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FULL LENGTH ARTICLE

The Impact of Building Material Modeling on Enhancing Building Sustainability (Energy Efficiency): A Case Study of a Residential Building in Basilia

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ABSTRACT

This research aims to study the impact of building materials modeling on enhancing building sustainability through a case study of a residential building within the Basilia City planning scheme in Damascus, which is being transformed into a sustainable area using sustainable design techniques. The study is based on analyzing plot EA-189 in the Kfar Sousseh area by evaluating the thermal efficiency of the proposed building materials and comparing them with other materials using the Insight Solar tool in Autodesk Revit. The study involves analyzing three scenarios using different building materials: (1) concrete blocks with air insulation and a bituminous insulated roof, (2) brick with fiberglass insulation and a green roof, and (3) a mix of brick and concrete blocks on different facades and a green roof. The results show that the second scenario provides the highest energy efficiency and best indoor air quality, despite its higher cost. The third scenario, which combines brick and concrete blocks, offers a balance between energy efficiency and cost, making it the optimal choice for future construction projects. The study demonstrates that Building Information Modeling (BIM) enhances the effectiveness of sustainable design strategies and contributes to improved energy performance and environmental comfort of buildings.

Keywords: Building Sustainability ▪ Sustainable Design Techniques ▪ Building Information Modeling (BIM) ▪ Thermal Efficiency ▪ Energy Efficiency in Buildings ▪ Green Building Materials ▪ Thermal Insulation

1. INTRODUCTION

Sustainability in buildings is one of the fundamental goals in modern urban development, aiming to achieve a balance between environmental, economic, and social performance. Basilia City in Damascus is considered an ideal model for transforming it into a sustainable area through the application of sustainable design techniques and building materials modeling.

In this context, the study presents a case study of a residential building within plot EA-189 in the Kfar Sousseh area, where the impact of using Building Information Modeling (BIM) techniques on enhancing building sustainability is evaluated. The study relies on analyzing the thermal efficiency of various building materials using the Insight Solar tool in Revit to compare the energy and environmental performance of three different design scenarios.

The study includes an analysis of the impact of the materials used on energy efficiency, cost, and indoor comfort. It evaluates how materials affect solar energy absorption, thermal insulation, and indoor air quality, reflecting the importance of selecting appropriate materials for improving building sustainability. The results show that combining materials and applying sustainable design strategies can lead to significant improvements in energy performance and cost savings, contributing to achieving sustainability goals in construction [1].

2. LITERATURE REVIEW

Building sustainability is one of the primary goals in the development of modern cities, aiming to achieve a balance between environmental, economic, and social performance. The evolution of sustainability from the Brundtland framework to the Sustainable Development Goals emphasizes the importance of integrating environmental and socioeconomic considerations [2]. Recent research on green building practices further shows that renewable-energy integration, supportive policies, and technological innovation can improve the environmental performance of the construction sector [3].

Building Information Modeling (BIM) contributes to green building design by enabling building-performance analysis and supporting more informed decisions regarding materials and design [4]. Its incorporation into architectural education and infrastructure projects also demonstrates the broader adoption of BIM across the construction sector [5, 6].

Thermal efficiency is a key factor in achieving building sustainability, as effective thermal insulation helps maintain stable indoor temperatures and reduces heating and cooling demand. Reviews of thermal-insulation materials identify material properties and selection as important determinants of occupant comfort and building performance [7]. Energy-efficient operation also depends on appropriate heating, ventilation, and air-conditioning strategies and technologies [8].

Material selection can affect both energy performance and indoor environmental quality. Research on rigid polyurethane foam evaluates its effects on insulation, indoor conditions, and sustainable development [9], while studies of volatile organic compounds from paint production highlight the importance of controlling potentially harmful emissions [10]. Evidence from the green building movement also identifies combined energy-saving, emission-reduction, and health benefits [11]. Air-treatment systems designed for tropical buildings provide another route to improving indoor air quality while reducing energy consumption [12]. Overall, the literature indicates that integrating sustainable design techniques, BIM [13], and appropriate material selection is central to improving building performance.

3. METHODOLOGY

The research methodology involves studying the impact of building material modeling on enhancing building sustainability through a case study of a residential building within the Basilia City master plan in Damascus. The methodology begins with selecting the specific site in the Kafr Sousa area within the plan, where initial data is collected on the current building specifications and architectural design details, including construction materials and insulation systems.

Autodesk Revit is used to apply Building Information Modeling (BIM) techniques, with the building details entered into a 3D model that accurately reflects its design. The Insight Solar tool within Revit is then utilized to analyze the building's energy performance based on three different design scenarios. The first scenario involves using concrete blocks with air-gap insulation and a bitumen-insulated roof, where the impact of these materials on energy efficiency and photovoltaic energy production is analyzed. The second scenario uses bricks with fiberglass insulation and a green roof, evaluating how these modifications affect environmental performance and energy efficiency. The third scenario combines bricks and concrete blocks on the facades according to a specific distribution, maintaining good insulation and analyzing its impact on energy performance.

After conducting the analyses, each scenario is evaluated based on indicators such as photovoltaic energy production, energy savings, required solar-panel area, and payback period. The results are compared between scenarios to determine which provides the best balance between energy performance, cost, and environmental comfort. The resulting data is analyzed to identify the benefits and drawbacks of each design scenario, and recommendations are made for improving building sustainability through design modifications and more effective material choices. The research findings and recommendations are presented in a comprehensive report aimed at providing practical guidance for enhancing building sustainability in future construction projects.

3.1 Data Analysis

3.1.1 First Case

This case involves using a concrete block with a thickness of 10 cm, followed by an air-gap insulation of 5 cm, and another concrete block with a thickness of 10 cm, in that order, with the roof insulated with bitumen.

First, the project's geographical location is determined and the solar settings are adjusted. The "Solar" option is then selected for solar studies, specifying an annual study (Annual PV). Next, the surfaces to be studied are chosen manually, and the settings are applied to all faces and areas of the project exposed to sunlight (external walls and roof surface).

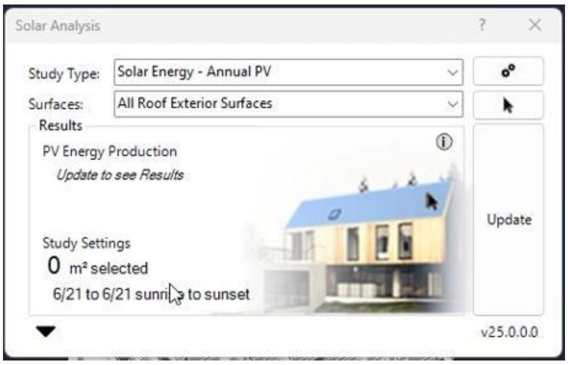

Figure 1. Adjusting the solar settings in the Insight analysis tool.

After that, the "Update" tool is selected and the analysis is allowed to display the results. The results are shown visually in color on the 3D view and are also presented in written form within the list, as illustrated in Figure 2.

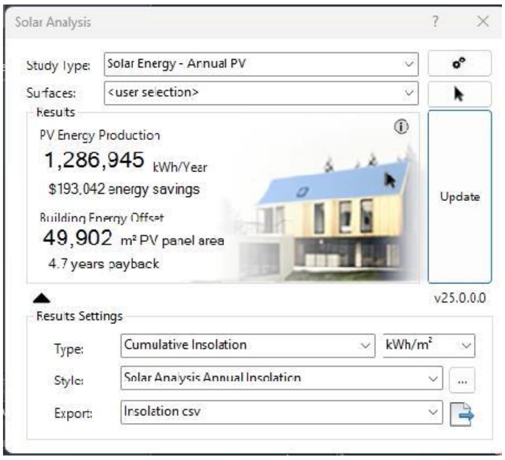

Figure 2. Solar analysis results in Revit for the first case.

Analysis of Results:

- **PV Energy Production:** 1,286,945 kWh/year. This figure represents the amount of energy required from photovoltaic cells to offset the building's energy consumption. It is measured in kilowatt-hours.
- **Energy Saving:** $193,042. This amount reflects the financial savings resulting from the use of photovoltaic energy compared to traditional energy sources. This saving indicates the effect of reducing energy consumption from the main grid and suggests a partial recovery of the investment in solar panels through reduced energy bills.
- **PV Panel Area:** 49.902 m^2. This area represents the total surface of photovoltaic panels needed to be installed on the roof or within the building to achieve the stated energy production.
- **Payback Period:** 4.7 years. This is the estimated payback period for investing in photovoltaic systems, meaning that the initial costs of installing the systems are expected to be recovered through savings on energy bills within 4.7 years. This indicates a viable investment.

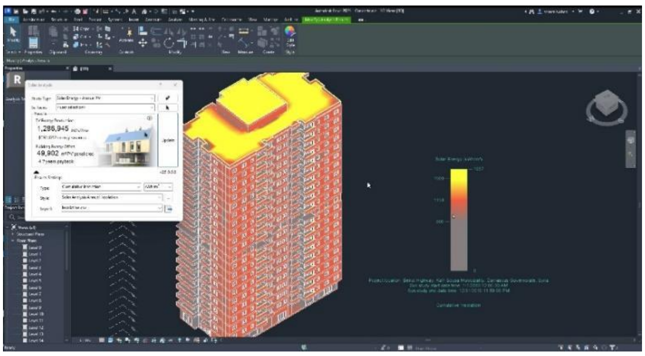

Figure 3. Reflection of solar analysis results on the 3D view of the studied model in the first case.

3.1.2 Second Case

Envelope: The envelope consists of a layer of 10 cm-thick brick block, followed by 5 cm of fiberglass insulation, and another 10 cm layer of brick block. **Roof:** The roof construction includes a 40 cm-thick reinforced concrete slab, 20 cm of rigid insulation, a 1.5 cm EPDM membrane roofing, 5 cm of sand, and 30 cm of planted earth.

The same study procedures were applied; however, the results differed due to the change in building materials.

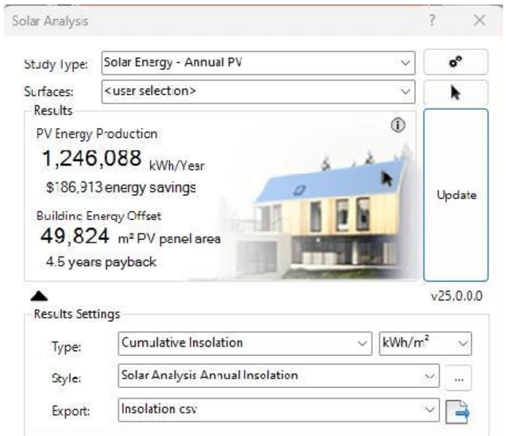

Figure 4. Solar analysis results in Revit for the second case.

Analysis of Results:

- **PV Energy Production:** 1,246,088 kWh/year. This represents the amount of energy produced by photovoltaic cells annually to meet the building's energy needs and offset industrial energy consumption within the building.
- **Energy Savings:** $186,913. This amount reflects the financial savings achieved by using photovoltaic energy compared to traditional energy sources, indicating the reduction in energy consumption from the main grid and partial recovery of the investment in solar panels through lower energy bills.
- **PV Panel Area:** 49,824 m^2. This area indicates the total size of photovoltaic panels required to be installed on the roof or within the building to achieve the specified energy production.
- **Payback Period:** 4.5 years. This period represents the estimated time to recover the initial investment in photovoltaic systems through savings on energy bills.

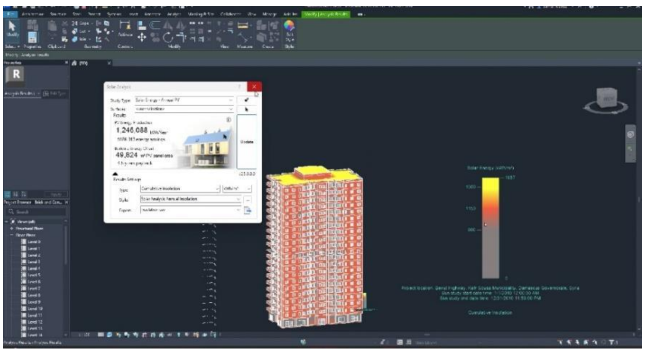

Figure 5. Reflection of solar analysis results on the 3D perspective of the studied mass in the second case.

3.1.3 Comparison of the First and Second Cases

In the first case, the building's photovoltaic energy requirement is 1,286,945 kWh/year, whereas in the second case it is 1,246,088 kWh/year. This indicates a reduction of 40,867 kWh/year in the photovoltaic energy requirement in the second case compared with the first. Thus, the building's energy efficiency improved with the substitution of concrete blocks with bricks, leading to a decreased need for photovoltaic cells.

Additionally, the impact of these materials on the occupants' mental health is considered:

- **Concrete Blocks:** These are generally lower in off-gassing compared with some other materials, as they emit fewer chemicals such as formaldehyde and volatile organic compounds. However, adhesives, fillers, and paints used with concrete blocks may still be sources of emissions that negatively affect indoor air quality, potentially leading to health issues such as headaches, irritation, allergies, and respiratory problems. These health issues can, in turn, negatively affect the occupants' mental well-being.
- **Bricks:** Bricks have the ability to "breathe," which helps in regulating humidity within the building. This improves indoor air quality, positively impacting the mental and physical health of the occupants. They also provide good thermal insulation, helping to maintain a comfortable and stable indoor temperature. This creates a stable indoor environment that contributes to psychological comfort and a sense of security. Additionally, bricks effectively insulate against noise, reducing indoor noise pollution and helping occupants feel calmer and more focused, especially in busy urban environments.

In summary, the second case demonstrates better energy efficiency and healthier indoor air quality compared with the first scenario. However, considering material costs in the Syrian market, the cladding cost in the second case will be six times higher than that in the first case, which is a significant increase. This highlights the need to consider a third proposal that enhances the building's energy efficiency while also taking cost into consideration.

3.1.4 Third Case

As a result, a third proposal was considered, which involved using bricks on the east and west facades that are directly exposed to sunlight, requiring additional insulation. These facades constitute only 33% of the cladding area, while the cement blocks are retained on the north and south facades.

Envelope: The envelope consists of brick blocks with a thickness of 10 cm and an air gap of 5 cm, followed by another layer of brick blocks with a thickness of 10 cm, used for the eastern and western facades. Concrete blocks with a thickness of 10 cm and an air gap of 5 cm, followed by another layer of concrete blocks with a thickness of 10 cm, are used for the northern and southern facades. **Roof:** Reinforced concrete slab, 40 cm; rigid insulation, 20 cm; EPDM membrane roofing, 1.5 cm; sand, 5 cm; and earth, 30 cm, with planted soil.

The same study procedures were applied; however, the results differed due to the change in building materials.

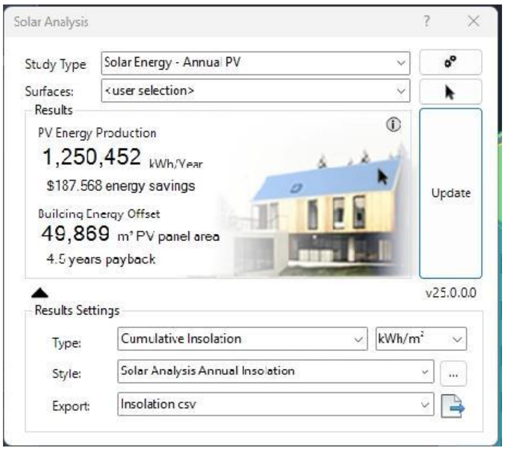

Figure 6. Solar analysis results in Revit for the third case.

Analysis of Results:

- **PV Energy Production:** The photovoltaic energy production is 1,250,452 kWh/year. This measures the amount of energy required by the building from photovoltaic cells to offset the building's energy consumption.
- **Energy Saving:** The energy saving amounts to $187,568. This figure represents the financial savings achieved by using photovoltaic energy compared with conventional energy sources. This saving reflects the impact of reduced energy consumption from the main grid and indicates the partial recovery of the investment in solar panels through lower energy bills.
- **PV Panel Area:** The area of solar panels is 49.869 m^2. This area represents the total size of the photovoltaic panels that will be installed on the roof or within the building to achieve this level of production.
- **Payback Period:** The payback period is 4.5 years. This is the estimated period for recovering the investment in PV systems, meaning that the initial costs of installing the systems are expected to be offset by energy savings after 4.5 years.

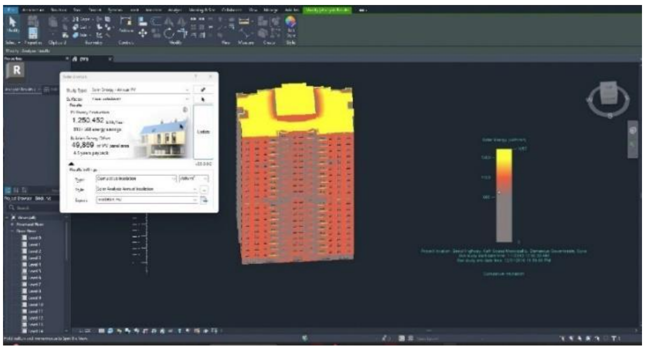

Figure 7. Reflection of solar analysis results on the 3D view of the studied mass in the third case.

3.1.5 Comparison of the Three Cases

In the first case, the building's need for photovoltaic (PV) energy is 1,286,945 kWh/year. In the second case, the need for PV energy is 1,246,088 kWh/year. In the third case, the building's PV energy requirement is 1,250,452 kWh/year.

- **First Case vs. Third Case:** The PV energy requirement in the third case is 36,493 kWh/year less than in the first case.

- **Second Case vs. Third Case:** The PV energy requirement in the third case is 4,364 kWh/year more than in the second case.

Comparing the results, the second case remains the most efficient in terms of energy performance, although the difference between it and the third case is very small. However, considering the cost, the second case would increase the envelope cost by six times, while the third case would only double the cost, with energy efficiency being close to that of the second case. Therefore, the third case is considered the best option when balancing both cost and energy performance.

4. DISCUSSION

The analyses conducted on the three cases for improving building sustainability through various materials and designs reveal important insights into their impact on energy performance, cost, and indoor environmental comfort. In the first case, where concrete block walls with an air cavity and a bitumen-insulated roof were used, the photovoltaic solar energy production was the highest, reaching 1,286,945 kWh annually. Despite the abundant energy, the external envelope cost was high, with energy savings of $193,042 and a payback period of 4.7 years, indicating a strong return on investment but at a high cost.

In the second case, using brick with fiberglass insulation and a green roof, the need for photovoltaic solar energy was slightly lower (1,246,088 kWh annually), with energy savings of $186,913 and a shorter payback period of 4.5 years, along with improved indoor air quality and comfort. However, the high cost of the external envelope made it less practical. The third case, which combined brick and concrete block with a similar roofing system to the first case, achieved a slightly lower photovoltaic energy requirement (1,250,452 kWh annually), with energy savings of $187,568 and a payback period of 4.5 years. The cost increase was more moderate compared with the second case, making it a more cost-effective option with energy efficiency close to the second case. Overall, while the second case offers superior energy performance and better environmental benefits, the third case provides a good balance between cost and performance, offering a practical compromise between initial expenditure and energy efficiency.

5. CONCLUSIONS

5.1 Summary of Key Findings

The analyses conducted on various cases for enhancing building sustainability through different techniques and designs revealed significant findings. A notable variation was observed in energy performance, cost, and indoor environmental comfort across different design options. Regarding photovoltaic solar energy production, the results indicated that different systems provide varying levels of energy output, reflecting the efficiency of each system in meeting the building's energy needs. In all cases, the energy production levels were sufficient to cover a substantial portion of the energy demand, though differences in efficiency were evident.

Concerning financial savings and payback periods, the results were positive, with the systems providing varying degrees of financial savings and payback periods ranging from 4.5 to 4.7 years. This highlights the efficiency of investments in solar energy, although the cost of the exterior envelope impacted the economic feasibility in some cases. In terms of indoor environmental comfort, the quality of indoor air and user comfort improved thanks to the use of natural materials and enhanced insulation designs, contributing to better psychological and physical well-being of the occupants. Overall, the results emphasize the importance of selecting appropriate materials and designs to achieve a balance between energy performance and costs while considering the effects on environmental comfort [14].

5.2 Concluding Remarks

In conclusion, the results highlight the importance of integrating energy sustainability, cost-effectiveness, and indoor environmental comfort in building design. It is evident that utilizing sustainable design techniques, such as photovoltaic solar systems, can significantly improve energy efficiency, though the cost associated with implementing these technologies can be high. Therefore, it is essential to consider both energy benefits and economic costs when making design decisions.

The study recommends investing in sustainable design technologies and utilizing advanced tools such as Building Information Modeling (BIM) [13, 4] to accurately assess building performance. These tools provide detailed analyses that aid in making informed decisions regarding materials and designs that enhance energy efficiency and reduce costs. It is also crucial to focus on selecting materials that improve indoor air quality and user comfort, such as natural materials with good breathable properties that contribute to a better living and working environment.

Furthermore, investments in green technology should be carefully considered to ensure maximum value for money. The cost of materials and technologies remains a significant factor in determining long-term sustainability feasibility. At the regional scale, policy and trade integration can also influence the transition toward renewable energy [15]. Therefore, continuous research and development of new and innovative solutions in sustainable construction are recommended. This includes exploring new technologies, improving existing materials, and continuously evaluating their environmental and economic impacts. These building-level recommendations should also be viewed within broader sustainability and biodiversity objectives, for which long-term governance and evaluation remain important [16].

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