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Addressing the Carbon Footprint Issue in Construction Projects Based on BIM

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Abstract: Both the construction industry and academic scholars have investigated innovative approaches to improving the sustainability of buildings, one of which is the application of current technologies such as Building Information Modelling (BIM). Social, economic, and environmental factors are included in the extensive scope of contemporary studies. In their comprehensive research, the present authors conducted a complete assessment of the numerous sustainability challenges in the construction industry, categorized according to the BIM environment. A case study of a standard room is offered to demonstrate the CO_2 emissions of a BIM object. The findings imply that storing the CO_2 emissions of a given object can add an element of sustainability to the object structure. In addition, it helps reduce emissions by measuring and storing the energy consumption of each appliance in the room and emphasizing the potential for energy savings in the site environment.

Keywords: *Sustainability in construction, CO_2 emissions, BIM environment, sustainability issues, revit software*

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I. INTRODUCTION

The construction industry is a significant economic and social factor in sustainable development [1]. Different organizations are involved in the different stages of a construction project, with each stakeholder having an individual viewpoint and vision of the final asset. Different tools, including software packages and in-house techniques, can create complex difficulties between these actors, hindering a common understanding, integration, and data model. For this purpose, BIM plays an essential role in construction projects by integrating different phases of the project into one coordinated working unit [2, 3, 4].

BIM uses the shared digital representation of a built asset to facilitate the design, construction, and operation processes and form a reliable basis for decisions. The use of BIM in construction projects can enhance the understanding of projects and positively affect the decision-making process in the supply chain. It redefines the construction process and relationships between key stakeholders, saving time and cost and providing the most efficient design since its customized tools allow customers to adjust the outcomes to suit their needs [5].

Currently, industrialized nations emit the most carbon dioxide (CO_2), but estimates suggest that in the coming decades, developing nations will contribute more to global warming [6]. The United States nowadays emits nearly twice as much CO_2 per capita as China and Brazil, sixteen times as much as India, and fifty times as much as Nigeria and Sudan. Over the past two decades, people's ecological behavior has dramatically changed their quality of life. Not only is a pleasant ecological environment vital for the quality of life, but it also contributes to the economic growth of nations [7].

The excessive use of energy by residential consumers has contaminated the ecosystem [8, 9, 10]. According to [11], household customers are responsible for 70% of carbon dioxide emissions worldwide, while home appliances such as refrigerators, televisions, and air conditioners account for around 50% of these emissions. This paper

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presents a scenario addressing a sustainability issue: how a reduction in carbon dioxide emissions can be presented within the BIM environment. The activities applied in building operation can affect energy consumption, obtaining better performance by the building.

II. REVIEW OF THE RELATED LITERATURE

A. *Sustainability and Carbon Footprint*

Sustainability is a significant factor in most facets of infrastructure projects in the construction industry, involving many stakeholders with varying expectations. A considerable amount of research has looked into sustainability in the construction industry with an emphasis on environmental matters [1, 12, 13].

The high CO_2 emissions from the construction industry are attributable to the high levels of fossil fuel-powered energy consumed throughout the extraction, manufacture, and transportation of raw materials [14]. In addition, it has lately been raised that greater emphasis should be placed on reducing the embodied emissions which occur early in a building's life cycle, as opposed to use phase emissions, which occur over long periods and may not result in the expected energy savings [15, 16]. Furthermore, energy efficiency is currently a global priority due to rising environmental and economic concerns [17].

B. *Carbon Dioxide Emissions from Operating the Building*

The importance of energy efficiency in reducing carbon dioxide emissions cannot be overstated, and adopting energy-efficient appliances helps reduce the total energy used [18].

[19] stated that trust in eco-labels boosts consumers' conviction in the credibility of a product and aids the process of decision-making before purchase. [20] highlighted the relevance of a brand name and reputation, the existence of a label, and the reputation of the certifiers for developing consumers' trust in organic food. In the context of purchasing eco-friendly products, researchers discovered that ambient factors positively affect consumers' pro-environmental behavior [21, 22]. In addition, researchers discovered a close correlation between environmental concerns and customers' perceptions of their ability to acquire energy-efficient household appliances [21].

Existing research reveals that good customer attitudes have a crucial impact on ecological behavior [23, 24, 25]. We hypothesize that consumers' attitude toward energy-efficient household appliances will influence their purchasing desire. Perceived Consumer Effectiveness (PCE) is the notion that individual environmental protection initiatives are crucial [26]. [21] In purchasing energy-efficient equipment, perceived customer effectiveness was the most significant predictor of purchase intention. Nevertheless, [27] argued that PCE was not directly associated with purchasing environmentally friendly products.

C. *An Overview of BIM-Level Standards and Structures*

Numerous studies have acknowledged the benefits of using BIM, particularly in large-scale construction projects. These benefits include sustainable performance, effective design, collaboration among key stakeholders, a reduction in the total cost, and the facilitation of visual evaluation methodologies, such as those based on color. Actors examine the design for visible flaws, as well as for efficient and effective management, [5, 28, 29]. [30, 31] BIM has four levels of maturity, from 0 to 3, which represent the following degrees of collaboration:

1. Level 0 indicates an elementary CAD system with no access to BIM. Level 1 employs very basic 2D and 3D CAD systems with access to BIM but is mostly dependent on in-house data, meaning that various parties use separate databases.

2. Level 2 includes administrative, technical, and geometric data and represents the beginnings of effective BIM-based collaboration. ISO 19650-2018, the international standard, is Level 2 of the BIM standard based on BS PAS 1192.

In conventional building industry operations, Levels 1 and 2 are still prevalent.

The primary problem at these levels is how the various stakeholders collaborate and communicate information.

3. Level 3 focuses solely on life-cycle asset management and maximizes collaboration. Each side acquires its data from a single source. However, no standards have been published yet; hence, the market continues to anticipate Level 3.

III. CALCULATION OF CARBON FOOTPRINT IN CONSTRUCTION BUILDING

The conversion coefficient in the United Kingdom is 0.21233 $kgCO_2e/kWh$ (that is, each kWh of UK grid electricity adds the equivalent of 0.21 kg of carbon dioxide to the atmosphere) [32].

A. *Method of Calculation*

To compute the carbon dioxide emitted by a certain device:

Power rating x conversion coefficient = emissions per hour (1)

[Be careful with units] Activity data (Power (kW)) x conversion coefficient (kgCO_2e/kWh) = emissions (kg CO_2 per hour)

To compute the carbon dioxide emitted by a certain device, determine its kilowatt rating. For instance, let assumptions for a heater be rated at 2 kilowatts (kW), a desktop at around 200 watts (including computer, internet modem, printer, and loudspeakers), and a lightbulb at 14 Watts (W). The value for the heater can be used directly, but that for the computer and lightbulb's power must be converted to kilowatts by dividing it by 1000; thus, 0.2 and 0.014 kW, respectively. The CO_2 emissions per hour are found by multiplying the rating by the conversion coefficient. To calculate the annual CO_2 total emissions for the room:

$$\text{Room Total } CO_2 = LCO_2 + ECO_2 + HCO_2 \quad (2)$$

where LCO_2 = CO_2 emissions from Lighting consumption; ECO_2 = CO_2 emissions from Electronics consumption; HCO_2 = CO_2 emissions from Heating resource consumption.

Lighting consumption:

14 W lightbulb emits 0.014 x 0.21233 = 0.003 kg CO_2 per hour (3 grams)

1 lightbulb = 0.003 kg CO_2 per hour

10 lightbulbs = 0.003 x 10 = 0.03 kg CO_2 per hour (30 grams).

Assuming that the lightbulbs are switched on for 8 hours a day (10 lightbulbs consumption per hour), 0.03 x 8 = 0.24 kg CO_2 per day.

Therefore, the annual Consumption comes to 88 kg of CO_2.

Electronics consumption:

200 W desktop emits 0_2 x 0.21233 = 0.042 kg CO_2 per hour (42 grams).

0.042 x 8 = 0.336 kg CO_2 per day.

Therefore, the annual Consumption comes to 123 kg CO_2.

2 desktops emission = 246 kg CO_2

Heating Consumption:

2 kW heater emits 2 x 0.21233 = 0.42 kg CO_2 per hour 0.42 x 8 = 3.4 kg CO_2 per day,

Therefore, the annual Consumption (excluding 3 months of summertime) comes to 918 kg CO_2. 2 heaters' emissions = 1836 kg CO_2

Room Total CO_2 = 88 + 246 + 1836 = 2170 kg CO_2.

IV. DIFFERENT SCENARIOS FOR ADDRESSING THE CARBON FOOTPRINT ISSUE

An example of addressing the issue of sustainability in the BIM environment is the calculation of CO_2 emission rates for the various activities and appliances that could produce CO_2 if they were operating in a single room. This paper details how the essential data were collected from a single room, including the many appliances that generate daily CO_2 emissions. In addition to wall geometry, technical data, and administrative data, it shows how the calculation results for CO_2 emissions are contained in the BIM object as sustainability data. The authors believe that the object's sustainability data can be represented in the following ways.

1. The present typical object structure might be used to extract the data required to perform the sustainability calculations, as shown in Fig. 1 (C).

2. The current typical object structure might be modified and the sustainability aspect incorporated into the object (geometric, technical, administrative, and sustainability) as depicted in Fig. 1 (D). Consultation with the industry suggests that the element of sustainability will include a list of predefined sustainability issues, such as carbon reduction, energy efficiency, waste control, cost control, and water efficiency.

3. The current conventional object structure might be changed, but retaining the usual geometry, technical, and administrative parts and adding a new element called "Sustainability" with economic, environmental, and social sub-elements, as depicted in Fig. 1 (E).

It must be indicated within the BIM object what sustainability challenges are associated with the various parts of an asset and those generated from industry consultation, reducing CO_2 emissions, and energy use. Theoretically, the CAD system should provide the optimal calculation approach related to each sustainability issue and BIM capture, together with precise calculation data. This means that each BIM object should incorporate all the identified CO_2 emissions issues for each room.

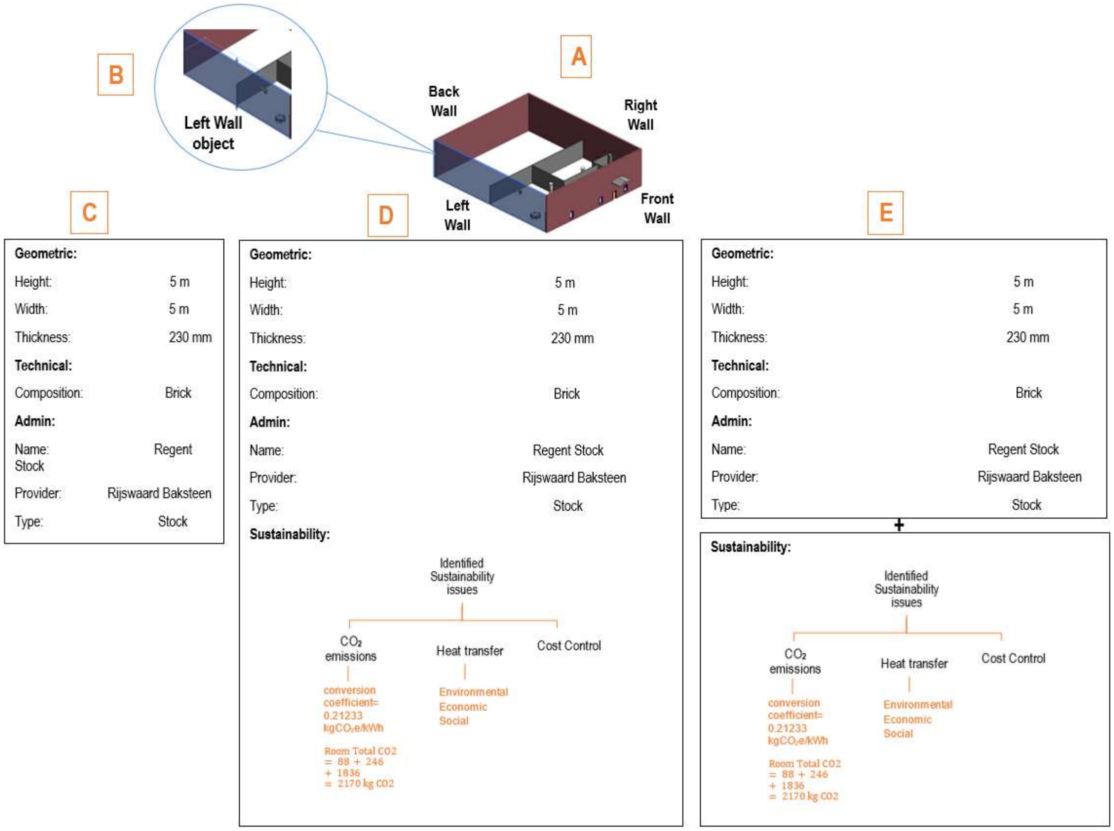

Fig. 1. Detailed sustainability scenarios

V. CONCLUSION

The relevance of addressing construction sustainability in the BIM environment has been outlined in this study. The literature review highlighted the CO_2 emissions from Consumption in a single-room case study in the construction industry. The research demonstrates that the existing BIM Level 2 object structure does not include any sustainability data. The authors describe several ways the current object structure could be modified to add sustainability data covering environmental, economic, and social factors.

The authors also emphasized the need for BIM objects to capture a variety of crucial sustainability challenges. Such sustainability challenges include carbon dioxide reduction, heat transfer, and cost management. The authors suggest that CAD systems provide appropriate calculation methods for each sustainability issue, using BIM to collect and store the generated data. The computation of annual CO_2 emissions of appliances in a created room, as depicted in Fig. 1, illustrates the suggested methodology by addressing a particular sustainability issue. Both CAD and BIM vendors should, in our opinion, consider altering the object structures to meet further sustainability concerns. This research focuses on the sustainability of an asset as a step towards achieving sustainability in BIM structures.

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