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THE APPLICABILITY OF CARBON EMISSION ESTIMATION WITH BIM ENVIRONMENT: SRI LANKAN CONTEXT

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ABSTRACT

The global construction industry is increasingly adopting sustainable practices and advanced technologies to enhance efficiency and reduce environmental impacts. Within this context, managing carbon emissions has emerged as a critical component of sustainable development, with Building Information Modelling (BIM) serving as a pivotal tool in this pursuit. While developed countries have already integrated BIM and carbon emission estimates, there is a notable opportunity for similar advancements in developing countries, potentially leading to significant progress within the industry. Hence, this paper aims to explore the applicability of implementing BIM for carbon emission estimations in the Sri Lankan construction industry. A comprehensive review of existing literature identified the importance of carbon emission simulations, BIM implementation strategies and estimation procedures in other countries. Further, this research involved a survey to assess the familiarity and experience levels of construction professionals with BIM tools for carbon emission estimations in Sri Lanka. Findings from the research point to Autodesk Insight as the primary software tool used within the industry. While the industry demonstrates an awareness of these processes, its progress is hampered by a lack of experience in using these technologies for carbon emission estimation scenarios and the absence of crucial databases such as Environmental Product Declarations. The study recommends enhancing industry capacity through targeted training and the adoption of advanced tools. It also encourages further research to assess the compatibility of BIM technologies in the local context, aiming to bridge the gap and drive sustainable transformation in Sri Lanka's construction sector.

Keywords: *BIM; Carbon Emission; Construction Industry; Factors; Sustainability.*

1. INTRODUCTION

The construction industry plays a vital role in driving economic growth and fostering socio-economic advancement (Jiang et al., 2022). In line with the global progression of this sector, the integration of digitalisation has become a defining trend. As a result, Building Information Modelling (BIM) has emerged as an indispensable integrated approach, providing comprehensive project information spanning the stages of design,

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construction, and operations as illustrated in Figure 1 (Chen et al., 2024). The shift from conventional construction methodologies to BIM-based design has been a prominent subject of discourse within the construction domain since the 1970s. Within the realm of BIM, the various types and specificities of digitised building-related data essential for a construction project are termed BIM dimensions, encompassing a spectrum from 2D to 7D (Ding et al., 2014).

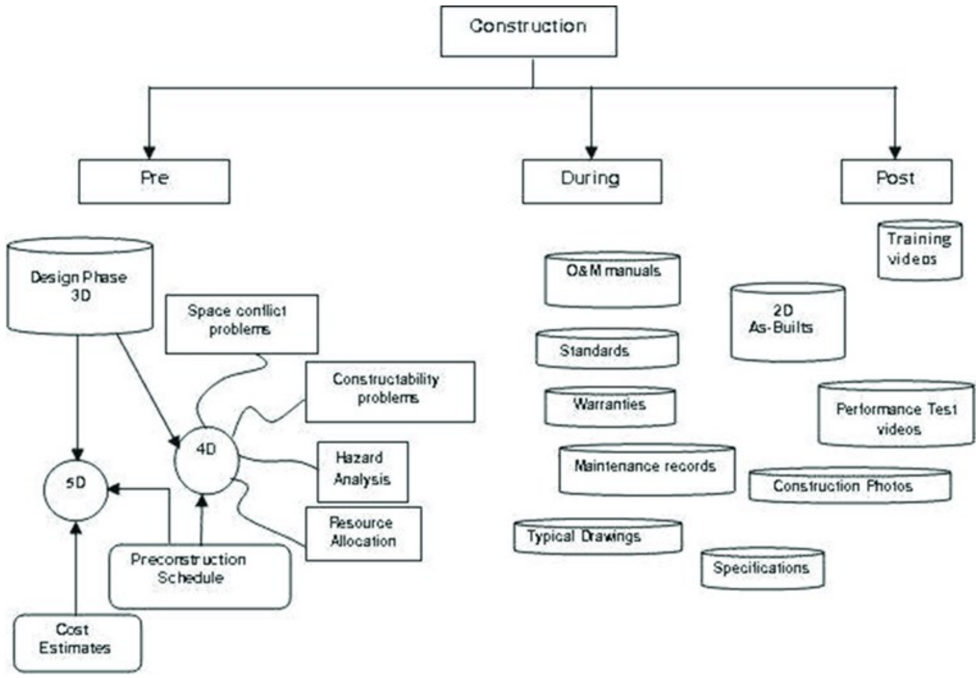
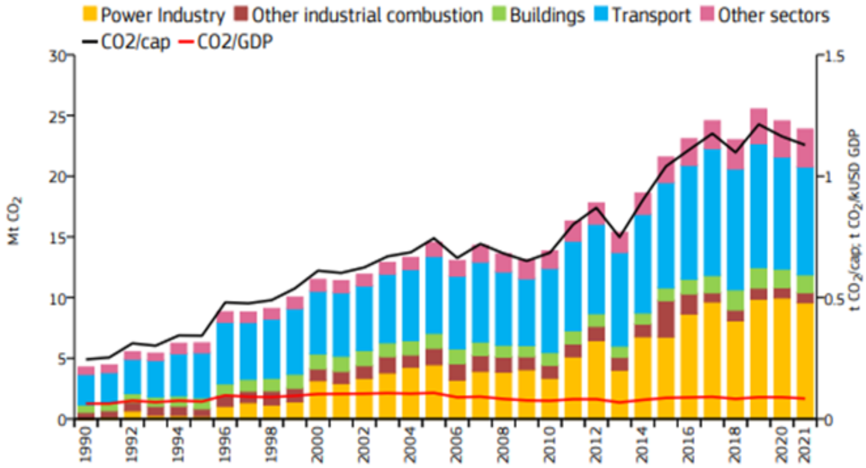


Figure 1: Current status of BIM in construction

The construction sector is progressively embracing sustainable development strategies to attain a harmonious blend of economic progress, environmental preservation, and societal welfare (Yao et al., 2023). Within this context, the growing utilisation of BIM technology is geared toward addressing sustainability concerns at various stages of construction. These include the selection of eco-friendly building materials, the analysis of energy efficiency, and the assessment of the feasibility of renewable energy systems (Wong and Fan, 2013).

Conversely, the term "carbon footprint" denotes the complete volume of greenhouse gases generated by human activities. This encompasses both direct emissions from energy production and indirect emissions stemming from the combustion of fossil fuels during manufacturing, warming, and transportation (Whig et al., 2022). Carbon dioxide (CO2) emissions are a major concern for ecological conservation and sustainable development. Buildings account for 39% of global energy-related carbon emissions, with 28% being functional and 11% from materials and development processes (World Green Building Council, 2023). In Sri Lanka, carbon emission contribution in different sectors is shown in Figure 2. Though Sri Lanka own insignificant amount of CO2 emission compared to other countries, the CO2 emission gradually increased every year (United States Environmental Protection Agency [US EPA], 2016). CO2 emissions contribute to global warming, exacerbate glaciers and polar ice melting, cause hazardous rainfalls, and lead to coastal and ocean acidification (Nußholz et al., 2019). They further illuminated that while acting as a greenhouse gas it also retains heat in the environment like a blanket, making it difficult for the earth to cool. Construction operations, such as clearing land, burning waste, and using engine-emitting equipment, contribute to environmental pollution. Further, the manufacturing and transportation of materials account for 82-96% of all CO2 emissions during the construction period (Sizirici et al., 2021).

In the world context, China, the US, the EU, India, the Russian Federation, and Japan are the largest emitters of carbon dioxide, with global fossil (Nejat et al., 2015). Yet, CO2 emissions decreased by 5.3% in 2020 due to the COVID-19 pandemic. In 2021, global emissions returned to pre-pandemic levels, reaching 37.9 Gt, 0.36% less than in 2019, according to the European Commission Joint Research Centre. In June 2022, building regulations mandate significant industry changes, with developed countries requiring new homes to produce 30% less CO2 emissions (Woodfield, 2022).



Year	CO_2 emissions Mt CO_2/yr	CO_2 emissions per capita t CO_2/cap/yr	CO_2 emissions per unit of GDP PPP t CO_2/kUSD/yr	Population
2021	23.863	1.128	0.084	21.146M
2020	24.537	1.164	0.089	21.084M
2005	14.535	0.744	0.107	19.525M
1990	4.250	0.245	0.063	17.330M

Figure 2: CO2 emissions by sector in Sri Lanka
Source: (Crippa et al., 2023)

Calculations of carbon emissions might differ based on the technique and data sources utilised (Cherubini et al., 2009). However, direct and indirect emissions are some typical approaches for estimating carbon emissions. Carbon emissions are detected throughout a building's life cycle, including design, manufacturing, and distribution. It derives in the design stage, as architects, planners, and engineers use energy and transportation (Hussain et al., 2023). Manufacturing involves local development and imports of goods. Distribution releases CO2 during freight and business travel.

On the other hand, Life Cycle Assessment (LCA), BIM, Environmental Product Declarations (EPDs), and Energy Modelling are several approaches for estimating carbon emissions in the construction sector (Nußholz et al., 2019). They further emphasised that LCA is a method for evaluating the environmental impact of a product, process, or service throughout its life cycle, considering every stage from extraction to disposal. LCA considers various environmentally affected areas, such as resource depletion, waste generation, water use, greenhouse gas emissions, and energy use. It is essential for calculating carbon emissions and estimating carbon footprints throughout a product's life cycle (Nguyen et al., 2021). The approach and main concepts used in LCA in Sri Lanka are the same as those used in other locations. However, the evaluation might take into account certain factors and data sources that are pertinent to Sri Lanka (Amarasinghe et al., 2021).

A building's carbon emissions during construction, usage, and end-of-life can be estimated using BIM (Peng, 2016). Accordingly, the application of BIM can make it easier and more accurate to detect and measure the emissions brought on by the usage of materials, energy, transportation, and waste. Improved accuracy, early design analysis, and cost savings are some main advantages of utilising BIM for carbon emission estimation (Zhang et al., 2022). They further emphasised that assigning emission factors, gathering data, calculating emissions, and analysing the results are the steps that can be used to calculate carbon emissions using BIM. BIM software can be complemented with specialist software or plugins for carbon emission studies, even if it doesn't directly compute emissions (Mousa et al., 2016). Common software used in conjunction with BIM for carbon emission analysis are Autodesk Insight, IES Virtual Environment (IESVE), Design Builder, Green Building Studio (GBS), and Sefaira.

The construction sector's carbon emissions can be estimated with BIM. The factors are necessary for BIM's estimation of carbon emissions, such as building design data (including a building's geometry, components, and systems, can be recorded using BIM), energy consumption data (the energy consumption of a building can be simulated using BIM, which is necessary for estimating operational carbon emissions), transportation data (the transportation of equipment and materials to locations and from the building sites can be monitored using BIM), location data (the location of construction can have an impact on the carbon emissions related to the transportation of materials and the energy utilized throughout the operation), and material data (data about the materials involved in developing the building can be collected with BIM) (Heydari & Heravi, 2023).

According to Ministry of Environment (2023) Sri Lanka is expected to achieve net zero status by 2050. Further, as a non-annex-I-member country of Paris agreement Sri Lanka has pledged 14.5% GHG emissions by 2030 (Fernando et al., 2023). However, Sri Lanka lacks the proven evidence to use BIM for carbon emission estimations. This has been further acknowledged by Amarasinghe et al. (2021), stating that the integration of BIM with LCA presents a valuable area for further research. This lack of knowledge accumulates in reducing possible early design analysis, value-engineered sustainable approaches, cost savings and accurate carbon emission calculations. In line with this, the present study aims to explore the applicability of implementing BIM for carbon emission estimations in the Sri Lankan construction industry. To achieve this aim, it is necessary to assess the level of new technology adoption within the construction industry, identify the key factors involved in carbon emission estimation using BIM, and identify the key challenges of carbon emission estimation using BIM within the Sri Lankan construction industry. To close the knowledge gap two rounds of data were gathered and analysed. The findings of the data collection are discussed in later sections of this paper.

2. METHODOLOGY

The preliminary study addresses significant and pertinent facts from a work's perspective, identifying a gap in research. It reveals that while recognised construction projects use

BIM technology to estimate carbon emissions, no one has examined its use in Sri Lankan building construction. The study aims to fill this gap in the Sri Lankan building sector.

The research aimed to achieve its initial objectives through a comparative literature review and data collection. A mixed-methods approach was adopted in this research to achieve the objectives by capturing both measurable trends, such as familiarity with BIM tools, and deeper contextual understanding through qualitative insights (Taguchi, 2018). Given the need to identify the knowledge gap regarding the use of new technologies in the construction industry, a questionnaire survey was conducted. As the research explores an emerging area that requires specialised expertise, snowball sampling was selected as an appropriate strategy to access and recruit knowledgeable professionals in the industry (Leighton, 2021). Fifty responses were received out of sixty sent questionnaires, where only forty-one completed questionnaires were available. To gather data about factors used for carbon emission estimation with BIM and for the advancements within the industry, semi-structured interviews with experts in different domains of expertise were carried out. The gathered data was then analysed to establish a comprehensive understanding of the topic. The research sample and participants for the questionnaire survey are illustrated in Table 1.

Table 1: Classification of responses by profession and years of experience

	Project Manager	**Engineer**	**Architect**	**Quantity Surveyor**	**BIM Manager**
0 - 5 Years		3	1	18	
6 - 10 Years	1	6	1	1	
11 - 15 years	1	2	3	1	1
16 – 20 years		2			
More than 20 Years					

Since, this study initially aimed to determine the awareness of Sri Lankan construction industry professionals regarding BIM software and tools used for carbon emission estimation in building construction projects, data, collected through questionnaires were analysed using MS Excel. Relative Importance Index (RII) is used to rank the frequency of used BIM based carbon emission estimate software and tool. Also, this study aimed to determine the frequency of use of various BIM software and tools and their collaboration for carbon emission estimation. The next step of the study was conducted through semi-structured interviews with industry professionals and experts, including BIM experts, carbon emission estimating professionals, and professionals familiar with carbon emission estimation projects and BIM technologies, to understand the concept of carbon emission estimation in the Sri Lankan construction industry. The summary of the methodology conducted in this research is shown in figure 3.

The study conducted semi-structured interviews with industry professionals and BIM specialists in Sri Lanka focused on estimating carbon emissions using BIM. Three experts were chosen for the study as shown in Table 2. The literature review explores the concept of carbon emissions in construction projects and the process of carbon emission estimation using BIM. Interviewees E(1) and E(3) have good knowledge about carbon emission estimation scenarios, yet E(2) has a better understanding and experience in zero carbon emission projects. E(2) has contributed to implementing carbon emission estimation software, while E(3) has extensive experience working with such software.

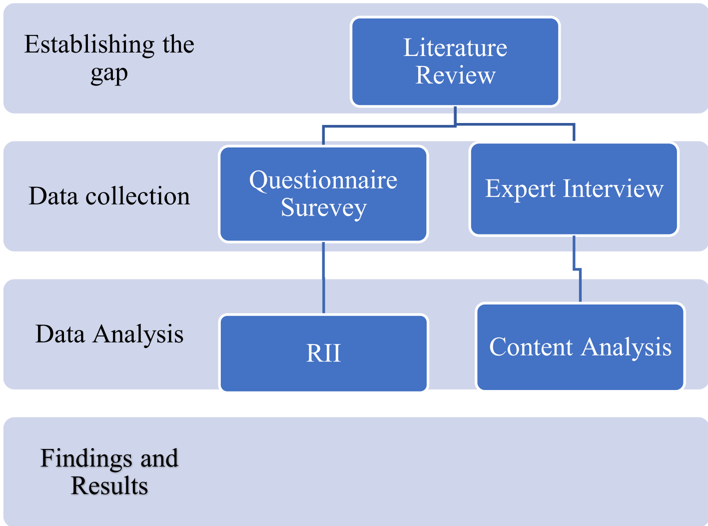


Figure 3: Summary of the methodology

Table 2: Professionals and their designation, qualification, and years of experience

Interview	Designation	Qualifications	Years of experience
E (1)	BIM Specialist	BSc. Physical science, UOC MSc. In GIS, USJ	13
E (2)	Professor of Civil Engineering	Researcher Carbon emission estimation expert	> 20 years
E (3)	Civil Engineer	Chartered Civil Engineer	12

3. DATA ANALYSIS AND DISCUSSION

3.1 EXPERIENCE WITH COMMON BIM SOFTWARE AND TOOLS

Figure 4 shows that all respondents of the questionnaire survey are experienced with AutoCAD, with a majority not having experience with Tekla Structures. 75% of respondents have experienced Autodesk Revit, while 22% have no experience.

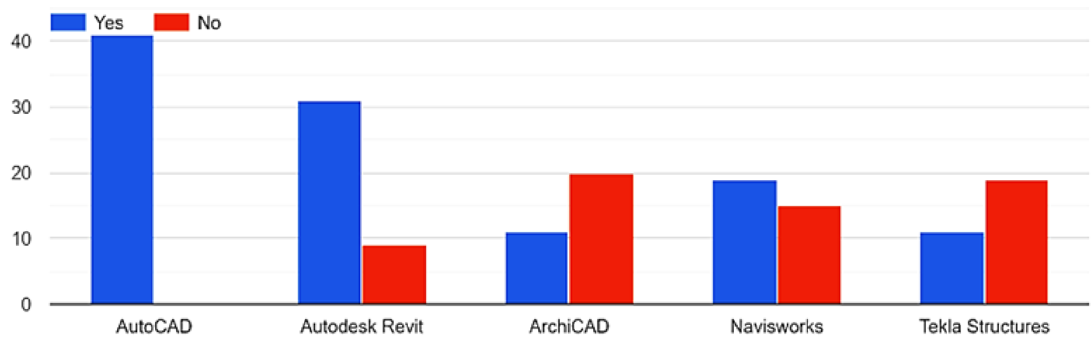


Figure 4: Classification of responses using common BIM software and tools

ArchiCAD software has a higher number of inexperienced respondents than experienced ones, while Navisworks has the opposite result. The research indicates that while most construction professionals have experience with 2D BIM software tools, they lack in extensive experience with 3D modelling software tools, with an average professional having a good understanding of Revit software.

3.2 THE AWARENESS AND INVOLVEMENT IN CARBON EMISSION ESTIMATION SCENARIOS

The study aims to identify the level of knowledge and experience in developing countries regarding carbon emission estimation. The survey showed that 48.8% of respondents were moderately aware of carbon emission scenarios, with one respondent having a very high level of awareness. 22% had a high level of awareness, 17.1% had a low level of awareness, and 9.8% had the least awareness. This information further illustrated in Figure 5, is crucial for advancing carbon emission estimation in developing countries.

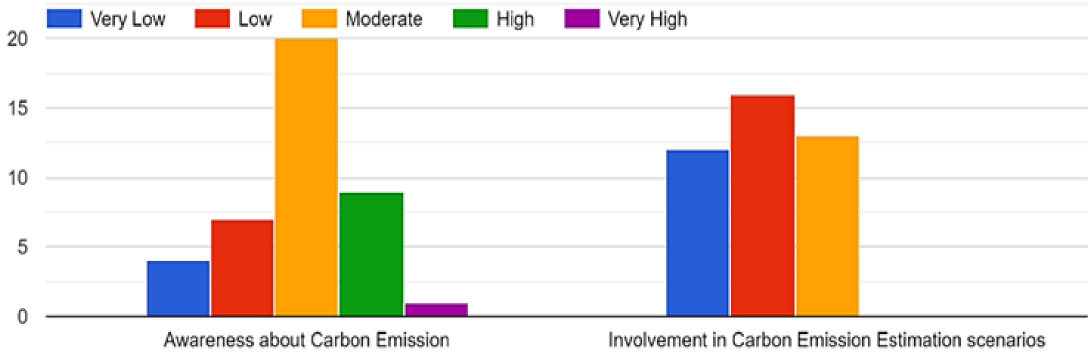


Figure 5: Awareness and involvement in carbon emission estimation scenarios

The majority of construction industry professionals in Sri Lanka have a moderate level of awareness about carbon emission processes, still their involvement in carbon emission estimation scenarios is low. The survey indicates that 29.3% have been involved in very low levels, and 31.7% have been involved up to a moderate level. Despite this, the majority of professionals have limited experience with carbon emission estimation scenarios, indicating a need for further education and training in this area.

3.3 THE AWARENESS OF SOFTWARE AND TOOLS USED FOR CARBON EMISSION ESTIMATION WITH BIM

BIM can help predict and measure carbon emissions from a development's construction, use, and end-of-life. Professionals have moderate experience with Autodesk Insight (48.8%) and Design Builder (36.6%), yet have a low experience of 39% with IESVE, GBS, and Sefaira as shown in Figure 6. Accordingly, Autodesk Insight, IESVE and Green Building Studio ranked the highest aware software used with BIM. However, a few professionals have good experience with these tools, indicating a need for further development in this area. The majority of respondents are familiar with Autodesk Insight and Design Builder software for carbon emission estimation with BIM, yet have limited knowledge about IESVE, GBS, and Sefaira tools. A few respondents claim to be proficient in using this software and tools.

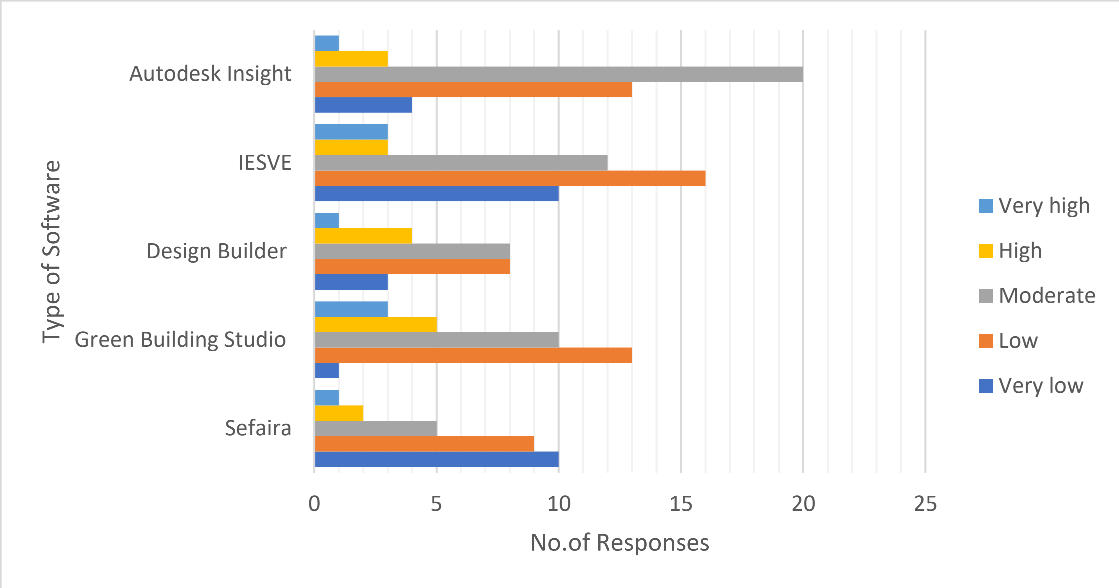


Figure 6: Awareness of software and tools used for carbon emission estimation with BIM

3.4 FACTORS REQUIRED FOR CARBON EMISSION ESTIMATION WITH BIM AND WAY OF COLLECTING THEM

Carbon emission estimation using BIM involves identifying factors such as building design data, energy consumption data, transportation data, location data, material data, and waste data. Building design data can be easily gathered using BIM, while material and transportation data can also be identified using BIM. Autodesk Revit is recommended for this purpose. In developing countries like Sri Lanka, the government lacks good documentation with the EPD, making it difficult to estimate carbon emissions before construction. However, new technology-based tools can automate and will minimise errors, making carbon emission estimation more efficient and accurate. Data can be derived from previous similar projects, as there is no advanced database for collecting information. Waste data is not suitable for BIM-based carbon emission estimation, and operational data may also be considered. The companies are planning to start projects using Revit software for carbon emissions estimation, creating new opportunities in estimation processes in Sri Lanka and developed countries.

3.5 CHALLENGES OR LIMITATIONS ASSOCIATED WITH USING BIM FOR CARBON EMISSION ESTIMATION IN SRI LANKA

The construction industry in Sri Lanka faces challenges in adopting new technology-based scenarios due to various factors. Many professionals lack the knowledge and skills to work with BIM software and tools, and the government lacks a good database for EPDs. Traditional procedures are preferred, and the government changes and inflation are implementing new rules and regulations that may negatively impact the industry. Common challenges were identified, including lack of data quality and availability, lack of BIM adoption, localised guidelines and standards, lack of BIM libraries and resources, and limited knowledge and training. Despite these challenges, the Sri Lankan construction industry is moving towards implementing BIM technology yet facing challenges such as a lack of EPD data, limited awareness about carbon emission estimation factors, and limited knowledge and training. Despite these obstacles, the industry is moving towards a more advanced and efficient approach to construction.

4. CONCLUSIONS

The research aimed to determine the potential of the Sri Lankan construction industry in carbon emission estimation using Building Information Modelling (BIM). The objectives were to identify the concept of carbon emissions in construction projects, which have a significant impact on global climate change. Buildings are currently responsible for 39% of all energy-related carbon emissions worldwide. New legislation requires new construction developments to produce 30% less CO2 emissions.

The process of carbon emission calculation with BIM was identified with some main BIM software, such as Autodesk Insight, IESVE, Design Builder, GBS, and Sefaira, as effective for carbon emission estimation. However, most professionals had moderate awareness of these tools, with Autodesk Insight being the most well-known. Factors required for carbon emission calculation with BIM include building design data, transportation data, material data, location data, energy consumption data, and waste data. Additionally, operational data could be added as a new factor. The Sri Lankan government lacks proper documentation for obtaining data like EPD data, which poses challenges for carbon emission estimation scenarios. All factors were applicable except waste data, and it was suggested to add operational data.

In a nutshell, the Sri Lankan industry is working with carbon emission estimation projects using BIM, yet there is a need for more databases and better documentation. Industry professionals know software, tools, and working procedures; nonetheless, carbon emissions are not widely considered in construction projects. As sustainability continues to gain momentum globally, future construction projects in Sri Lanka must calculate carbon emissions as a main requirement due to continuous sustainability updates and validated considerations. BIM is a key component for this, and early identification of carbon emissions is advantageous. While the industry possesses the foundational knowledge and tools needed to support such initiatives, the availability of updated documentation and clear regulatory frameworks remains crucial.

Building on these findings, this study provides valuable insights into the applicability of implementing BIM for carbon emission estimation in the Sri Lankan construction industry. Nevertheless, certain limitations should be acknowledged, including a constrained sample size due to the specialised expertise required and the lack of access to comprehensive national databases. The study recommends enhancing industry capacity through targeted training and the integration of advanced technological tools to support more effective BIM adoption. It also emphasises the need for further research to assess the suitability of BIM technologies within the local context, particularly in addressing the challenges identified. Bridging these gaps is essential for promoting sustainability and enabling meaningful transformation within the Sri Lankan construction sector.

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