BIM-based Climate Action for Mitigation and Adaptation: Carbon-Neutral Buildings and Regional Carbon Footprint Management

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Introduction:

To address the threat of extreme climate events, this study proposes to apply a design decision model based on Building Information Modelling (BIM) to take climate action. In terms of mitigation, BIM, as an information modeling and management tool for the whole life cycle of buildings, can calculate the operational carbon footprint of the entire life cycle of buildings, as well as the embodied carbon footprint of building materials, as a basis for carbon emission reduction, as well as a rating. Regarding adaptation, the digital twin geographic information system of BIM is introduced to provide visualization of the regional carbon footprint, which is conducive to developing carbon-neutral urban planning. Following international GHG ISO standards and carbon trading platform regulations, this study systematically examines the feasibility and constraints of a BIM-based design decision model.

Main Idea

To address the threat posed by extreme weather, the United Nations Sustainable Development Goals (SDGs) emphasize Goal 13: Climate Action, urging comprehensive measures to mitigate and adapt to climate change and its impacts [3]. Countries worldwide have implemented proactive policies and strategies to address this global challenge. From a building perspective, effective "mitigation" measures must be taken, including controlling the building's energy consumption and carbon footprint, adjusting and optimizing energy-efficient design, and adopting clean energy technologies. Concerning adaptation, planning in building regulations, urban design, land planning, infrastructure investment, security, and disaster prevention systems must be re-evaluated. Ultimately, all efforts are aimed at achieving the goal of carbon neutrality.

Building Information Modelling (BIM) is a tool for modeling and managing information throughout the life cycle of a building, capable of calculating the operational carbon footprint of a building during its occupancy phase and assessing the embodied carbon footprint of building materials. In addition, the integrated digital twin form of geographic information system (GIS) with BIM and the Internet of Things (IoT) provides real-time, visualization of the region's carbon footprint, facilitating decision-making on carbon-neutral zoning. Based on these considerations, this study proposes a thorough examination of the conditions and limitations of BIM-based design decision-making processes, particularly the climate actions involved in the mitigation and adaptation aspects of these decision-making processes.

In Liu's (2022) bibliometric analysis titled " Building Information Modeling (BIM) Driven Carbon Emission Reduction Research: A 14-Year Bibliometric Analysis, Current research on BIM and carbon emissions is focused on the design phase, with a particular emphasis on resource efficiency, i.e., the calculation of carbon emissions associated with a building's energy. However, the application of BIM technology in the carbon emissions of buildings throughout their life cycle has not been widely explored. Liu's analysis identifies five popular research directions in the field of BIM in terms of sustainable buildings and carbon emissions. These areas include building life cycle assessment, sustainable materials, energy efficiency and design, and environmental protection strategies. These areas represent key themes in which BIM technology is actively applied in the context of sustainable architecture and design to address and reduce carbon emissions. The study highlights the need for further research and exploration of the wider application of BIM at all stages of a building's life cycle to improve its effectiveness in reducing carbon emissions. [6]

The goal of the United Nations Framework Convention on Climate Change (UNFCCC) is to reduce carbon emissions from economic activities (known as mitigation) and mitigate the inevitable impacts of climate change (known as adaptation) [3]. As shown in Fig. 1, mitigation measures include carbon trading schemes, product and process standards, technology incentives and investments, carbon taxes, renewable energy rollout, and renewable portfolio standards. Adaptation strategies include modifications to building codes, urban design, land planning, infrastructure investment, security, and disaster prevention systems [4]. Building Information Modelling (BIM) plays a vital role in mitigation efforts as an information modeling and management tool throughout the life cycle of buildings. It can calculate the energy consumption and carbon footprint of the building, and adjust and optimize the design goals, direction, and functional layout. BIM can also predict and evaluate carbon reductions based on criteria defined by the government or agency. This is conducive to investing in clean energy mechanisms or participating in carbon trading decisions, offsetting and compensating carbon emissions, and effectively controlling global carbon emissions through market mechanisms [5]. In the context of adaptation planning, the integration of BIM with geographic information systems (GIS) and the Internet of Things (IoT) is crucial. From the perspective of urban carbon emission control, this integration allows for real-time visualization (monitoring) of the dynamic carbon footprint of urban citizens, facilities, transportation, and other urban systems. It can track historical records and analyze and review the dynamic distribution of carbon sources and sinks in the region. Therefore, the effectiveness of adaptation measures in achieving carbon neutrality can be verified through this comprehensive approach.

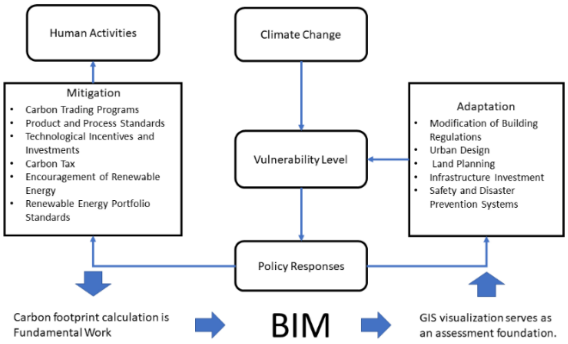

Fig. 1: Mitigation and adaptation measures in climate policies (adapted from Labatt, 2008 a [4]).

The concept of a net-zero carbon (carbon-neutral) building lacks a universally defined framework but can be derived from the closely related concept of a net-zero energy building. A net-zero energy building is defined as one that is highly energy efficient and generates enough energy locally to meet its annual energy needs. The fundamental elements include (1) building systems, (2) energy networks, and (3) weighted systems. In addition to achieving net-zero targets and making clear balancing measures, the boundaries of building systems that use on-site renewable energy must be demarcated. Within this boundary, when the renewable power generation system generates excess power, the building system directs the surplus energy (including electricity, natural gas, on-site renewables, and grid power) back to the grid. In addition, different weighting systems are selected according to different design goals. For example, building owners may prioritize the equalization of energy costs over energy equilibrium, leading them to opt for a weighted system that converts energy into costs [2],[1] (Fig. 2, left). Similarly, a net-zero carbon (carbon-neutral) building can be defined as a structure that has an efficient carbon reduction capacity and has an on-site carbon sink equivalent to its annual carbon emissions. The basic elements include (1) building systems, (2) trading networks, and (3) carbon trading platforms. To achieve a clear balance calculation of net-zero targets, it is essential to delineate the boundaries of building systems with on-site carbon emissions and carbon sinks. Within this boundary, if the total amount of carbon emissions exceeds the designated emission rights, the building needs to purchase carbon credits from the carbon trading market. Conversely, any remaining emission reductions can be sold on the carbon market (Fig. 2, right). The framework calculates emissions and offsets through a carbon trading mechanism, providing a structured approach to achieving the goal of net-zero carbon construction. "Carbon emissions" can be thought of as a common unit of energy consumption, materials, and supplies for buildings. Through the conversion of carbon coefficients (also known as weighting systems), building energy consumption can be converted into carbon emissions, so net-zero energy buildings are considered to be members of the family of net-zero carbon buildings [8]. A net-zero energy building is defined as achieving carbon neutrality during the operational phase of a building's use (i.e., electricity, water, and fuel consumption). The diagram shows that acquisitions or offsets from renewable energy without taking into account carbon credits are referred to as "net-zero energy buildings" or, if external factors are involved, "net-zero operational carbon buildings". However, if the carbon neutrality calculation includes the embodied carbon component, it is referred to as a "net-zero full-lifecycle carbon building" and represents the most comprehensive form of a net-zero carbon building (Fig. 3).

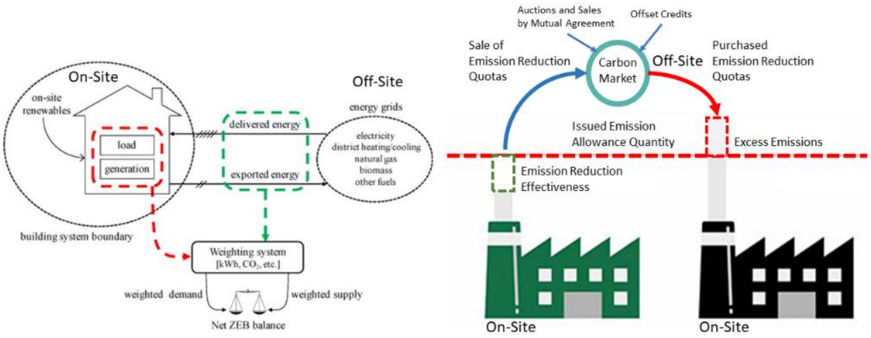

Fig. 2: Key elements of net zero energy building (left) [6] vs. net zero carbon building (right).

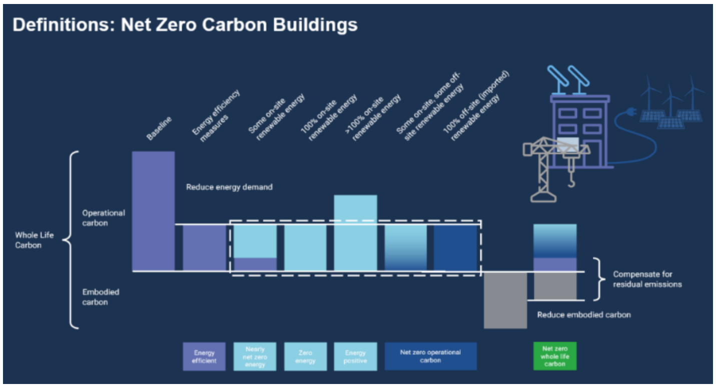

Fig. 3: Net-zero carbon building family [8].

Building Information Modelling-based design decision models are used to take climate action for mitigation and adaptation. As shown in Fig. 4, the design project aims to achieve regional carbon neutrality. A BIM component library platform with a carbon emission coefficient, which supports BIM-based calculation of the whole life cycle carbon footprint (including operational carbon and embodied carbon); According to the carbon emission benchmark established by the building management agency, the rating and evaluation of carbon emission reduction shall be carried out; Through the carbon trading platform, the legitimacy and adjustment offset of carbon emissions are calculated; The BIM-GIS information integration platform provides a visual distribution of dynamic carbon footprints, and provides a basis for feedback on adaptive planning and initiatives for regional carbon neutrality. According to the model, we can consider the practice of a mandatory market in the foreseeable future. Following the cap principle, companies will be allocated predetermined emission allowances within the statutory carbon emission limits. Businesses can pay taxes to the government or opt for voluntary offsets, which involve purchasing emission reduction allowances to offset excess carbon emissions. The total amount of control is based on the actual needs of regional development. Regional carbon neutrality within demarcated boundaries means that legal thresholds control the carbon emissions of buildings within the area. Buildings in the area demonstrate efficient carbon reduction and have enough local carbon sinks to meet their annual carbon emission requirements.

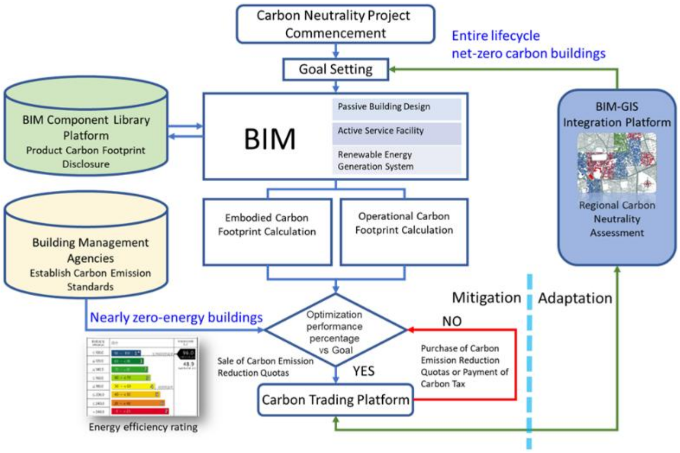

Fig. 4: Integrated design process for mitigation and adaptation based on BIM.

<u>Conclusion and Recommendations:</u>

Following international greenhouse gas ISO standards and the principles of carbon trading platforms, this study utilizes BIM technology as its foundation. It examines the capabilities of BIM in calculating building carbon footprints to achieve regional carbon neutrality. The objective is to establish a design decision-making process for carbon-neutral buildings, contributing to the fulfillment of United Nations Sustainable Development Goals (SDGs) 13 on climate action, specifically addressing mitigation and adaptation measures.

In terms of mitigation, BIM currently serves as the foundational platform for information exchange throughout the different phases of a building's lifecycle. It is a core tool for collaboration, communication, and management among various stakeholders, enabling the calculation of partial operational and embodied carbon footprints with reliability. However, there is a need for the development of BIM modules for predicting building water usage and legislative measures to mandate the disclosure of carbon footprints for building materials and products, which should be integrated into the BIM component platform. Furthermore, building management authorities should establish and publicly disclose unit-area baseline values for annual carbon emissions, encompassing both operational and embodied carbon, and clearly define the recognized calculation categories and boundaries.

In terms of adaptation, the integration of BIM and AIoT technologies in a 3D GIS information integration platform can facilitate the development of various visualization techniques for analyzing and assessing the city's regional carbon neutrality capabilities. This includes a focus on afforestation efforts alongside land development projects that may contribute to increased carbon emissions.

Furthermore, achieving a net-zero carbon building throughout its entire lifecycle is an incremental process. As calculation tools, policy formulation, certification authorities, and carbon trading markets gradually fall into place, it is recommended to commence the promotion of high-energy-efficient buildings. Subsequently, efforts should progress towards nearly zero-energy buildings, net-zero energy buildings, and net-zero operational carbon buildings, culminating in the ultimate achievement of net-zero carbon buildings throughout the entire lifecycle.

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