The Impact of Building Material Modeling on Enhancing Building Sustainability (Shadow and Lighting): A Case Study of a Residential Building in Basilia

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Abstract

This study examines the impact of building material modeling on enhancing building sustainability through a case study of a residential building in the city of Basilia. The focus is on using Revit 2023 to model the building and analyze how building materials affect its sustainability. The modeling process includes analyzing the shadows cast by architectural elements and studying their impact on the performance of the building materials. Shadow reflections on energy and material efficiency are measured to determine how building sustainability can be improved through material design and distribution adjustments. Additionally, Revit Insight 2025 is used to evaluate the extent to which natural lighting is achieved through the building envelope and to study the impact of materials on lighting quality and energy efficiency. The research addresses how the building benefits from natural lighting and how this can be optimized with appropriate materials to achieve maximum energy efficiency and reduce environmental impact. The study aims to provide a comprehensive model demonstrating how building sustainability can be enhanced through improved modeling of building materials and analysis of their environmental performance. Through these analyses, the research seeks to offer strategies and recommendations for designing more sustainable and energy-efficient buildings.

Keywords: Sustainable Buildings; Green Buildings; Environmental Assessment; Assessment Systems; Building Information Modelling (BIM); Building Envelopes; Building Sustainability; Shadow Analysis; Sustainable Design; Environmental Performance Assessment.

1. Introduction

The growing focus on the aesthetic aspects of building envelopes often leads architects to neglect their energy efficiency. This results in a reliance on mechanical systems to provide thermal comfort, compensating for disruptions caused by arbitrary surface use in facades. This study addresses the environmental damage the lack of knowledge about latent thermal energy storage in building envelopes. Additionally, it considers the impact of removing green spaces like Razi Gardens for construction using unsustainable materials.

The objective of this study is to explore how Building Information Modeling (BIM) can enhance the sustainability of residential buildings. Using a residential building in Basilia as a case study, the research defines the principles and standards of green architecture design, assesses the impact of toxic

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emissions from building materials, and addresses the knowledge gap in thermal energy storage techniques. It evaluates how building envelopes can improve thermal performance and reduce energy loads and demonstrates how BIM technology can achieve sustainability.

The research highlights the need to redefine building practices to promote environmental sustainability and understand how construction can conserve the environment. It assesses the role of building envelopes in reducing cooling and heating loads and leverages BIM for sustainable construction. The study aims to reduce pollutant emissions from buildings, promote sustainable assessment tools, and present global examples of sustainable projects using BIM. This research proposes an improved model for building envelopes that manage climatic elements to achieve indoor comfor.

The study emphasizes the importance of sustainable construction practices and promotes the culture of sustainability in Syria. It aims to understand the role of building materials in thermal performance and mitigate the environmental impact of converting green spaces into construction zones.[1]

1. Literature Review

Sustainability and Sustainable Architecture Standards

This article explores the evolution and principles of sustainability within the context of architecture and construction. Originating in the 1970s amid growing concerns over environmental degradation and developmental challenges, sustainability emerged as a pivotal concept. It gained prominence following the 1987 Brundtland Report, which defined sustainable development as meeting present needs without compromising future generations. Subsequent global conferences, such as Rio de Janeiro in 1992 and Johannesburg in 2002, underscored the urgency of integrating sustainability into global and local development agendas.

Sustainability, encompassing ecological, economic, and social dimensions, remains central to architecture and construction. Sustainable architecture, an integrated design approach, emphasizes resource efficiency and environmental responsibility across a building's lifecycle—from design and construction to operation and demolition. Key strategies include minimizing environmental impact, conserving energy and water, reducing waste, and promoting reuse and recycling[2]. Materials such as steel, glass, and prefabricated components are favored for their sustainability credentials, contributing to lower resource consumption and enhanced environmental stewardship.

Moreover, sustainable buildings not only mitigate environmental footprints but also offer economic benefits, including reduced operational costs and increased property values. They enhance indoor environmental quality, promoting occupant health and productivity while aligning with broader goals of sustainable development. Overall, the article underscores the importance of sustainable practices in architecture and construction, advocating for their integration into future building endeavors to ensure long-term environmental and societal well-being.

BIM Technology and its Role in Achieving Sustainability and Sustainable Building Assessment Systems

Building Information Modeling (BIM) has emerged as a transformative methodology in the Architecture, Engineering, Construction, and Operations (AECO) industries, facilitating comprehensive information management throughout a building's lifecycle. Since its inception, BIMhas gained fundamental recognition within these sectors. BIM encompasses the coordinated and computable building data and facilitates design decision-making, building performance prediction, cost estimation, and construction planning. Chang & Hsieh (2020) define BIM as a set of interactive policies, processes, and technologies that form a methodology for managing building design basics and data in a digital format throughout the building's lifecycle. The advent of BIM has revolutionized traditional building design processes by adapting to additional layers of data, enabling new methods of information exchange and communication among project stakeholders. With BIM, designers can modify building components in a unified model, allowing system-wide dissemination of changes across all project views. Moreover, the application of BIM in real construction projects, as a single-model concept serving as a single-source information repository, presents several challenges. However, the benefits of BIM methodology are numerous. [3]Visualization: BIM provides a better understanding of the building project and links additional data dimensions to building models. Change Management: Changes made in a BIM model are automatically reflected in all views, such as floor

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plans, sections, and elevations, facilitating collaboration on coordinated models and expediting documentation. Building Simulation: BIM models include more than just architectural data; they encompass information about structural models, Mechanical, Electrical, and Plumbing (MEP) systems, sustainability information, and other properties, enabling project teams to assess building performance in advance of actual construction. Data Management: The underlying idea of applying BIM is to capture information and manage construction projects. The shift to BIM methodology and radical transformations towards green building concepts have enabled stakeholders in the AECO industry to integrate the emerging trends known as "Green Building Information Modeling" (green BIM) to expedite sustainable building design practices (Autodesk 2018a). The benefits of implementing BIM in sustainable building design have been well-documented in both literature and industry practices. The advantages of sustainable building design using BIM precisely relate to accurate information exchange, building performance analysis, accurate cost estimation, and timely project completion (GSA 2015). BIM implementation can be realized in the development of sustainable buildings across three outlined areas, The BIM context covers a wide range of diverse areas, such as interactive policies, processes, modeling techniques, imaging, analysis, simulation, and documentation of sustainable building projects.[4]BIM technology for green building design is the most explored field in BIM literature. There are two main types of BIM software solutions: BIM authoring solutions and BIM performance analysis solutions. BIM authoring tools are often large, powerful applications used by design firms to generate and organize most of the information in the BIM model. Currently, BIM authoring tools like Revit, ArchiCAD, and Bentley have interfaces with additional functions such as presentation rendering, cost estimation, and energy analysis. On the other hand, dedicated BIM analysis and performance tools are specifically designed for sustainability analysis in buildings, such as energy efficiency analysis, code compliance, building orientation selection through solar energy analysis, and construction sequencing. These programs simplify complexities in implementing sustainable building projects across various stages (Autodesk 2018). Building Performance Analysis (BPA) tools use data such as latitude, longitude, and solar orientation to determine the actual orientation of the building, contributing to building sustainability performance. Which illustrates optimal building orientation selection based on daily and annual solar paths.[5]Thus, Ecotect software automatically determines the best building orientation for natural lighting use, significantly reducing the demand for artificial lighting contributing to heat gain inside buildings. To maximize the benefits of using natural lighting, an efficient analysis of natural lighting is performed, and its characteristics are accurately analysed. [6]Proper provision of natural lighting depends on building orientation, envelope configuration (position of glass, materials, construction assemblies), and massing. Compatibility tools are added to BIM tools through the interoperability that enables information exchange (IE) between different applications and tools that support sustainable building design, Industry Foundation Classes (IFC), developed by the International Alliance for Interoperability (IAI), are likely to become the international standard for data exchange and integration between applications and tools that support sustainable building design.

Shadow Analysis and Its Impact

Shadow analysis is a critical element in building design, as it impacts various aspects such as energy efficiency, natural lighting, and material performance. According to Kalamees et al. (2007)[7], shadow analysis helps in understanding the impact of the building's shape and orientation on energy consumption and daylight availability. Integrating shadow analysis into BIM models allows for a detailed assessment of how shadows affect material performance over time (O'Donnell, 2015)[8].

2. Methodology

This study is based on a case study of a residential building in the city of Basilia, selected due to its design criteria and materials used. The modeling process began with the use of Revit 2023, where a three-dimensional model was created encompassing all design details and materials, with accurate data on the physical and chemical properties of the materials inputted. This was followed by shadow analysis using the program's tools to assess the impact of shadows cast by architectural elements on energy and material efficiency. Natural lighting was also evaluated using Revit Insight 2025, to study the distribution of natural light within the building and the impact of the materials used on its quality and efficiency. The environmental analysis included integrating the results from material modeling, shadow analysis, and natural lighting assessment to determine how building sustainability could be improved through modifications in material design and distribution. Data was collected from the BIM model and analyzed using integrated analysis tools, with results reviewed and compared against

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environmental standards. The study encountered limitations related to data accuracy and the integration of various analyses, which were addressed through advanced analytical techniques and alternative solutions as needed.

3. Case Study (EA-189, Basilica City)

Design and Research Methodology:

The study centers on EA-189 within Basilica City, Damascus, specifically in the Kafarsouseh district. The methodology includes:

- Modeling process using Revit 2023 software.
- Shadow analysis within the program to assess its impact on building materials (Revit 2023).
- Evaluation of natural lighting facilitated by the building envelope and its interaction with construction materials (Revit Insight 2025, Lightning Energy).

This structured approach ensures a thorough investigation into sustainable building practices using BIM technologies, aiming to contribute scientifically to the field of architecture and sustainable urban development.

EA-189 Tower: A residential tower comprising a ground floor, 19 typical floors, a technical floor, and 4 basements.

Areas and Heights:

- Ground Floor: 847 sqm - 4.75 m
- Typical Floor: 947 sqm - 3.40 m
- Technical Floor: 862 sqm - 2.80 m
- Basements: 1900 sqm each (including the entire tower area) - 3.40 m

The number of residential apartments per typical floor is 8, as illustrated in Figure 1.

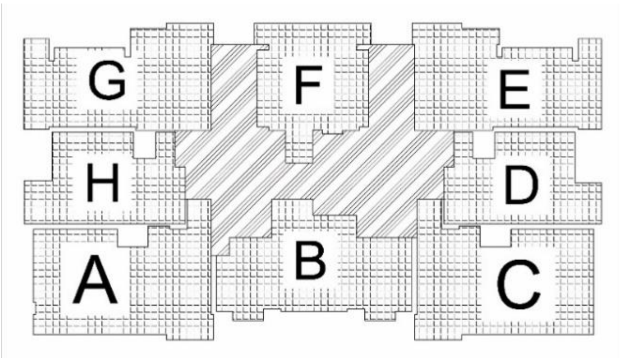

Figure 1: Illustrates the number and distribution of apartments on a typical floor - Source: General Company for Studies

Data Collection Tools:

Engineering drawings of the studied building provided by the General Company for Studies in Damascus city, which will be used as the basis for modeling in Revit software. The data is available in DWG format.

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Data Analysis

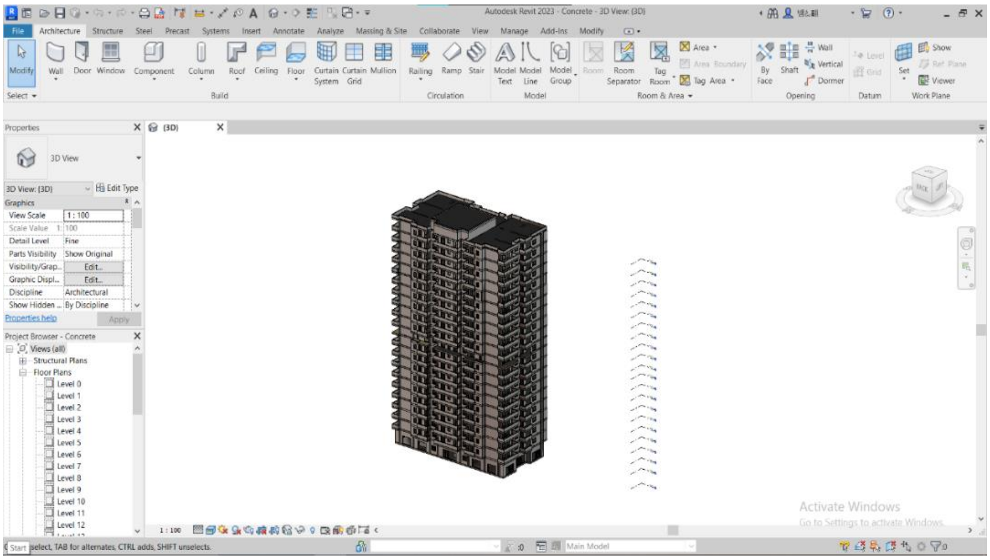

Figure 2: Illustrates the building modeling process within the Revit software – Researcher

Shadow Study and Analysis of Its Impact on Building Materials

Fundamental criteria for sustainable construction focus on optimal climate compatibility, effective reduction of energy consumption, and commitment to sustainability. Therefore, buildings must be designed and executed according to standards that reduce reliance on fossil fuels and depletable energy sources harmful to the environment. Hence, construction must significantly emphasize the utilization of renewable natural resources, particularly solar energy.

Shadow analysis for the building was conducted during four time periods in 2030 (March, June, September, January) from 7:00 AM to 5:00 PM.

Initially, the geographic location of the project was determined using the Location command, ideally with internet connectivity for precise geographic location determination.

- Simulating Sun Settings for Spring Season (March) and Analyzing Shadows at 7 AM - 12 PM - 5 PM respectively, as depicted in the figure.

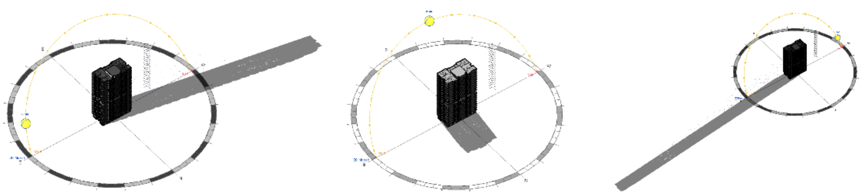

Figure 3: Illustrate Shows shadows in the spring season - Researcher

- Simulating Sun Settings for Summer Season (June) and Analyzing Shadows at 7 AM - 12 PM - 5 PM respectively, as depicted in the figure.

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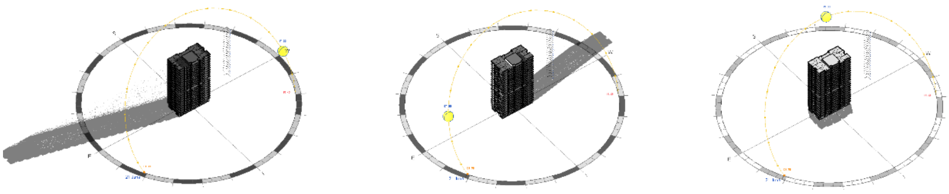

Figure 4: Illustrate Shows shadows in the summer season - Researcher

- Simulating Sun Settings for Autumn Season (September) and Analyzing Shadows at 7 AM - 12 PM - 5 PM respectively, as depicted in the figure.

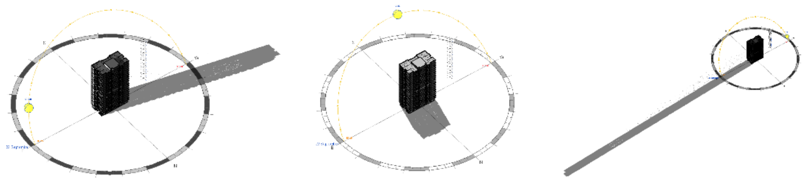

Figure 5: Illustrate Shows shadows in the autumn season - Researcher

- Simulating Sun Settings for Winter Season (January) and Analyzing Shadows at 9 AM - 12 PM - 3 PM respectively, as depicted in the figure.

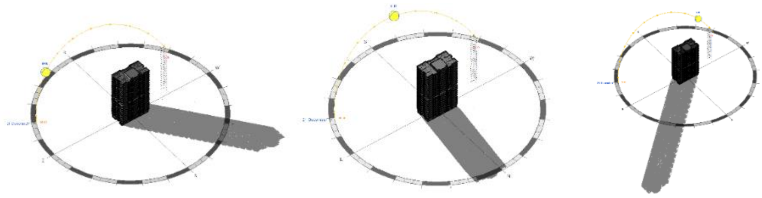

Figure 6: Illustrate Shows shadows in the winter season - Researcher

The study emphasizes the profound impact of direct sunlight on the roof and east-west facades, collectively comprising 33% of the building envelope's total facade area. Despite this, the building's orientation predominantly along the north-south axis minimizes these areas relative to its overall size.

Aligning the building in a north-south direction offers numerous advantages, especially in terms of sustainable architectural design and energy efficiency. This orientation facilitates balanced natural lighting inside the building throughout the day, with east and west facades receiving morning and afternoon sunlight respectively, while north and south facades benefit from consistent natural light distribution, reducing reliance on artificial lighting.[9]

Moreover, north-south orientation helps in controlling temperatures by minimizing direct sunlight exposure on east and west facades, thus decreasing the need for air conditioning. This, in turn, contributes to lower energy consumption and operational costs.[10]

The choice of building materials and their response to orientation and sunlight exposure is crucial for regulating thermal transmittance and maintaining a comfortable indoor environment. Materials with high thermal mass, such as brick or stone, store heat during the day and release it at night, contributing to temperature regulation inside the building.[11]

Furthermore, utilizing materials with high thermal resistance and sustainable sourcing practices enhances the environmental performance of the building over its lifetime. Integrating effective shading strategies and maximizing natural lighting not only improves energy efficiency but also enhances visual comfort and indoor air quality.[6]

In conclusion, strategic building orientation and thoughtful material selection are pivotal in mitigating solar impacts, improving energy efficiency, and fostering a sustainable and comfortable indoor

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environment. By orienting buildings north-south, architects and designers can optimize natural resources like sunlight and shading systems, thereby creating healthier and more cost-effective living spaces for occupants.[10]

Study of Achieving Natural Lighting Provided by the Building Envelope and the Impact of Building Materials on It

Building materials play a crucial role in determining the level of natural lighting inside buildings. These materials can be categorized based on their impact on natural lighting into two main categories:

- Transparent Materials: This category includes glass, some types of plastics, and other materials that allow sunlight to pass through. Using these materials in building design maximizes the utilization of natural light within indoor spaces, reducing the need for artificial lighting during daylight hours and contributing to energy savings. Additionally, they can enhance the psychological and productive state of users by providing visual connection to the outdoor environment.
- Opaque Materials: These materials do not allow light to pass through and include most types of bricks, stone, concrete, and insulation materials. Using opaque materials is essential to provide privacy, security, and thermal insulation for buildings. However, careful planning is required to distribute these materials within the building to ensure a balance between privacy and protection while providing sufficient natural lighting.

Analysis of Lighting in the Studied Building

After adjusting the site settings and sun settings, we select "Lighting" from the Insight 2025 menu and adjust the lighting settings as illustrated in Next Figure.

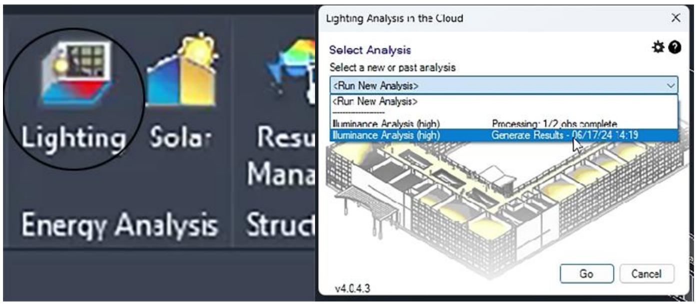

Figure 7: Illustrates the lighting settings within Insight 2025 - Researcher

After pressing "go" and awaiting the analysis for displaying results, the outcomes are visually presented in color on the three-dimensional perspective and analytically displayed as shown in Next Figure.

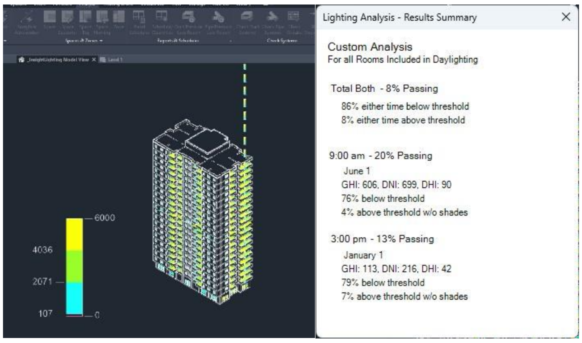

Figure 8: Illustrates the results of the lighting analysis within the building Source: Researcher

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The analysis of the results highlights several key findings regarding natural lighting:

Global Horizontal Irradiance (GHI), which measures total solar irradiance on a horizontal surface, and Direct Normal Irradiance (DNI), measuring direct solar irradiance without reflection or scattering, are crucial indicators for assessing solar potential. Additionally, Diffuse Horizontal Irradiance (DHI) represents solar irradiance scattered in the sky.

Overall, only 8% of the measured times or areas meet the required standards for natural lighting. This low percentage suggests inadequacies in the current building design or distribution of natural lighting.

Specifically, at 9:00 am, only 20% of measurements exceeded the specified threshold for natural lighting, indicating suboptimal lighting conditions in most areas at this time. Similarly, at 3:00 pm, just 13% of measurements surpassed the required threshold, highlighting significant deficiencies in appropriate natural lighting.

A predominant 86% of measurements fall below the required threshold across different times, emphasizing widespread insufficiency of natural lighting. Conversely, 8% of areas exceed the required threshold, potentially leading to issues such as excessive heat due to over-illumination.

In conclusion, these findings underscore the critical need to optimize natural lighting strategies in building design. Enhancing energy efficiency and improving occupant comfort are essential goals, alongside addressing potential challenges like overheating associated with excessive natural light.

Analysis of lighting on the repeated floor plan and its impact on interior spaces:

The floor plan was isolated to observe the effect of lighting on interior spaces in a more detailed and illustrative manner, as shown in Next Figure.

Figure 9: Illustrates the percentage of natural lighting and its impact on interior spaces - Researcher

Through the analysis process, the following observations were made:

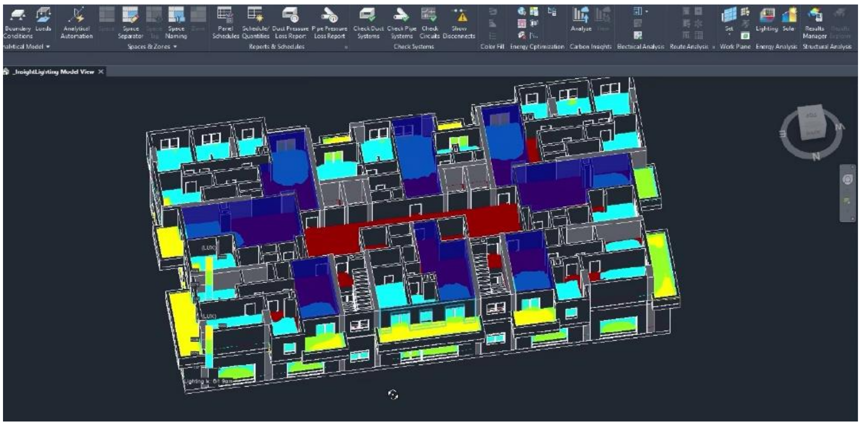

Figure 10: Illustrates interior spaces with weak natural lighting. Source: Researcher

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The areas highlighted in blue on the floor plan indicate very weak natural lighting. Therefore, it is crucial to take this into consideration and propose appropriate solutions to address this issue.

Comparison and analysis of the results: After studying and analyzing the lighting using analytical tools, it was found that the necessary standards for natural lighting in the building were not achieved. To address these issues, the following solutions are proposed:

1. Increasing floor heights: Expanding the vertical distance between floors can reduce the shading impact from upper floors onto lower ones, thereby maximizing the use of natural light.
2. Increasing the proportion of transparent materials: Increasing the ratio of glass windows in facades, with taller window designs extending from floor to ceiling, helps in receiving more natural light and providing a wider field of vision.
3. Use of light-reflective elements: Installing surfaces or materials that reflect light on interior or exterior facades, or beneath windows, can effectively redirect natural light indoors.

Results of Practical Simulation:

The construction sector significantly contributes to annual environmental degradation. Sustainability practices extend the productive lifespan of buildings, saving energy, money, and materials. Green buildings aim to maintain a balance between the building and its surrounding environment, protecting inhabitants from climatic conditions without harming the environment or depleting resources, ensuring future generations have access to their fair share. Green building techniques substantially reduce global carbon emissions. The production process of building materials needs improvement in efficiency and effectiveness, as it heavily impacts the surrounding environment. Utilizing building technology is crucial for designing green buildings, focusing on building operation systems, reducing energy consumption, and providing thermal comfort for users, thereby enhancing efficiency.

Regarding the practical study of the residential building in Basilia City:

The results highlight the importance of building orientation and effective design in minimizing unwanted thermal effects and enhancing the environmental comfort of residents. Shading and sunlight play a crucial role in influencing energy consumption and thermal comfort inside the building, with proper building orientation successfully reducing thermal load during the hottest months. The strategic use of transparent and opaque materials within the building improved natural lighting levels while maintaining comfortable temperatures and reducing reliance on artificial lighting. Insulating materials significantly impact thermal insulation, reducing unwanted heat transfer and thereby lowering energy consumption for cooling and heating. Careful selection of building materials significantly contributes to creating a comfortable indoor environment. The study indicated that materials with low thermal conductivity reduce excessive heat transfer indoors, leading to higher energy efficiency. Replacing building materials with sustainable alternatives reduced the building's carbon footprint. Intelligent use of materials can enhance the overall sustainability levels of the building.

Recommendations of Practical Simulation:

Encourage the proper use of sustainable green building materials. Promote sustainability awareness among key players in the construction market (owners, consultants, contractors, companies) through public lectures, training courses, studies, and research. Government intervention is crucial through the development of mandatory local regulations and the implementation of sustainable practices in all types of buildings. All companies and institutions in the construction sector should begin using sustainable and green materials to improve the building process. Encourage the use of energy modeling programs to achieve energy efficiency in the built environment.

Regarding the practical study of the residential building in Basilia City:

Extend the sustainability study to include all buildings within Basilia City. Adopt precise design approaches that consider the effects of shading and sunlight. Choose building materials that help achieve thermal balance and improve natural lighting. Conduct regular evaluations of the thermal performance of used materials and continue researching to innovate new materials that reduce carbon emissions and reflect sustainability principles.

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4. Discussion

This study examines the impact of building material modeling on enhancing building sustainability through a case study of a residential building in Basilia City. Data analysis indicates that modeling the building using Revit 2023 was effective in determining how shadows and natural lighting affect the building's environmental performance. Shadow analysis was conducted at different times of the year (March, June, September, January) to observe the effects of shadows on the building's east and west facades. The results showed that the north-south orientation of the building reduces the impact of shadows on material energy efficiency, as the north and south facades benefit from balanced natural light distribution, reducing reliance on artificial lighting and lowering cooling costs.

Building materials play a crucial role in determining the level of natural lighting inside the building. Materials were categorized into transparent and opaque types, with transparent materials like glass increasing natural light entry and reducing the need for artificial lighting, thereby enhancing user comfort.

Results from the lighting analysis using Revit Insight 2025 showed that natural lighting levels do not meet required standards in most areas, with only 8% of measurements exceeding the specified natural lighting threshold, indicating deficiencies in the current building design or natural lighting distribution. The study recommends increasing floor heights, increasing the proportion of transparent materials in facades, and using light-reflective elements to improve natural lighting in the building.

The study also indicates that solar energy represents a powerful and renewable resource that significantly impacts building sustainability and efficiency. Dark-surfaced materials absorb more solar energy, leading to easier heating, while light-surfaced materials reflect more light, helping to maintain moderate indoor temperatures. Additionally, using materials with good thermal insulation reduces the need for heating and cooling, thereby lowering energy consumption.

5. Conclusions

Summary of Key Findings:

This study provides significant insights into the impact of modeling building materials on enhancing building sustainability through the use of Revit 2023. The shadow analysis results revealed that the north-south orientation of the building plays a crucial role in improving natural light distribution and reducing the effects of shadows on energy efficiency. This orientation helps decrease reliance on artificial lighting and reduce cooling costs. Additionally, the study found that using building materials with high thermal mass, such as brick and stone, aids in regulating indoor temperatures by storing and releasing heat at night, thereby improving the building's environmental performance. Regarding natural lighting, the study demonstrated that the materials used in the building envelope significantly affect the level of illumination inside the building. Transparent materials, such as glass, increase natural light entry and reduce the need for artificial lighting, enhancing user comfort. In contrast, opaque materials provide privacy and thermal insulation, but careful planning is required to balance these factors and ensure adequate natural light. The results from using Revit Insight 2025 indicated that natural lighting levels in many areas do not meet the required standards, highlighting the need for improved building design and natural light distribution. The study recommended increasing floor heights, increasing the proportion of transparent materials in facades, and using light-reflective elements to improve natural lighting in the building. Overall, the study underscores the importance of optimal design orientation and appropriate material selection in enhancing building sustainability by improving the balance between shadows, natural lighting, and energy efficiency.

Concluding Remarks:

The study emphasizes the importance of strategic orientation and careful material selection in reducing solar impacts and improving energy efficiency, contributing to the creation of comfortable and sustainable indoor environments. The study recommends extending the sustainability study to include all buildings in Basilia City, adopting precise design approaches that consider the effects of shadows and natural lighting, and updating materials to achieve thermal balance and improve natural lighting.

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Furthermore, it advocates for promoting the use of sustainable green materials and increasing sustainability [12]awareness among all stakeholders in the construction sector through lectures and training courses. Government intervention is also necessary by developing local regulations and incorporating sustainability practices in all types of buildings. Additionally, encouraging the use of energy modeling programs to achieve energy efficiency in the built environment is advised[13].

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