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

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Abstract

This study addresses the impact of modeling building materials on improving building sustainability by analyzing a case study of a residential building in the Baselia area of Damascus, which has experienced the removal of orchards, leading to negative environmental impacts. The research focuses on evaluating the carbon footprint of the building materials used in the structure and cladding, utilizing Autodesk Forma to analyze life cycle and energy efficiency. The study includes an analysis of the impact of five different building materials on carbon emissions during the stages of production, transportation, installation, use, and disposal. Results show that composite steel has the highest carbon emissions compared to other materials, while wood materials, such as timber frame and mass timber, have the lowest emissions. For internal cladding, the differences between materials were relatively minor. The study recommends selecting building materials with lower environmental impact and enhancing energy efficiency, which contributes to reducing carbon emissions in the construction sector and supports achieving sustainability goals.

Keywords: Sustainability in Construction; Modeling Building Materials; Life Cycle Analysis; Environmental Impact of Building Materials; Carbon Emissions; Environmental Sustainability

1. Introduction

Sustainability in construction is a crucial field in the modern era, with urban projects aiming to minimize environmental impacts and enhance resource efficiency. The choice of building materials is a key factor affecting the carbon footprint of buildings, encompassing all emissions arising from the processes of production, transportation, installation, use, and disposal of materials. The Baselia area in Damascus has experienced significant urban changes, such as the removal of orchards and their conversion into residential and commercial areas, leading to noticeable environmental impacts[1]. This study aims to assess the impact of modeling building materials on the carbon footprint of buildings in this area, using Autodesk Forma to analyze material life cycles and energy efficiency[2]. By analyzing the effects of building materials used in both the structure and cladding, the study seeks to provide design recommendations that enhance energy efficiency and reduce carbon emissions. The objectives focus on studying the impact of different materials on carbon emissions, comparing various materials to select the most sustainable ones, and using modeling tools to make informed design decisions. The research findings contribute to improving building sustainability in the Baselia area by offering practical solutions to reduce carbon emissions and enhance energy efficiency, supporting industry efforts to achieve sustainability goals and providing a model applicable to similar urban projects.

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2. Literature Review

Sustainability in construction is a vital area that has garnered significant attention due to increasing pressures to reduce environmental impacts and enhance resource efficiency. Building material modeling contributes to sustainability by providing precise insights into the effects of materials throughout the building's life cycle[3]. According to Azhar (2011), Building Information Modeling (BIM) helps analyze the impact of materials on life cycle and energy efficiency, leading to more sustainable design decisions. Additionally, Gossauer et al. (2020) highlight that the use of sustainable building materials can significantly reduce the carbon footprint of buildings[4]. On the other hand, Life Cycle Analysis (LCA) is considered a critical tool for evaluating the environmental impact of materials, as emphasized [5]by ISO 14040 (2006), which underscores the importance of this analysis in identifying materials that contribute to reduced carbon emissions[6]. Studies such as Jones & Sutherland (2017) show that materials like composite steel and reinforced concrete contribute to higher carbon emissions compared to other materials like mass timber[7]. The literature focuses on the need to improve design and material selection to achieve effective environmental sustainability, as highlighted by Kibert (2016) through design strategies and techniques that support sustainability goals in construction projects[8].

3. Methodology

This research aims to analyze the impact of different building materials on the carbon footprint of buildings through a case study of a residential building in the Baselia area of Damascus. Autodesk Forma will be used to analyze the life cycle of materials and assess their energy efficiency, which will help in identifying the most sustainable options and reducing carbon emissions. The study begins with selecting the appropriate case study, where data on materials used in the structure and cladding will be collected through reviewing technical documents and conducting interviews with architects and contractors. Autodesk Forma will be utilized to create a three-dimensional model of the building, including data on the number of floors, building height, and floor area. The environmental impacts of materials will be analyzed across stages of production, transportation, installation, use, and disposal to assess carbon emissions, and materials will be compared based on these emissions to identify the most sustainable options. Based on these analyses, recommendations will be made to improve building sustainability through the selection of materials with lower environmental impact and enhanced energy efficiency. Advanced analytical tools such as Autodesk Forma and 3D modeling will be employed to achieve the research objectives and provide practical solutions that support environmental sustainability in construction projects.

Analysis of the Impact of Building Materials on Carbon Emissions:

Building materials and their selection play a crucial role in determining the carbon footprint of buildings, not only during the construction process but also throughout the entire lifecycle of the building, from construction to demolition or recycling. The impact of building materials on carbon emissions is primarily evident in the following stages:

1. Production: The production of building materials such as cement, steel, glass, and bricks often require significant energy, usually derived from fossil fuel sources, leading to high carbon emissions.
2. Transport: The transportation of building materials from production sites to construction sites can also result in significant emissions, especially if the distances are long or if environmentally inefficient transportation means are used.
3. Installation and Construction: The actual building process also requires energy, leading to carbon emissions, especially when machinery and equipment running on fossil fuels are used.
4. Utilization: Building materials impact the energy efficiency of the building during its use. For example, poor insulation can lead to higher energy consumption for heating and cooling, increasing carbon emissions.
5. Dismantling and Disposal: At the end of its lifecycle, the process of dismantling buildings and disposing of building materials or recycling them requires energy, leading to further emissions. Materials that cannot be efficiently recycled contribute to carbon emissions through landfills.

Promoting energy efficiency in buildings and encouraging the use of building materials that require less energy in production, transportation, and installation are important steps to mitigate the impact of construction on carbon emissions.

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The study will span over **a 30-year** and its outcomes will encompass an analysis of carbon emissions for the materials from extraction and production phase through to the decommissioning and disposal phase.

- Initially, the site settings are adjusted in the Autodesk Forma application, followed by creating a three-dimensional model of the building.

Figure 1: Shows the creation of the three-dimensional model of the building within Autodesk Forma

- The number of floors, their height, and the building area are specified, along with the building's function.

Figure 2: Shows the specification of the number of floors of the building, its height, as well as its function

- The types of construction materials used in the structure, construction, building envelope, and internal partitioning of spaces that will be studied to determine their carbon emissions are then identified.

The types of building materials to be studied are determined to assess their carbon emissions through two types of use:

1. Those used in constructing the building's structure
2. Those used in cladding and interior partitioning of the building

The following results were obtained:

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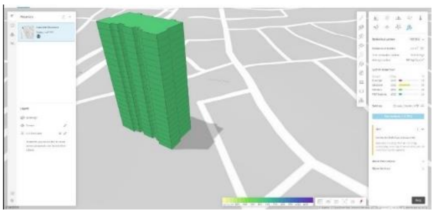
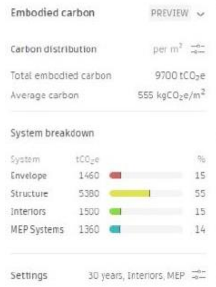
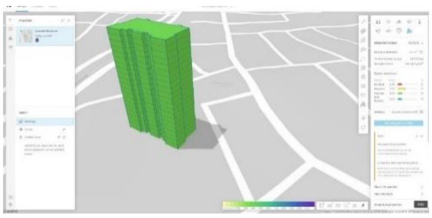
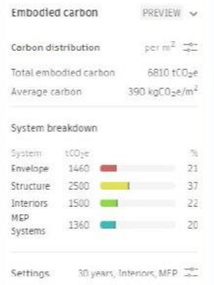
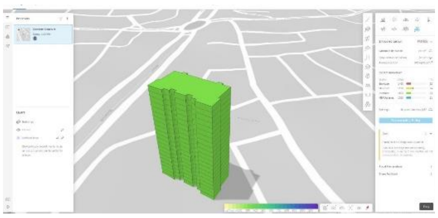
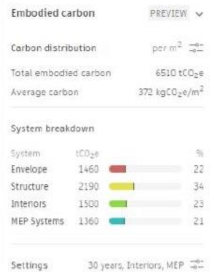
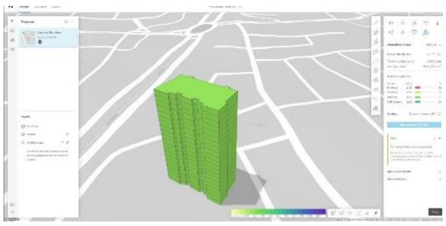
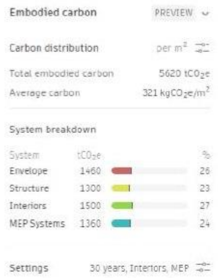
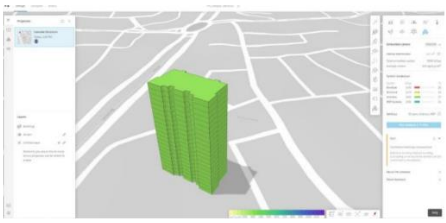
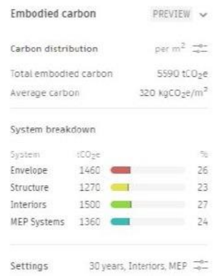
Table 1: Illustrates the results of the carbon emissions analysis by replacing construction materials in the structural framework

The Material	Analysis Result	Carbon Emissions Rate
Composite Steel 		Total embodied carbon: 9700 ${}_tCO_2e$ Average carbon: 555 $kgCO_2e/m^2$
Reinforced Concrete 		Total embodied carbon: 6810${}_tCO_2e$ Average carbon: 390 $kgCO_2e/m^2$
Hybrid Concrete Steel 		Total embodied carbon: 6510${}_tCO_2e$ Average carbon: 372 $kgCO_2e/m^2$
Lightwood Frame 		Total embodied carbon: 5620${}_tCO_2e$ Average carbon: 321 $kgCO_2e/m^2$
Mass Timber 		Total embodied carbon: 5590${}_tCO_2e$ Average carbon: 320 $kgCO_2e/m^2$

The results of the analysis of the materials used in building cladding and interior partitioning.

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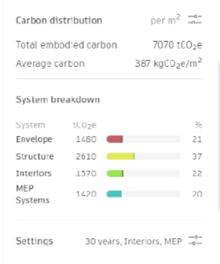
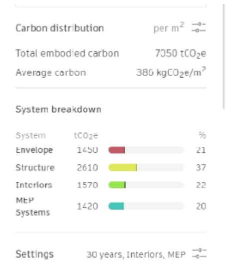
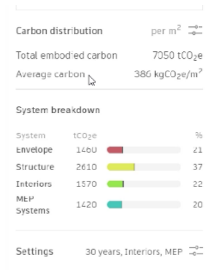
Table 2: Illustrates the results of the carbon emissions analysis materials in building cladding and interior partitioning.

The Material	Analysis Result	Carbon Emissions Rate
Thin Brick		Total embodied carbon: 7070_tCO_2e Average carbon: 387 $kgCO_2e/m^2$
Formed Steel		Total embodied carbon: 7050_tCO_2e Average carbon: 386 $kgCO_2e/m^2$
Hard wood		Total embodied carbon: 7050_tCO_2e Average carbon: 386 $kgCO_2e/m^2$

Comparing the results, we find that carbon emissions are significantly affected by the material used in the building's structure, with the materials ranked from highest to lowest emissions as follows:

1. Composite Steel
2. Reinforced Concrete
3. Hybrid Concrete Steel
4. Lightwood Frame
5. Mass Timber

In contrast, when comparing the materials used in the building's cladding and interior partitioning, the differences are minimal, with the materials ranked from highest to lowest emissions as follows:

1. Thin Brick
2. Formed Steel
3. Hard Wood

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4. Discussion

This discussion reviews the results of a study on the impact of different building materials on the carbon footprint of buildings[9], using a case study of a residential building in the Baselia area of Damascus. The study, using Autodesk Forma, found that composite steel had the highest carbon footprint due to the intensive energy processes involved in its production and transportation, while reinforced concrete had a slightly lower but still significant carbon footprint due to the production of cement and steel reinforcements. Conversely, hybrid concrete with steel showed a relatively lower emission due to the combination of material benefits. Wood frames and mass timber recorded the lowest carbon footprint, attributed to their renewable nature and lower energy requirements during production, enhancing their sustainability. On the other hand, the differences in emissions among the materials used for cladding and interior partitioning were relatively minor, with thin brick showing the highest emissions. The results highlight the importance of material selection in sustainable design, where low-carbon materials like mass timber significantly contribute to reducing the carbon footprint and supporting broader sustainability goals.

5. Conclusion

Summary of Key Findings:

This study provides a comprehensive assessment of the impact of different building materials on the carbon footprint of buildings, based on an analysis of a residential building in the Baselia area of Damascus using Autodesk Forma. The results show that composite steel registers the highest carbon emissions due to the significant energy required for its production and transportation. In contrast, reinforced concrete has a slightly lower carbon footprint, although it remains significant due to the use of cement and steel. Hybrid concrete with steel presents a relatively lower emission thanks to the combination of material advantages. On the other hand, timber frames and mass timber exhibit the lowest carbon footprints due to their renewable nature and lower energy requirements during production. Additionally, the internal cladding and finishing materials show smaller differences in emissions, with thin brick recording the highest emissions among these materials. The results highlight the importance of selecting appropriate building materials to achieve significant improvements in environmental sustainability and reduce the carbon footprint[10].

Concluding Remarks:

This study provides an in-depth understanding of the impact of different building materials on the carbon footprint of buildings, based on a detailed analysis of a residential building in the Basilea area of Damascus. The results revealed that composite steel contributes to the highest levels of carbon emissions due to the energy-intensive processes associated with its production and transportation, while reinforced concrete has a slightly lower carbon footprint, though it remains significant due to the use of cement and steel. In contrast, hybrid concrete with steel demonstrated a relative reduction in emissions, highlighting the benefits of material integration in minimizing environmental impact. On the other hand, timber frames and mass timber have proven to be among the most sustainable materials due to their renewable nature and low energy needs during production, emphasizing the environmental benefits of using low-carbon footprint building materials. For cladding and interior finishing materials, the study showed that emissions differences are less pronounced compared to structural materials, with thin brick recording the highest emissions among these materials. Therefore, it is recommended to use low-carbon footprint materials such as mass timber for the primary structure of buildings,[11] enhance the use of renewable materials in new designs, apply life cycle assessment tools like Autodesk Forma to evaluate material efficiency, and improve the selection of cladding and interior finishing materials. Encouraging research and development in new building materials can contribute to innovative solutions for reducing carbon footprints and enhancing environmental sustainability, supporting the creation of a greener and more sustainable future[12].

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