The building information of the nursing-house designed

Nursing Home Building Information	
Carrier System:	Framed building
Number of Floors:	Ground floor, 1., 2., 3., 4., 5. floor
Story Height:	Ground floor: 3.5 m, 1., 2., 3., 4., 5. floor: 3 m
Dimensions:	24.15 m × 22.75 m
Gross Area:	3300 m^2
Net Area:	2870 m^2
Wall Thickness:	32 cm

construction, design, planning, and utilize of a structure convenience is called as "Building information modelling" (Azhar et al., 2008). Utilizing Autodesk Revit, a third-dimensional modelling of the specified construction is produced. Importing the first and second floor plans into the model is the first step in creating the model. Revit's many tools are used to build the model, and the necessary input data are provided. Different construction elements, like the doors, roof, walls, flooring, and windows, are given materials. A 3D view of the produced model can mimic an actual view of the building. The necessary alterations that must be made in the construction to be changed into a green construction can be simply examined by allowing the construction to be seen as a third-dimensional modelling. Building energy analysis and simulation are widely acknowledged as realistic approaches for evaluating architectural designs (Mostafavi et al., 2015; Balo & Sua, 2018). It is essential to have a thorough viewpoint of all the capabilities of the simulation utilized for energy modeling in order to use it confidently and effectively. The input provided determines how accurate the analysis's findings will be. Revit software, one of the BIM technologies, is utilized to constitute modelling designs that are more precise and of higher quality. The Revit is utilized as a modelling arena and combined with Green Building Studio and Autodesk Ecotech for day-light assessment in a study by Moakher and Pimplikar (2012).

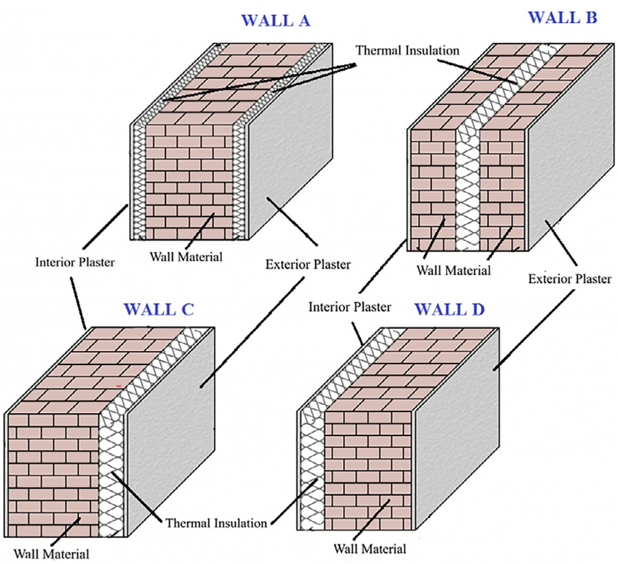

Figure 4. The wall structures analysed of the nursing-house designed

Software called Autodesk Revit is used to model buildings and analyse their energy usage. BIM software called Autodesk Revit is used to precisely, efficiently, and conceptually model designs. It is designed exclusively for BIM, enabling the construction industry's experts to include their opinions into a perspective from the early design steps. The functions for architecture, equipment (plumbing, electrical, and mechanical), construction, and structures are all included in one program called Revit. Autodesk Revit is used for this study's BIM model construction as well as the building's energy calculations. BIM-based 3D modelling of nursing-house designed is displayed in Figure 5.

Using Autodesk Revit, the nursing home modelling is received for energy performance assessment operation. First discussed are the planning's site and its fundamentals. All the building's construction materials' thermal characteristics are listed. Before beginning the energy analysis, energy settings are made. The energy analysis is carried out following the creation of an energy analytical model. Energy-saving components are added to the nursing house modelling to transform it into a green structure in light of the findings from the energy analysis.

Table 4. Types created in different wall structures according to building, insulation and roof materials

	Insulation material	Building material		Type		Type			Type		Type	
WALL A	Straw	CSS, KS, EKS, DBS	Tile roof	1–4	There is not green wall	53–56	There is green wall	Green roof	105–108	There is not green wall	157–160	There is green wall
	Cellulose fibre	CSS, KS, EKS, DBS		5–8		57–60			109–112		161–164	
	Hemp fibre	CSS, KS, EKS, DBS		9–12		61–64			113–116		165–168	
WALL B	Straw	CSS, KS, EKS, DBS		13–16		65–68			117–120		169–172	
	Cellulose fibre	CSS, KS, EKS, DBS		17–20		69–72			121–124		173–176	
	Hemp fibre	CSS, KS, EKS, DBS		21–24		73–76			125–128		177–180	
WALL C	Straw	CSS, KS, EKS, DBS		25–28		77–80			129–132		181–184	
	Cellulose fibre	CSS, KS, EKS, DBS		29–32		81–84			133–136		185–188	
	Hemp fibre	CSS, KS, EKS, DBS		33–36		85–88			137–140		189–192	
WALL D	Straw	CSS, KS, EKS, DBS		37–40		89–92			141–144		193–196	
	Cellulose fibre	CSS, KS, EKS, DBS		41–44		93–96			145–148		197–200	
	Hemp fibre	CSS, KS, EKS, DBS		45–48		97–100			149–152		201–204	
	[plaster+20 cm wall+plaster]	CSS, KS, EKS, DBS [non-insulated]		49–52		101–104			153–156		205–208	

Table 5. The thermo-physical properties of building envelope components

Wall Materials	Thermal Conductivity	Density
Çol sarisi stone	0.25 W/(m·K)	1087 kg/m^3
Kizilotesi stone	0.47 W/(m·K)	1730 kg/m^3
Erciyes karasi stone	0.3 W/(m·K)	1200 kg/m^3
Diyarbakir basalt stone	1.22 W/(m·K)	2282 kg/m^3
Plaster	1.0 W/(m·K)	1800 kg/m^3
İnsulation Materials	Thermal Conductivity	Density
Straw	0.052 W/(m·K)	100 kg/m^3
Cellulose fibre	0.038 W/(m·K)	45 kg/m^3
Hemp fibre	0.041 W/(m·K)	35 kg/m^3
Slab Materials	Thermal Conductivity	Density
Slab on grade – Reinforced concrete slab	2.5 W/(m·K)	2400 kg/m^3
Bedding mortar – Reinforced screed	1.4 W/(m·K)	2000 kg/m^3
Protective concrete	1.65 W/(m·K)	2200 kg/m^3
XPS	0.04 W/(m·K)	35,00 kg/m^3

Table 6. The building components' U values

Floor Slab	U Value
	0.7729 W/(m^2·K)
Suspended Slab	U Value
	8.3333 W/(m^2·K)
Roofing Type	U Value
Tile Roof	0.33 W/(m^2·K)
Green Roof	0.12 W/(m^2·K)

Table 7. Thicknesses and layers of building components

Floor Slab (cm)			
Slab on grade (50.00)	Waterproofing (0.10)	Bedding mortar (5.00)	XPS (4.00)
Suspended Slab (cm)			
Wall paint (0.10)	Plaster (2.00)	Reinforced concrete slab (15.00)	Reinforced screed (5.00)
Tile Roof (cm)			
Vapour Barrier	Isolation – Wierer – Rock Wool	Vapor Retarder – Wierer – Divoroll Universal 25	Wood – Tile Batten
Green Roof (cm)			
Vapour Control Layer	Mineral Wool	Protan SE Titanium	Extensive Green Roof Layers (sedum/drainage)

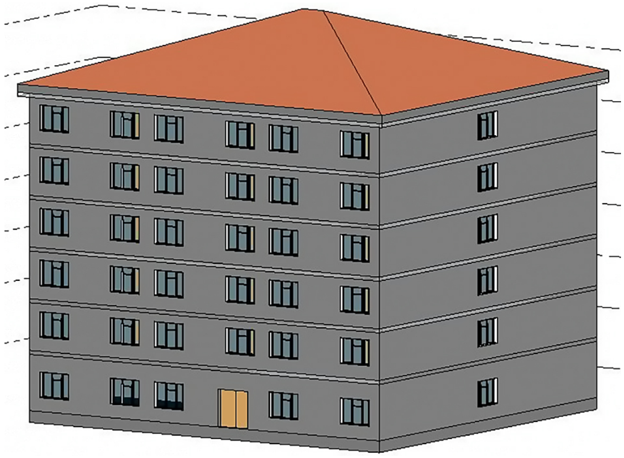

Figure 5. BIM-based 3D modelling of nursing-house designed

3. Results and discussion

3.1. Energy efficiency analysis by Green Building Studio

In this article, the energy performance as a significant efficiency criterion class for maintainable constructions was examined. The building is significantly impacted by the walls and lighting. As the project is a residential construction, the exterior heat loads – which result from thermal transmission such radiation, convection, and conduction by the building external wall from the weather, wind, and sun – have larger thermal gains and losses than the interior heat loads. Nearly everything in this project adds to the cooling loads, although walls do so more so. In the summer, there are more cooling demands.

The major target of this paper is to transform a nursing home into an energy-efficient structure by increasing energy ideas that promote sustainability. This can be accomplished through developing a third-dimensional BIM modelling of the nursing-house and evaluating the building's energy efficiency using Autodesk Revit. To accomplish a green building model and energy-efficiency, different materials are used in the construction process. The energy outputs' comparison for various characteristics between the various wall kinds displays how effective BIM is in terms of sustainability.

In this study, a nursing home was designed in Adana city (Turkey) climatic conditions. Modeled nursing-house designed using Autodesk Revit 2021 simulation. Then, the technical features of all building components of the designed building were transferred to the simulation as input. The thickness and ordering of the nursing-house building layers were determined in the Autodesk Revit 2021 simulation. The 208 different ".gbxml" files were created. These files were uploaded one by one to the Green Building Studio simulation to obtain energy analysis. The energy consumption values obtained by Green Buildings Studio software of the nursing home designed are given in Figure 6.

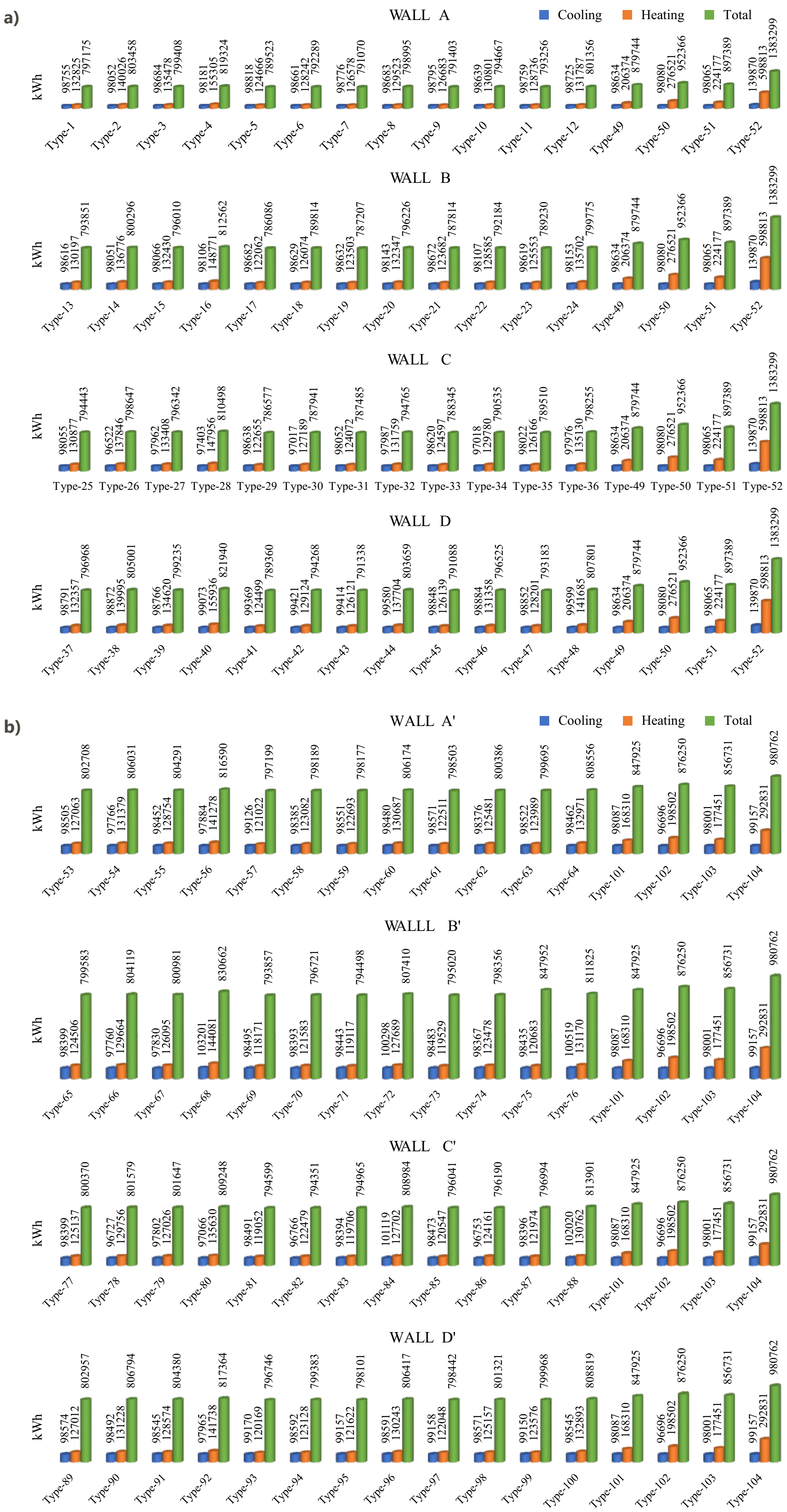

Figure 6. *Continued on next page*

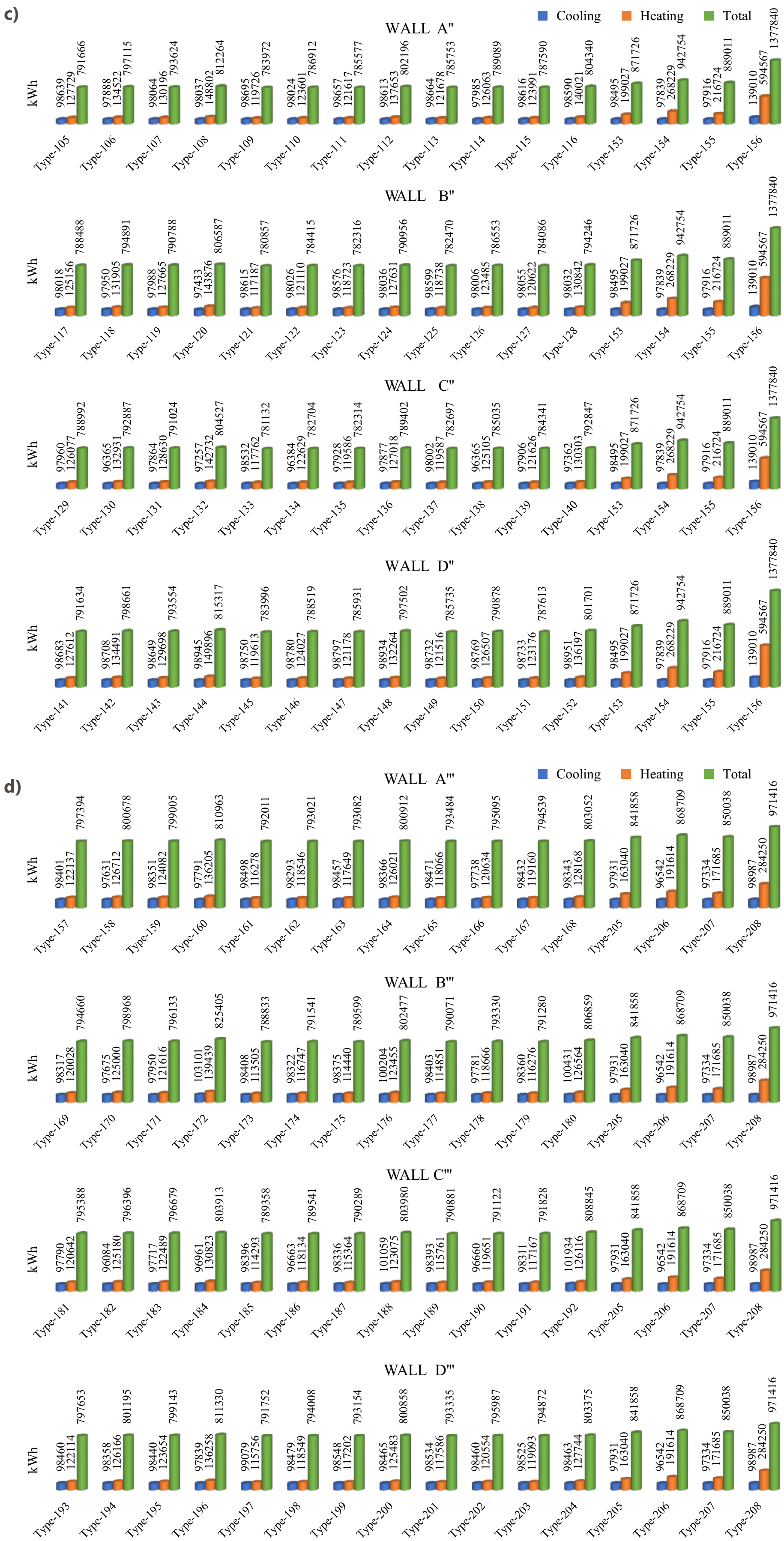

Figure 6. The energy consumption values obtained by Green Buildings Studio software of the nursing home designed: a – tile roof and no green wall; b – tile roof and green wall present; c – green roof and no green wall; d – green roof and green wall present

In terms of annual energy consumption, the lowest energy performances were determined in uninsulated walls.

The lowest performance in non-insulated walls was obtained by Type 52 (1383299 kWh), Type 156 (1377840 kWh), Type 104 (980762 kWh), Type 208 (971416 kWh) when DBS was used as the building material. The second lowest energy performance values after DBS were determined by Type 50 (952366 kWh), Type 154 (942754 kWh), Type 51 (897389 kWh), Type 155 (889011 kWh) from CSS. After CSS the lowest performances were found from EKS and KS among non-insulated walls, respectively.

Considering annual cooling loads excluding non-insulated walls, the highest energy consumption values are obtained by Type 68 (Wall B-DBS, Straw, tile roof and green wall), Type 172 (Wall B-DBS, Straw, green roof and green wall), and Type 88 (Wall C-DBS, hemp fibre, tile roof and green wall) as 103201 kWh, 103101 kWh, 102020 kWh, respectively. The lowest energy consumption values are found by Type 182 (Wall C-KS, straw, green roof and green wall), Type 138 (Wall C-KS, hemp fibre, green roof and green wall), and Type 130 (Wall C-KS, straw, green roof and no green walls) as 96084 kWh, 96365 kWh, 96365 kWh, respectively.

After non-insulated wall types, the worst total energy performances were obtained by Type 75 (Wall B-EKS, hemp fibre, tile roof, and no green wall), Type 68 (Wall B-DBS, straw, tile roof, and no green wall), Type 172 (Wall B-DBS, straw, green roof, and green wall present), Type 40 (Wall D-DBS, straw, tile roof, and no green wall) as 847952 kWh, 830662 kWh, 825405 kWh, 821940 kWh, respectively.

The best total energy performance values from Type 121 (Wall B-CSS, cellulose fibre, green roof and no green wall), Type 133 (Wall C-CSS, cellulose fibre, green roof and no green wall), Type 135 (Wall C-EKS, cellulose fibre, green roof and no green wall), and Type 123 (Wall B-EKS, cellulose fibre, without green roof and green wall) obtained as 780857 kWh, 781132 kWh, 782314 kWh, 782316 kWh, respectively.

Considering the annual heating loads, the lowest energy consumptions were obtained by Type 173 (Wall B-CSS, Cellulose fibre, green roof and green wall), Type 185 (Wall C-CSS, Cellulose fibre, green roof and green wall), Type175 (Wall B –EKS, Cellulose fibre, green roof and green wall) as 113505 kWh, 114293 kWh, 114440 kWh, respectively. Except for non-insulated wall types, the highest energy consumptions were found by Type 40 (Wall D-DBS, straw, no tile roof and green wall), Type 4 (Wall A-DBS, straw, no tile roof and green wall), Type 144 (Wall D -DBS, straw, no green roof and green wall) as 155936 kWh, 155305 kWh, 149896 kWh, respectively.

The most positive alternatives of all scenarios are illustrated in Figure 7.

Considering the annual total (between Type 182 and Type 52), heating loads (between Type 173 and Type 52) and cooling loads (between Type 121 and Type 52), the improvements in energy consumption values by replacing the existing wall components were found as 31.313%, 81.104%, and 43.551%, respectively.

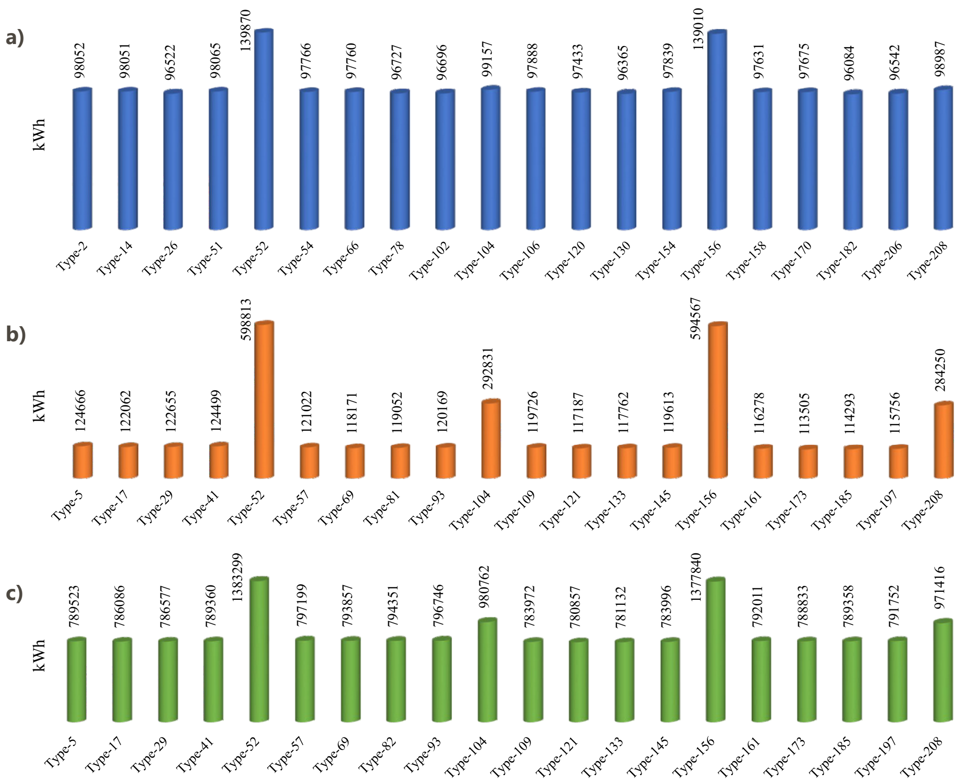

Figure 7. The most positive alternatives of all scenarios: a – annual total cooling energy consumption; b – annual total heating energy consumption; c – annual total energy consumption

3.2. Hybrid MCDM approach

In this study, the CRITIC, LOPCOW and LODECI methods will be used to weight the parameters, while the AROMAN-M (Modified AROMAN) method will be used to evaluate the stones.

3.2.1. The CRITIC method

This method is used to obtain the objective weights of criteria. The stages of the CRITIC method are shown below (Diakoulaki et al., 1995; Pajić et al., 2024).

Stage 1: A decision matrix $E=\left[e_{ij}\right]_{m\times n}$ is drawn up.

Stage 2: Eqn (1) (for beneficial criteria) and Eqn (2) (for cost criteria) are used to normalise the values in this decision matrix:

$$f_{ij}=\frac{e_{ij}-\min\left(e_{ij}\right)}{\max\left(e_{ij}\right)-\min\left(e_{ij}\right)}; \tag{1}$$

$$f_{ij}=\frac{\max\left(e_{ij}\right)-e_{ij}}{\max\left(e_{ij}\right)-\min\left(e_{ij}\right)}. \tag{2}$$

Stage 3: Eqn (3) is used to compute the weights of the criteria (w_{jCRT}):

$$w_{jCRT}=\frac{g_j}{\sum_{h=1}^{n} g_h}. \tag{3}$$

In Eqn (3), g_j represents the amount of information stored in the jth criterion, which is calculated using Eqn (4) (Huskanović et al., 2023):

$$g_j=\sigma_j\sum_{h=1}^{n}\left(1-k_{hj}\right). \tag{4}$$

In Eqn (4), σ_j represents jth criterion's the standard deviation, while k_{hj} represents the correlation coefficient between the hth and jth criteria.

3.2.2. The LOPCOW method

The LOPCOW method is used to achieve the objective weights of criteria. The stages of the LOPCOW method are indicated below (Ecer & Pamučar, 2022).

Stage 1: A decision matrix $E=\left[e_{ij}\right]_{m\times n}$ is drawn up.

Stage 2: Eqn (1) (for beneficial criteria) and Eqn (2) (for cost criteria) are utilised to normalise the values in this decision matrix.

Stage 3: Eqn (5) determines the percentage values (p_{ij}) for each criterion:

$$p_{ij}=\left|\ln\left(\frac{\sqrt{\frac{\sum_{i=1}^{m} f_{ij}^2}{m}}}{\sigma}\right).100\right|, \tag{5}$$

where m denotes the number of alternatives and σ indicates the standard deviation.

Stage 4: Eqn (6) is used to identify the weights of criteria (w_{jLCW}):

$$w_{jLCW}=\frac{p_{ij}}{\sum_{j=1}^{n} p_{ij}}. \tag{6}$$

3.2.3. The LODECI method

The LODECI method is also used to obtain the objective weights of criteria. The stages of the LODECI method are shown below (Pala, 2024).

Stage 1: A decision matrix $E=\left[e_{ij}\right]_{m\times n}$ is drawn up.

Stage 2: The values in this matrix are normalized by Eqn (7) (for beneficial criteria) and Eqn (8) (for cost criteria):

$$c_{ij}=\frac{e_{ij}}{\max\left(e_{ij}\right)}; \tag{7}$$

$$c_{ij}=\frac{\min\left(e_{ij}\right)}{e_{ij}}. \tag{8}$$

Stage 3: The DV (Decomposition Value) of each element in the normalized matrix is calculated by using Eqn (9):

$$DV_{ij}=\max\left\{\left|c_{ij}-c_{rj}\right|\right\}. \tag{9}$$

Stage 4: Eqn (10) is utilised to determine the Logarithmic Decomposition Value (LDV) of each criterion:

$$LDV_j=\ln\left(1+\frac{\sum_{i=1}^{m} DV_{ij}}{m}\right). \tag{10}$$

Stage 5: The weights of the criteria (w_{jLOD}) are achieved by means of Eqn (11):

$$w_{jLOD}=\frac{LDV_{ij}}{\sum_{j=1}^{n} LDV_{ij}}. \tag{11}$$

The criteria weights determined by CRITIC, LOPCOW and LODECI methods are combined with the following equation (Zavadskas & Podvezko, 2016):

$$w_{jCBM}=\frac{w_{jCRT}w_{jLCW}w_{jLOD}}{\sum_{j=1}^{n} w_{jCRT}w_{jLCW}w_{jLOD}}. \tag{12}$$

3.2.4. The AROMAN-M method

The stages of AROMAN method are shown below (Bošković et al., 2023).

Stage 1: A decision matrix $E=\left[e_{ij}\right]_{m\times n}$ is drawn up.

Stage 2: Unlike the classical AROMAN method, separate normalization techniques will be applied for the cost criteria in this study. Eqns (13) and (15) will be used for the normalization of beneficial criteria, while Eqns (14) and (16) will be used for the normalization of cost criteria.

$$d_{ij}=\frac{e_{ij}-\min\left(e_{ij}\right)}{\max\left(e_{ij}\right)-\min\left(e_{ij}\right)}; \tag{13}$$

$$d_{ij}=\frac{e_{ij}-\max\left(e_{ij}\right)}{\min\left(e_{ij}\right)-\max\left(e_{ij}\right)}; \tag{14}$$

$$d_{ij}^{*}=\frac{e_{ij}}{\sqrt{\sum_{i=1}^{m} e_{ij}^2}}; \tag{15}$$

$$d_{ij}^{*}=1-\frac{e_{ij}}{\sqrt{\sum_{i=1}^{m} e_{ij}^2}}. \tag{16}$$

Stage 3: Eqn (17) is used to compute the aggregated averaged normalized values as:

$$d_{ij}^{norm} = \frac{\beta d_{ij} + (1-\beta) d_{ij}^{*}}{2}, \quad (17)$$

where β denotes a weighting factor taking values from 0 to 1.

Stage 4: Eqn (18) is used to calculate the weighted aggregated averaged normalized values:

$$\hat{d}_{ij} = w_{jCBM} d_{ij}^{norm}. \quad (18)$$

Stage 5: The values found are summed separately for the cost criteria (minimum type) and for the beneficial criteria (maximum type):

$$L_i = \sum_{j=1}^{n} \hat{d}_{ij}^{(\min)}; \quad (19)$$

$$A_i = \sum_{j=1}^{n} \hat{d}_{ij}^{(\max)}. \quad (20)$$

Stage 6: Final ranking of alternatives is computed as:

$$T_i = L_i^{\lambda} + A_i^{(1-\lambda)}. \quad (21)$$

In Eqn (21), λ denotes the coefficient degree of the criterion type.

3.3. Application

In this study, the performance of 4 natural stones will be evaluated based on 14 parameters. The natural stones to be examined in the study are as follows:

- Kizil Ötesi Stone (KS);
- Erciyes Karasi Stone (EKS);
- Col Sarisi Stone (CSS);
- Diyarbakır Basalt Stone (DBS).

The parameters to be considered in the study are as follows:

- Strength Decrease after Freezing % Resistance (SDFR);
- Schmidt Hammer Hardness (SHH);
- Hardness (H);
- Tensile Strength in Bending (TSB);
- Compressive Strength (CS);
- Actual Porosity, (total) (AP);
- Water Absorption at Pressure (WAP);
- Specific Gravity of Solid Part (SGSP);
- Unit Bulk Weight (Dry), (density) (UBW);
- Thermal Insulation Coefficient (TIC);
- Strength Decrease after Freezing % (SDF);
- Frost Resistance (Weight Reduction) (FR);
- P-wave Velocity Reduction after Frost (PVRF);
- Seismic Velocity, (P-wave sound velocity) (SV).

The first six of these parameters are beneficial parameters and the other parameters are not beneficial (i.e. cost) parameters. Table 8 presents the decision matrix including natural stones and parameters.

The CRITIC method, then the LOPCOW method and finally the LODECI method are applied to this decision matrix to obtain the objective weights of the parameters. Then, these weights are combined with Eqn (12). Table 9 shows the parameters weights and combined weights according to the mentioned methods.

The weights of the parameters are calculated as follows. The values of the beneficial parameters are normalized by Eqn (1). Eqn (1) is used for the normalization of the beneficial parameters in both the CRITIC and LOPCOW methods. To indicate this calculation, the value of KS natural stone in the SDRP parameter will be taken as an example.

$$f_{11} = \frac{e_{11} - min(e_{ij})}{\max(e_{ij}) - min(e_{ij})} = \frac{27 - 18.10}{92 - 18.10} = 0.1204.$$

After finding the normalized values, correlation coefficients and standard deviations of the parameters are obtained. Eqn (4) is used to determine of g_j values. Then, Eqn (3) is used to determine the weights of the parameters according to the CRITIC method. To illustrate this calculation, SDRP parameter will be taken as an example.

$$w_{1CRT} = \frac{g_1}{\sum_{h=1}^{n} g_h} = \frac{7.1163}{7.1163 + 4.5110 + \ldots + 5.9451} = 0.0935.$$

Table 8. The decision matrix

Parameters / Natural Stones	SDFR	SHH	H	TSB	CS	AP	WAP
KS	27	24	3	110	425	33.2	16.5
EKS	89.3	19	2.50	50	87.5	51.1	31.3
CSS	92	13	2	75	27.50	56.5	39.34
DBS	18.10	33	3	163	600	4.86	0.98

Parameters / Natural Stones	SGSP	UBW	TIC	SDF	FR	PVRF	SV
KS	2.590	1.73	0.47	4.10	0.21	3.50	2700
EKS	2.453	1.20	0.3	3.95	0.55	4.10	2250
CSS	2.500	1.087	0.25	5.20	0.64	6.10	1800
DBS	2.282	2.35	1.22	0.9	23.70	0.04	4860

Table 9. The weights of parameters

Weights \ Parameters	SDFR	SHH	H	TSB	CS	AP	WAP
w_{jCRT}	0.0935	0.0593	0.0672	0.0634	0.0679	0.0795	0.0622
w_{jLCW}	0.0564	0.0657	0.0818	0.0593	0.0538	0.0854	0.0602
w_{jLOD}	0.0837	0.0586	0.0374	0.0663	0.0905	0.0849	0.0988
w_{jCBM}	0.0769	0.0385	0.0385	0.0385	0.0577	0.1154	0.0769
Weights \ Parameters	**SGSP**	**UBW**	**TIC**	**SDF**	**FR**	**PVRF**	**SV**
w_{jCRT}	0.0623	0.0807	0.0812	0.0607	0.0855	0.0583	0.0781
w_{jLCW}	0.0611	0.0822	0.0933	0.0506	0.0956	0.0629	0.0917
w_{jLOD}	0.0138	0.0566	0.0752	0.0861	0.0875	0.1008	0.0599
w_{jCBM}	0.0192	0.0769	0.1154	0.0577	0.1346	0.0769	0.0769

In the LOPCOW method, the percentage value of each parameter is obtained after the normalization process. Eqn (5) determines the percentage values (p_{ij}) for each parameter. To illustrate this calculation, SDRP parameter will be taken as an example.

$$p_{ij} = \left| \ln\left(\frac{\sqrt{\frac{\sum_{i=1}^{m} f_{ij}^2}{m}}}{\sigma} \right).100 \right| =$$

$$\left| \ln\left(\frac{\sqrt{\frac{(0.1204)^2 + (0.9635)^2 + \ldots + (0)^2}{4}}}{0.462917} \right).100 \right| = 40.9133.$$

Eqn (6) is utilised to obtain parameters' weights according to the LOPCOW method. To illustrate this calculation, SDRP parameter will be taken as an example.

$$w_{1LCW} = \frac{p_{ij}}{\sum_{j=1}^{n} p_{ij}} =$$

$$\frac{40.9133}{40.9133 + 47.6545 + \ldots + 66.4819} = 0.0564.$$

In the LODECI method, with Eqn (7), normalization is performed for the beneficial parameters. To indicate this calculation, the value of KS natural stone in the SDRP parameter will be taken as an example.

$$c_{11} = \frac{e_{11}}{\max(e_{ij})} = \frac{27}{92} = 0.2935.$$

With Eqn (9), the Decomposition Value is obtained for each parameter. Then the Logarithmic Decomposition Value is obtained with Eqn (10). After obtaining the Logarithmic Decomposition Value, the weights of the parameters are obtained with the help of Eqn (11). To illustrate this calculation, SDRP parameter will be taken as an example.

$$LDV_1 = \ln\left(1 + \frac{\sum_{i=1}^{m} DV_{ij}}{m}\right) = \ln\left(1 + \frac{3.0871}{4}\right) = 0.5720;$$

$$w_{1LOD} = \frac{LDV_{ij}}{\sum_{j=1}^{n} LDV_{ij}} =$$

$$\frac{0.5720}{0.5720 + 0.4004 + \ldots + 0.4091} = 0.0837.$$

Eqn (12) is used to combine the weights of parameters. To illustrate this calculation, SDRP parameter will be taken as an example.

$$w_{1CBM} = \frac{w_{1CRT} w_{1LCW} w_{1LOD}}{\sum_{j=1}^{n} w_{jCRT} w_{jLCW} w_{jLOD}} =$$

$$\frac{0.0935 \times 0.0564 \times 0.0837}{(0.0935 \times 0.0564 \times 0.0837) + (0.0593 \times 0.0657 \times 0.0586) + \ldots + (0.0781 \times 0.0917 \times 0.0599)} = 0.0769.$$

After finding the weights of the parameters, the AROMAN-M method is applied to evaluate the performance of natural stones.

Linear normalisation is first performed using Eqns (13) and (14). Table 10 shows the results of linear normalisation.

With Eqns (13) and (14), the values of the parameters are normalized by the linear normalisation procedure. To indicate this calculation, the value of KS natural stone in the SDRP parameter will be taken as an example.

$$d_{11} = \frac{e_{11} - \min(e_{ij})}{\max(e_{ij}) - \min(e_{ij})} = \frac{27 - 18.10}{92 - 18.10} = 0.120\,.$$

Then, vector normalisation is performed using Eqns (15) and (16). Table 11 indicates the results of vector normalisation.

With Eqns (15) and (16), the values of the parameters are normalized by the vector normalisation procedure. To indicate this calculation, the value of KS natural stone in the SDRP parameter will be taken as an example.

$$d_{11}^* = \frac{e_{11}}{\sqrt{\sum_{i=1}^{m} e_{ij}^2}} = \frac{27}{\sqrt{(27)^2 + (89.3)^2 + \ldots + (18.10)^2}} = 0.204.$$

The aggregated averaged normalized values are obtained using Eqn (17). In this study, β value has taken 0.5.

Table 10. The results of linear normalisation

Natural Stones \ Parameters	SDFR	SHH	H	TSB	CS	AP	WAP
KS	0.120	0.550	1.000	0.531	0.694	0.549	0.595
EKS	0.963	0.300	0.500	0.000	0.105	0.895	0.210
CSS	1.000	0.000	0.000	0.221	0.000	1.000	0.000
DBS	0.000	1.000	1.000	1.000	1.000	0.000	1.000
Natural Stones \ Parameters	**SGSP**	**UBW**	**TIC**	**SDF**	**FR**	**PVRF**	**SV**
KS	0.000	0.491	0.773	0.256	1.000	0.429	0.706
EKS	0.445	0.911	0.948	0.291	0.986	0.330	0.853
CSS	0.292	1.000	1.000	0.000	0.982	0.000	1.000
DBS	1.000	0.000	0.000	1.000	0.000	1.000	0.000

Table 11. The results of vector normalisation

Natural Stones \ Parameters	SDFR	SHH	H	TSB	CS	AP	WAP
KS	0.204	0.512	0.564	0.509	0.574	0.399	0.688
EKS	0.675	0.406	0.470	0.231	0.118	0.614	0.409
CSS	0.696	0.277	0.376	0.347	0.037	0.679	0.257
DBS	0.137	0.704	0.564	0.754	0.810	0.058	0.981
Natural Stones \ Parameters	**SGSP**	**UBW**	**TIC**	**SDF**	**FR**	**PVRF**	**SV**
KS	0.473	0.482	0.656	0.472	0.991	0.570	0.569
EKS	0.501	0.640	0.780	0.491	0.977	0.496	0.641
CSS	0.492	0.674	0.817	0.330	0.973	0.251	0.713
DBS	0.536	0.296	0.106	0.884	0.001	0.995	0.224

Table 12. The aggregated averaged normalized matrix

Natural Stones \ Parameters	SDFR	SHH	H	TSB	CS	AP	WAP
KS	0.081	0.266	0.391	0.260	0.317	0.237	0.321
EKS	0.410	0.176	0.243	0.058	0.056	0.377	0.155
CSS	0.424	0.069	0.094	0.142	0.009	0.420	0.064
DBS	0.034	0.426	0.391	0.438	0.452	0.015	0.495
Natural Stones \ Parameters	**SGSP**	**UBW**	**TIC**	**SDF**	**FR**	**PVRF**	**SV**
KS	0.118	0.243	0.357	0.182	0.498	0.250	0.319
EKS	0.236	0.388	0.432	0.195	0.491	0.207	0.373
CSS	0.196	0.419	0.454	0.083	0.489	0.063	0.428
DBS	0.384	0.074	0.026	0.471	0.000	0.499	0.056

Table 12 presents the aggregated averaged normalized matrix.

Eqn (17) is used to determine the aggregated averaged normalized values. To indicate this calculation, the value of KS natural stone in the SDRP parameter will be taken as an example.

$$d_{11}^{norm} = \frac{\beta d_{11} + (1-\beta) d_{11}^{*}}{2} = \frac{0.5 \times 0.120 + (1-0.5) \times 0.204}{2} = 0.081.$$

The weighted aggregated averaged normalized values are obtained using Eqn (18). Table 13 presents the weighted aggregated averaged normalized matrix.

Eqn (18) is utilised to obtain the weighted aggregated averaged normalized values. To indicate this calculation, the value of KS natural stone in the SDRP parameter will be taken as an example.

$$\hat{d}_{11} = w_{jCBM} d_{11}^{norm} = 0.0769 \times 0.081 = 0.0062.$$

Table 13. The weighted aggregated averaged normalized matrix

Natural Stones \ Parameters	SDFR	SHH	H	TSB	CS	AP	WAP
KS	0.0062	0.0102	0.0151	0.0100	0.0183	0.0273	0.0247
EKS	0.0315	0.0068	0.0093	0.0022	0.0032	0.0435	0.0119
CSS	0.0326	0.0027	0.0036	0.0055	0.0005	0.0484	0.0049
DBS	0.0026	0.0164	0.0151	0.0169	0.0261	0.0017	0.0381
Natural Stones \ Parameters	**SGSP**	**UBW**	**TIC**	**SDF**	**FR**	**PVRF**	**SV**
KS	0.0023	0.0187	0.0412	0.0105	0.0670	0.0192	0.0245
EKS	0.0045	0.0298	0.0499	0.0113	0.0660	0.0159	0.0287
CSS	0.0038	0.0322	0.0524	0.0048	0.0658	0.0048	0.0329
DBS	0.0074	0.0057	0.0031	0.0272	0.0000	0.0384	0.0043

Eqns (19)–(21) are used to obtain the results of the AROMAN-M. In this study, λ value has taken 0.5. Table 14 demonstrates the results of the AROMAN-M method.

Table 14. The results of AROMAN-M

Natural Stones \ Parameters	L_i	A_i	T_i	Rankings
KS	0.208	0.087	0.751	3
EKS	0.218	0.097	0.778	1
CSS	0.202	0.093	0.754	2
DBS	0.124	0.079	0.633	4

Eqns (19)–(21) are used to derive the values of L_i, A_i and T_i respectively. To illustrate these calculations, the natural stone KS will be taken as an example.

$$L_1 = \sum_{j=1}^{n} \hat{d}_{ij}^{(\min)} = 0.0247 + 0.0023 + \ldots + 0.0245 = 0.208;$$

$$A_1 = \sum_{j=1}^{n} \hat{d}_{ij}^{(\max)} = 0.0062 + 0.0102 + \ldots + 0.0273 = 0.087;$$

$$T_1 = L_1^{\lambda} + A_1^{(1-\lambda)} = (0.208)^{0.5} + (0.087)^{(1-0.5)} = 0.751.$$

According to the results of the AROMAN-M method, natural stones are ranked as follows: EKS, CSS, KS and DBS. Thus, the natural stone with the highest performance is determined as Erciyes Karasi Stone.

3.4. Sensitivity and comparative analysis

In this part of the paper, we have checked the influence of the three most significant criteria on alternative ranks. We have reduced the weights of AP(C6), TIC (C10), and FR (C12) criteria until they will have no any values, i.e., will have no importance. New simulated criteria weights are shown in Figure 8.

Obtained new ranks (Figure 9) show the sensibility of initial ranks caused by changing criterion AP(C6) because in scenarios S10–S12 the best two alternatives change their places. In other scenarios, EKS kept the first position.

In comparative analysis we have performed calculations with the following MCDM methods: MARCOS (Stević et al., 2020), SAW (Puška et al., 2023b), WASPAS (Zavadskas et al., 2012), EDAS (Keshavarz Ghorabaee et al., 2015; Stević et al., 2022), MABAC (Puška et al., 2024), and CRADIS (Puška et al., 2023a). Results have been shown in Figure 10.

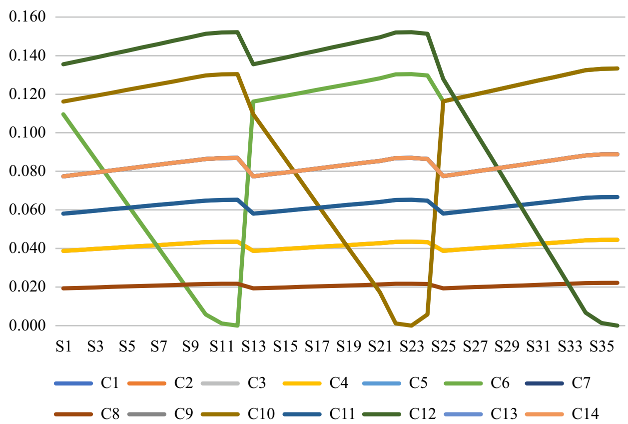

Figure 8. Simulated criteria weights in sensitivity analysis

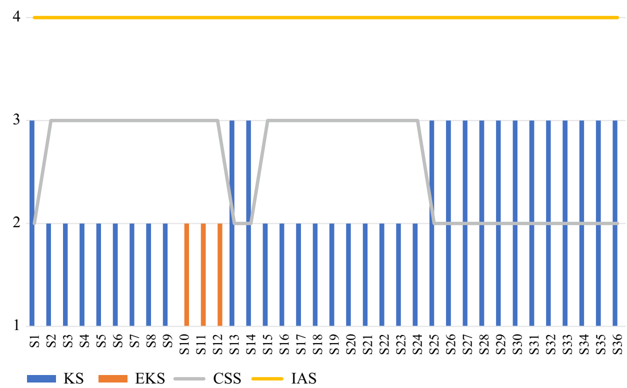

Figure 9. New obtained ranks in sensitivity analysis

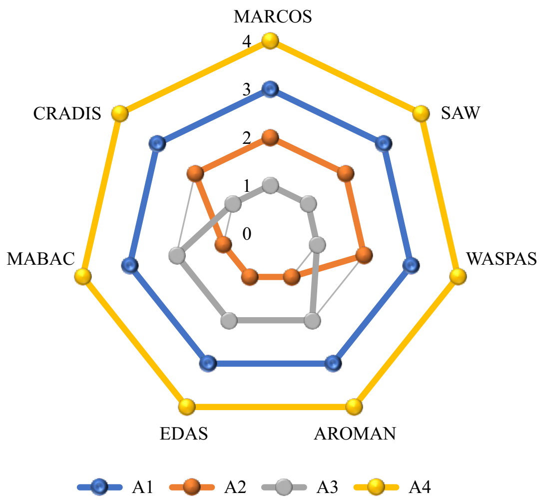

Figure 10. Results of comparative analysis

As can be seen in Figure 10 there are some deviations in ranks depending on the applied method, so we further have calculated correlation coefficients. We have calculated two coefficients: WS (Sałabun & Urbaniak, 2020) and SSC (Więckowski et al., 2023) which are shown in Table 15.

After performed analysis, average correlation coefficients are as follows: SCC = 0.902, WS = 0.857 which represents high correlation.

4. Conclusions

Energy is the primary source of economic and social development and the demand for energy is increasing in parallel with the development. On the other hand, energy resources are being depleted day by day, and the concept of "energy efficient design" gains importance for the conservation of existing energy and the development of renewable energy resources in order to plan the future in a healthy way.

The study is based on the building information modelling system. Building information modelling system is the process of creating a digital prototype in which the visible and functional characteristics of the building are assimilated and managed with the right decisions. Within the scope of the system, the energy analyses of the retirement home designed with the Autodesk Revit energy simulation program were achieved.

In the first stage of the work, the effects of changes in climatic factors such as the location, topography, and the climate zone where the designed retirement home is located, depending on the climate type, can be made on the building in terms of energy efficiency have been investigated. Then, the results of the energy analysis obtained by the Green Building Studio simulation were examined by making comparisons.

The highest annual cooling, annual heating and total energy consumption values were obtained with Diyarbakir Basalt Stone with its internally insulated wall structure. The lowest energy consumption values, energy consumption for annual cooling were determined by Kizilotesi stone for annual heating and total energy consumption by Çol sarisi stone with internally insulated wall design. The annual maximum energy consumption was obtained by using straw as insulation material, green roof as roof material, and green wall.

The annual minimum energy consumption has been determined by using cellulose fibre as insulation material green roof as roof material, and non-green wall. The reason why the green wall does not contribute much to the energy efficiency and heating loads may be the hot climate of Adana province. When the green wall is added, the walls cannot be supported directly from sufficient solar radiation.

In this study, four natural stones were evaluated with a new integrated MCDM model consisting of CRITIC, LOPCOW, LODECI and AROMAN-M methods. According

Table 15. Statistical correlation coefficients for comparative analysis

SCC	MARCOS	SAW	WASPAS	AROMAN	EDAS	MABAC	CRADIS	AV
MARCOS	1.000	1.000	1.000	0.800	0.800	0.800	1.000	0.914
SAW	1.000	1.000	1.000	0.800	0.800	0.800	1.000	0.914
WASPAS	1.000	1.000	1.000	0.800	0.800	0.800	1.000	0.914
AROMAN	0.800	0.800	0.800	1.000	1.000	1.000	0.800	0.886
EDAS	0.800	0.800	0.800	1.000	1.000	1.000	0.800	0.886
MABAC	0.800	0.800	0.800	1.000	1.000	1.000	0.800	0.886
CRADIS	1.000	1.000	1.000	0.800	0.800	0.800	1.000	0.914
WS	MARCOS	CODAS	COPRAS	MAIRCA	CRADIS	WASPAS	ARAS	
MARCOS	1.000	1.000	1.000	0.708	0.708	0.708	1.000	0.875
SAW	1.000	1.000	1.000	0.708	0.708	0.708	1.000	0.875
WASPAS	1.000	1.000	1.000	0.708	0.708	0.708	1.000	0.875
AROMAN	0.708	0.708	0.708	1.000	1.000	1.000	0.708	0.833
EDAS	0.708	0.708	0.708	1.000	1.000	1.000	0.708	0.833
MABAC	0.708	0.708	0.708	1.000	1.000	1.000	0.708	0.833
CRADIS	1.000	1.000	1.000	0.708	0.708	0.708	1.000	0.875

to the results of the proposed model, natural stones are ranked as follows: EKS, CSS, KS and DBS. Thus, the natural stone with the highest performance is determined as Erciyes Karasi Stone. In addition, the developed AROMAN-M method is compared with other MCDM methods. As a result of the comparison, it is confirmed that the developed AROMAN-M method reaches the correct results. In addition, by changing the weights of the criteria, it was evaluated whether this method is sensitive to the weight change. According to the results of the sensitivity analysis, it is concluded that the developed AROMAN-M method is sensitive to changes in the criteria weights.

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References

Alamdari, P., Nematollahi, O., & Mirhosseini, M. (2012). Assessment of wind energy in Iran: A review. *Renewable and Sustainable Energy Reviews*, *16*(1), 836–860. https://doi.org/10.1016/j.rser.2011.09.007

Araújo, C., Almeida, M., & Bragança, L. (2013). Analysis of some Portuguese thermal regulation parameters. *Energy and Buildings*, *58*, 141–150. https://doi.org/10.1016/j.enbuild.2012.11.024

Azhar, S., Nadeem, A., Mok, J. Y., & Leung, B. H. (2008). Building Information Modeling (BIM): A new paradigm for visual interactive modeling and simulation for construction projects. *Proceedings of the First International Conference on Construction in Developing Countries*, *1*, 435–446.

Azhar, S., Brown, J. W., & Sattineni, A. (2010). A case study of building performance analyses using building information modelling. In *Proceedings of the 27th International Symposium on Automation and Robotics in Construction* (*ISARC 2010*) (pp. 213–222), Bratislava, Slovakia. https://doi.org/10.22260/ISARC2010/0023

Azhar, S., Carlton, W. A., Olsen, D., & Ahmad, I. (2011). Building information modeling for sustainable design and LEED® rating analysis. *Automation in Construction*, *20*(2), 217–224. https://doi.org/10.1016/j.autcon.2010.09.019

Balo, F. (2011). Castor oil-based building materials reinforced with fly ash, clay, expanded perlite and pumice powder. *Ceramics-Silikáty*, *55*(3), 280–293.

Balo, F., & Sua, L. S. (2018). Techno-economic optimization model for "sustainable" insulation material developed for energy efficiency. *International Journal of Applied Ceramic Technology*, *15*(3), 792–814. https://doi.org/10.1111/ijac.12855

Balo, F., & Ulutaş, A. (2023). Energy-performance evaluation with Revit analysis of mathematical-model-based optimal insulation thickness. *Buildings*, *13*(2), Article 408. https://doi.org/10.3390/buildings13020408

Barison, M. B., & Santos, E. T. (2010, June). BIM teaching strategies: an overview of the current approaches. In *Proceedings of International Conference on Computing in Civil and Building Engineering* (*ICCCBE 2010*).

Bošković, S., Švadlenka, L., Jovčić, S., Dobrodolac, M., Simić, V., & Bačanin, N. (2023). An alternative ranking order method accounting for two-Step normalization (AROMAN) – A case study of the electric vehicle selection problem. In *EEE Access* (Vol. 11, pp. 39496–39507). https://doi.org/10.1109/ACCESS.2023.3265818

Chavan, S., & Gorade, S. B. (2022). Review on benefits, features, applications and implementation of building information modeling (BIM) for construction project. *International Research Journal of Engineering and Technology*, *9*(7), 2245–2254.

Clarke, J. (2007). *Energy simulation in building design*. Routledge. https://doi.org/10.4324/9780080505640

Cole, R. J. (2005). Building environmental assessment methods: redefining intentions and roles. *Building Research & Information*, *33*(5), 455–467. https://doi.org/10.1080/09613210500219063

Dhopte, S., & Daga, A. (2022). Exploring the journey of BIM in the Indian AECO industry (2008–2022) an Excelize perspective. *CSI Transactions on ICT*, *10*(2), 159–174. https://doi.org/10.1007/s40012-022-00364-9

Diakoulaki, D., Mavrotas, G., & Papayannakis, L. (1995). Determining objective weights in multiple criteria problems: The critic method. *Computers & Operations Research*, *22*(7), 763–770. https://doi.org/10.1016/0305-0548(94)00059-H

Dong, Y. H., & Ng, S. T. (2015). A life cycle assessment model for evaluating the environmental impacts of building construction in Hong Kong. *Building and Environment*, *89*, 183–191. https://doi.org/10.1016/j.buildenv.2015.02.020

Eadie, R., Browne, M., Odeyinka, H., McKeown, C., & McNiff, S. (2013). BIM implementation throughout the UK construction project lifecycle: An analysis. *Automation in Construction*, *36*, 145–151. https://doi.org/10.1016/j.autcon.2013.09.001

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). *BIM handbook*: *A guide to building information modeling for owners*, *managers*, *designers*, *engineers and contractors* (2nd ed.). John Wiley & Sons.

Ecer, F., & Pamucar, D. (2022). A novel LOPCOW-DOBI multi-criteria sustainability performance assessment methodology: An application in developing country banking sector. *Omega*, *112*, Article 102690. https://doi.org/10.1016/j.omega.2022.102690

Gökgür, A. (2015). *Current and future use of BIM in renovation projects Ata Gökgür*. Chalmers University of Technology.

Hamzakadı, A. (2019). *Building information modeling technology in conservation of environmental resources evaluation of provincial green building formation* [Master thesis]. Yıldız Technical University, Institute of Science and Technology.

Hire, S., Ruikar, K., Sandbhor, S., & Amarnath, C. B. (2021). A critical review on BIM for construction safety management. In *PMI Research & Academic Virtual Conference*, Mumbai, India.

Hire, S., Sandbhor, S., & Ruikar, K. (2022). Bibliometric survey for adoption of building information modeling (BIM) in construction industry – a safety perspective. *Archives of Computational Methods in Engineering*, *29*(1), 679–693. https://doi.org/10.1007/s11831-021-09584-9

Huskanović, E., Stević, Ž., & Simić, S. (2023). Objective-subjective CRITIC-MARCOS model for selection forklift in internal transport technology processes. *Mechatronics and Intelligent Transportation Systems*, *2*(1), 20–31. https://doi.org/10.56578/mits020103

Jadhav, S., & Ghadge, A. N. (2016). Application of Building information modeling in construction projects: A critical review. *International Journal of Engineering Research*, *5*(1), 26–31.

Keshavarz Ghorabaee, M., Zavadskas, E. K., Olfat, L., & Turskis, Z. (2015). Multi-criteria inventory classification using a new method of evaluation based on distance from average solution (EDAS). *Informatica*, *26*(3), 435–451. https://doi.org/10.15388/Informatica.2015.57

Krygiel, E., & Nies, B. (2008). *Green BIM*: *successful sustainable design with building information modeling*. John Wiley & Sons.

Kumar, B. (2022). Building information modeling ecosystem: an overview. In *Research companion to building information modeling* (Chapter 8, pp. 150–167). Edward Elgar Publishing. https://doi.org/10.4337/9781839105524.00016

Kumar, J. V., & Mukherjee, M. (2009). Scope of building information modeling (BIM) in India. *Journal of Engineering Science and Technology Review*, *2*(1), 165–169. https://doi.org/10.25103/jestr.021.30

Li, Y., Chen, X., Wang, X., Xu, Y., & Chen, P. H. (2017). A review of studies on green building assessment methods by comparative analysis. *Energy and Buildings*, *146*, 152–159. https://doi.org/10.1016/j.enbuild.2017.04.076

Meganathan, S., & Nandhini, N. (2018). A review on challenges involved in implementing building information modeling in construction industry. *International Research Journal of Engineering and Technology*, *5*(1), 1329–1331.

Moakher, P. E., & Pimplikar, S. S. (2012). Building information modeling (BIM) and sustainability – using design technology in energy efficient modeling. *IOSR Journal of Mechanical and Civil Engineering*, *1*(2), 10–21. https://doi.org/10.9790/1684-0121021

Mostafavi, N., Farzinmoghadam, M., & Hoque, S. (2015). Envelope retrofit analysis using eQUEST, IESVE Revit Plug-in and Green Building Studio: a university dormitory case study. *International Journal of Sustainable Energy*, *34*(9), 594–613. https://doi.org/10.1080/14786451.2013.848207

Motawa, I., & Carter, K. (2013). Sustainable BIM-based evaluation of buildings. *Procedia - Social and Behavioral Sciences*, *74*, 419–428. https://doi.org/10.1016/j.sbspro.2013.03.015

Nalawade, S., Ramani, H., Gaikwad, R., Pawar, P., & Sathe, P. (2019). Review of BIM technology in construction sector. *International Journal of Research and Analytical Reviews*, *6*(1), 1–3.

Olawumi, T. O., Chan, D. W., Wong, J. K., & Chan, A. P. (2018). Barriers to the integration of BIM and sustainability practices in construction projects: A Delphi survey of international experts. *Journal of Building Engineering*, *20*, 60–71. https://doi.org/10.1016/j.jobe.2018.06.017

Pajić, V., Andrejić, M., & Poledica, M. (2024). A novel approach based on CRITIC-MOOSRA methods for evaluation and selection of cold chain monitoring devices. *Journal of Intelligent Management Decision*, *3*(2), 68–76. https://doi.org/10.56578/jimd030201

Pala, O. (2024). Assessment of the social progress on European Union by logarithmic decomposition of criteria importance. *Expert Systems with Applications*, *238*, Article 121846. https://doi.org/10.1016/j.eswa.2023.121846

Puška, A., Hodžić, I., & Štilić, A. (2023a). Evaluating the knowledge economies within the European Union: A global knowledge index ranking via Entropy and CRADIS methodologies. *International Journal of Knowledge and Innovation Studies*, *1*(2), 103–115. https://doi.org/10.56578/ijkis010203

Puška, A., Stojanović, I., & Štilić, A. (2023b). The influence of objective weight determination methods on electric vehicle selection in urban logistics. *Journal of Intelligent Management Decision*, *2*(3), 117–129. https://doi.org/10.56578/jimd020302

Puška, A., Hodžić, I., Štilić, A., & Murtič, S. (2024). Evaluating European Union countries on climate change management: A fuzzy MABAC approach to the climate change performance index. *Journal of Green Economy and Low-Carbon Development*, *3*(1), 15–25. https://doi.org/10.56578/jgelcd030102

Rahimikhoob, A., Behbahani, S., & Nazarifar, M. H. (2008). Estimation of cooling degree days (CDDs) from AVHRR data and an MLF neural network. *Canadian Journal of Remote Sensing*, *34*(6), 596–600. https://doi.org/10.5589/m08-067

Ramesh, T., Prakash, R., & Shukla, K. K. (2010). Life cycle energy analysis of buildings: An overview. *Energy and Buildings*, *42*(10), 1592–1600. https://doi.org/10.1016/j.enbuild.2010.05.007

Roshan, G. R., Ghanghermeh, A. A., & Attia, S. (2017). Determining new threshold temperatures for cooling and heating degree day index of different climatic zones of Iran. *Renewable Energy*, *101*, 156–167. https://doi.org/10.1016/j.renene.2016.08.053

Sałabun, W., & Urbaniak, K. (2020). A new coefficient of rankings similarity in decision-making problems. In V. Krzhizhanovskaya, V., Závodszky, G., Lees, M. H., Dongarra, J. J., Sloot, P. M. A., Brissos, S., & Teixeira, J. (Eds.), *Lecture notes in computer science*: *Vol. 12138*. *Computational science – ICCS 2020* (pp. 632–645). Springer, Cham. https://doi.org/10.1007/978-3-030-50417-5_47

Salvi, S. A., Patil, M. A., Mhetre, M. S., Patil, M. Y., & Shinde, M. A. (2022). Review: Lifecycle assessment of a building by using BIM. *International Journal for Research in Applied Science and Engineering Technology*, *10*, 699–704. https://doi.org/10.22214/ijraset.2022.39901

Sarkar, D., & Shah, H. (2018). Integration of BIM and risk management: a review of literature. *International Journal of Management Technology and Engineering*, *8*, 489–499.

Saundhrya, A. R., & Uma, R. N. (2016). Building information modelling in construction industry – a review. *International Journal of Engineering and Technology*, *3*(11), 1324–1329.

Singh, A. K., Yadav, B. P., & Yadav, A. S. (2023). An application of building information modelling-based approach and current developments towards ergonomic risk assessment in the construction sector – a systematic review. *International Journal of Human Factors and Ergonomics*, *10*(1), 41–65. https://doi.org/10.1504/IJHFE.2023.128574

Solla, M., Ismail, L. H., & Yunus, R. (2016). Investigation on the potential of integrating BIM into green building assessment tools. *ARPN Journal of Engineering and Applied Sciences*, *11*(4), 2412–2418.

Sood, R., & Laishram, B. (2022). A review on unexploited features of n-dimensional BIM: An Indian construction scenario. In Y. G. Sandanayake, S. Gunatilake, & K. G. A. S. Waidyasekara (Eds.), *Proceedings of the 10th World Construction Symposium* (pp. 39–49), Sri Lanka. https://doi.org/10.31705/WCS.2022.4

Srimathi, S., & Uma, R. N. (2017). Implementation of BIM tools in construction project. *International Journal of Engineering Research* & *Technology*, *6*(11), 117–120. https://doi.org/10.17577/IJERTV6IS110056

Staub-French, S., Forgues, D., Iordanova, I., Kassaian, A., Abdulaal, B., Samilski, M., Cavka, H., & Nepal, M. (2011). *Building Information Modeling* (*BIM*) *'Best practices' project report*: *An investigation of 'best practices' through case studies at regional*, *national*, *and international levels*. University of British Columbia and École de Technologie Supérieure, Canada.

Stević, Ž., Pamučar, D., Puška, A., & Chatterjee, P. (2020). Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement of alternatives and ranking according to COmpromise solution (MARCOS). *Computers* & *Industrial Engineering*, *140*, Article 106231. https://doi.org/10.1016/j.cie.2019.106231

Stević, Ž., Subotić, M., Softić, E., & Božić, B. (2022). Multi-criteria decision-making model for evaluating safety of road sections. *Journal of Intelligent Management Decision*, *1*(2), 78–87. https://doi.org/10.56578/jimd010201

Succar, B. (2009). Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in Construction*, *18*(3), 357–375. https://doi.org/10.1016/j.autcon.2008.10.003

Summerfield, A. J., & Lowe, R. (2012). Challenges and future directions for energy and buildings research. *Building Research* & *Information*, *40*(4), 391–400. https://doi.org/10.1080/09613218.2012.693839

Wen, T. J., Siong, H. C., & Noor, Z. Z. (2015). Assessment of embodied energy and global warming potential of building construction using life cycle analysis approach: Case studies of residential buildings in Iskandar Malaysia. *Energy and Buildings*, *93*, 295–302. https://doi.org/10.1016/j.enbuild.2014.12.002

Więckowski, J., Kizielewicz, B., Shekhovtsov, A., & Sałabun, W. (2023). How do the criteria affect sustainable supplier evaluation? – A case study using multi-criteria decision analysis methods in a fuzzy environment. *Journal of Engineering Management and Systems Engineering*, *2*(1), 37–52. https://doi.org/10.56578/jemse020102

Wong, J. K. W., & Kuan, K. L. (2014). Implementing 'BEAM Plus' for BIM-based sustainability analysis. Automation in Construction, *44*, 163–175. https://doi.org/10.1016/j.autcon.2014.04.003

Zavadskas, E. K., & Podvezko, V. (2016). Integrated determination of objective criteria weights in MCDM. *International Journal of Information Technology* & *Decision Making*, *15*(2), 267–283. https://doi.org/10.1142/S0219622016500036

Zavadskas, E. K., Turskis, Z., Antucheviciene, J., & Zakarevicius, A. (2012). Optimization of weighted aggregated sum product assessment. *Elektronika ir elektrotechnika*, *122*(6), 3–6. https://doi.org/10.5755/j01.eee.122.6.1810