

ENHANCING PRODUCTIVITY AND SUSTAINABILITY THROUGH BIM-BASED PLUGINS: A CASE STUDY OF AUTOBIM CARBON DIAGNOSTICS SYSTEM

Saheed Ajayi¹, Ali Saad², Ade Oyegoke³ and Hafiz Alaka⁴

^{1&3} School of Built Environment, Engineering and Computing, Leeds Beckett University, 114, Northern Terrace, City Campus, Leeds, England, LS2 8AG, UK

² Architecture Building and Civil Engineering, Loughborough University, Leicestershire, LE11 3TU, UK

⁴ Big Data Technologies and Innovation laboratory, University of Hertfordshire, Hatfield, UK

To address the multifaceted challenges facing the construction industry, Building Information Modelling (BIM) has been envisioned as a transformative approach. In line with this development, the paper presents a development and implementation of a BIM-based plugin, AutoBIM Carbon Calculator, which is integrated with the Revit software, with a functionality that supports the estimation and management of embodied carbon in construction projects. The paper outlines the AutoBIM design and development methodology, which is based on participatory quasi-experimental setup approach, involving automated approach for data extraction from BIM models, and carbon calculation algorithm that is integrated with carbon convention factor library. Based on a case study, evidence shows the ability of the AutoBIM calculator in precisely reducing time spent on carbon calculation while also automatically identifying carbon hotspot to facilitate design optioneering for carbon effectiveness. In addition, a case study project demonstrates 14% carbon reduction by supporting alternative design decision making. AutoBIM calculator, as a BIM-based plugin serves as a promising example of how custom-built solutions could address challenges facing the industry by highlighting the potential of BIM-based plugins to enhance productivity, efficiency, and sustainability.

Keywords: Building Information Modelling; plugins; carbon calculator; sustainable construction; AutoBIM

INTRODUCTION

The construction industry, while being integral to job creation and economic growth in every nation, is well known for its poor productivity, accident-proneness, and negative impacts on the environment, which has made it a key target for the global sustainability agenda (Ajayi *et al.*, 2015). Due to its significance, researchers and governments across nations have recognised the need for addressing these challenges as a way of enhancing the industry's performance and aligning it with the sustainable development agenda. For instance, the UK government has constituted a series of

¹ arcileogbo@outlook.com

reports to explore the strategies for enhancing the productivity and overall performance of the UK construction industry (HM Government, 2022). Notable among comparable reports is the Egan report of 1998, which recommended the needs for client focus, collaborative, integrated and more streamlined approach as ways of addressing inefficiencies, low productivity, and lack of innovation in the UK construction (Egan, 1998).

As a way of addressing the multifaceted issues affecting the construction industry, a significant development that emerged was the concept of Building Information Modelling (BIM), a transformative approach that integrates information management with digital technologies. The philosophy behind the concept of BIM aligns with some of the early recommendations for enhanced collaboration, partnering, integration and modernisation, as encapsulated in Egan's and other reports into the UK housing and construction industry. As a collaborative digital information management approach to construction project delivery (Merschbrock and Munkvold, 2014), BIM is touted as an effective way of addressing issues affecting the productivity of the construction industry (Porwal and Hewage, 2013). BIM was introduced to address the collaborative challenges that are evident to result in several other issues affecting the construction industry, and its implementation transcends beyond the traditional silo way of working. With the use of BIM, project management is streamlined, collaboration is enhanced, and the design and construction are expected to be more precise if used as expected (Saad *et al.*, 2022). It is envisioned, therefore, that having a custom-built functionality accessible to construction professionals and researchers would revolutionise the construction industry by boosting its efficiency, reducing errors, and promoting sustainability and productivity.

While BIM is argued to be a process, its implementation is driven by the use of diverse tools and software systems for facilitating process automation and collaboration among project stakeholders. These series of software systems are often referred to as BIM software (Diana *et al.*, 2022), which serve as the backbone for BIM implementation. These include the digital infrastructure, tools and systems for designers, contractors, and other stakeholders to collaboratively create and manage a digital representation of the proposed building or infrastructure. Notwithstanding that the process has been argued to be the most important aspect of BIM's implementation, the choice of BIM software, its configuration, flexibility, and adaptability to meet a project's specific needs affect the overall effectiveness and efficiency of project delivery processes. Thus, BIM is considered as a holistic project delivery process and software solutions that are working in tandem to enhance project productivity. A complete BIM model is an augmentation of geometric and non-geometric information of all objects involved in a construction project.

To further enhance BIM implementation, and execute complex project issues, the development of tailored BIM plugins has emerged as a new trend in the construction industry, serving as innovations within innovation. According to Saad *et al.*, (2022), these sets of plugins help in extending BIM functionalities for such tasks as building lifecycle analysis, waste management, health and safety monitoring, cost analysis and optimisation of energy consumption among others. Studies in this area have shown that the plugin systems have the potential to enhance project productivity among other benefits. Evidence shows that their development is often to automate and address the repetitive processes, error proneness and dangers associated with some construction activities (Abbas *et al.*, 2022; Ajayi *et al.*, 2021).

This paper therefore subscribes to the statement by Saad *et al.*, (2024, 12), stating that; "the behaviour of seeking additional BIM capabilities through plugins is effective but is mostly research focused and research-led, portraying the contemporary nature of this occurrence and acting as a critical implicit to what may be the future ramifications on the prevailed understanding of BIM today". This paper aims to address this gap and contribute to the trend by developing a functional carbon management mechanism. Named AutoBIM Carbon Calculator, the presented BIM-based plugin was developed as an add on to Revit, the most popular widely used BIM design tool with the largest UK CAD software market share (NBS, 2016). By facilitating carbon estimation within the design platform, the study seeks to address the challenges associated with the accurate estimation and optimisation of embodied carbon in construction projects. Its specific objectives include:

- To conceptualise, develop, test and validate the BIM-based automated carbon calculation system.
- To evaluate the productivity and sustainability benefits of adopting the AutoBIM carbon calculator.

The study adopts a participatory quasi-experimental setup methodology, involving collaboration among the researchers, team of software developer, and construction industry stakeholders, including carbon management experts. This approach supports the claim by the UK study of Arogundade *et al.*, (2024, 17), who criticise "the keenness of contractors to tackle construction process carbon emission at their discretion without being compelled to do so.". This approach facilitates inputs from the potential end users from conceptualisation to completion.

LITERATURE REVIEW

BIM-based plugins are emerging to form a technological trend across a few construction-related studies, proving that the development and application of these plugins may present invaluable opportunities to the industry. However, challenges exist in the development of such plugins mainly due to the complexity of requiring experience in coding (Liu and Issa, 2014). Nonetheless, Saad *et al.*, (2022, 11) infer that "the challenges facing the authors throughout developing plugins" may offer scope for future research to address these challenges. Such arguments align with Chen and Nguyen (2017), who indicate the importance of BIM-based plugins in addressing contemporary construction challenges through custom-built solutions. Hence, leveraging the potential of plugins may align with this study's main objective.

BIM-based plugins' areas of application vary to cover a spectrum of important use cases, particularly in supporting users' decision-making. For instance, such plugins are proving highly effective in predicting energy consumption, predicting workplace hazards towards workers' safety, and predicting the most cost-efficient design options (Saad *et al.*, 2022). Because of its possibilities, designers can utilise BIM-based plugins to reduce waste (Sameer and Bringezu, 2021), better align with environmental building standards (Chen and Nguyen, 2019), and mitigate worker safety by directly receiving plausible areas of concern (Yuan *et al.*, 2019). Therefore, BIM-based plugins can provide an extended ability to address issues that may otherwise remain largely unresolved.

Despite the increasing and recent use of BIM-based plugins to overcome longstanding construction issues, such as Singh *et al.*, (2020), who developed a plugin to predict energy consumption, Chen and Nguyen (2019) to facilitate material selection in line

with green building standards, and Mohammadi *et al.*, (2023) to support effective budget allocations, there has been limited focus to relate plugin development with carbon reduction. Mostly, past research efforts that can be argued as most related have confirmed that areas of plugin application such as waste reduction (Jalaei *et al.*, 2019), dispute resolution (Ali *et al.*, 2020), and lower energy consumption (Zhang *et al.*, 2018), can provide scope for developing equally important systems related to measuring and reducing carbon in construction activities. In this vein, this study aims to develop a novel carbon reduction plugin that can guide decision-makers on the pressure points in which carbon can be reduced in a dynamic and complex work environment.

METHOD

The system is comprised of a plugin integrated into Revit, functioning as a Windows desktop application. This plugin connects to a cloud-based web server through REST API, which, in turn, provides access to a MySQL database housing industry-approved carbon factors ICE (Inventory of Carbon and Energy) data for building components. This interaction is facilitated through the utilisation of a C# .NET class Library. The choice of Revit as the platform for this integration was made, in part, due to its widespread adoption in the field of Building Information Modeling (BIM) design (Chen and Nguyen, 2019; Akinade, 2017). Thus, users engage with the plugin system to perform embodied carbon calculations for each component loaded into the Revit workspace, all within the Revit desktop environment,

The system incorporates a feature to update the carbon factor database, ensuring that it remains current with newly introduced components that may not have been recognised in the uploaded model prior to carbon factor calculation. Figure 1 provides a visual representation of this System Architecture.

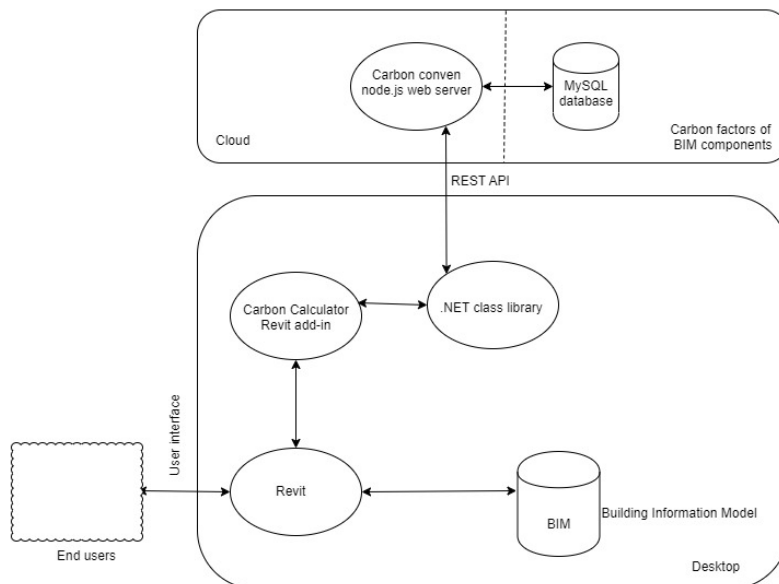


Figure 1: System Architecture for AutoBIM Calculator

Development of the BIM Embodied Carbon Calculator Plugin

The development of the BIM Embodied Carbon Calculator is a crucial step in this methodology. This calculator is designed to harness the power of Autodesk's BIM software and C# programming language to estimate the embodied carbon of various

construction components in a BIM model accurately. The following steps outline the process:

Data Extraction from BIM Models: To commence the development process, the BIM data must be extracted from the Autodesk software using the Autodesk C# .net API. The API allows for seamless access to the information stored within the BIM model. Key data points to be extracted include component types, materials used and geometry information such as volume of each material in the BIM model.

Carbon Calculation Algorithms: The calculator utilised established carbon calculation algorithms and methodologies to estimate the embodied carbon for each component and then sums it up to get the embodied carbon. The carbon calculator Revit plugin considers the material properties, quantities, volume and any other relevant data extracted from the BIM model and then initiates a POST RESTAPI call to the carbon calculator backend. The response is then consumed by the carbon calculator plugin within Revit to present the calculated embodied carbon of each component, which is summed up to form the overall embodied carbon of all the element within the BIM model.

Integration with the Carbon Convention Factor Library: This was done to apply the appropriate carbon factor to materials quantity automatically extracted in Revit. The carbon convention factor Library is a database of an approved Carbon Convention Factor Library, containing carbon emission factors for various construction materials and components from ICE (Inventory of Carbon and Energy) database (Hammond and Jones, 2008). The Node.js server, in conjunction with the MySQL database, forms the backend infrastructure for this REST API. Express.js is used to set up a Node.js server to create a REST API that will be consumed by the Revit plugin to calculate the embodied carbon of all the components in the BIM model. This creates an API Endpoint definition, which listens for incoming HTTP requests, specifically POST requests, containing the payload data (volume and material type) in the request body. When a client sends a POST request with volume and material type data to the /calculate-carbon endpoint, the route within the endpoint connects to MYSQL database server using mysql2 package (a MySQL library for Node.js) to establish connection and execute SQL query against the carbon factor database. This retrieves the relevant embodied carbon data based on the material type provided from the payload. It then performs calculations using the volume of the component and sends back the result of the embodied carbon for the component in the API response in JSON format. The response is subsequently consumed by the carbon calculator plugin within Revit to present the calculated embodied carbon of each component of the BIM model.

Finally, it is important to note that the calculator has been engineered to provide real-time updates directly from the library as needed. The feature ensures that accuracy is sustained, with precise alignment with the inserted carbon emission factors. Such integration between the library and the calculator means that users would have a real-time visibility of the estimates as a result.

Implementation and Testing

Following the collaborative design, development, testing and packaging of the carbon calculator, a real-life case study was conducted to evaluate its effectiveness from both sustainability and productivity standpoint, in line with the goal of the study. This section presents the case study project and the results from the case study analysis.

Case Study Building and Analysis

A case study of a research building, containing laboratory facilities and research space for over 1,000 researchers and students, located in the UK, was used for testing the AutoBIM carbon calculator. Once the Revit model of the building was imported into the AutoBIM carbon calculator dashboard within the Revit interface of the plugin, its material quantity is extracted and automatically mapped to the database. Figure 2 shows an overview of how the system extracted the building elements in terms of materials volume and applied the carbon factors, yielding a total carbon calculator output of 5,173,562kgCO₂e for the structural frame. Available columns are numbered from 1 to 10 in the Figure 2.

Using its library of carbon factors, the carbon calculator supports different forms of analysis, including carbon per building elements, historical analysis of buildings as the design changes, and comparison between two or more designs. Compared to the traditional method of carbon calculation, which involves manual multiplication of materials volume with the carbon factor. The embodied carbon per building element is automatically calculated using the output of materials volume extracted, carbon factor based on the ICE database and materials density. Where the materials are innovative or newly introduced, provision is made for manual input of the carbon factor, as provided by the materials manufacturer. This ensures that the carbon factors could be accurately captured to reflect the actual embodied energy of the building.

The screenshot shows the AutoBIM carbon calculator interface. At the top, there is a 'Filter' button and a dropdown menu. Below this, a list of 'Selected filters' includes Ceilings, Columns, Doors, Floors, Roofs, Structural Columns, Structural Foundations, and Structural Framing. The main table has four columns: Material, Volume, ICE Material I, and ICE Material II. The rows list various materials like UC203x203x46 (Steel), 400 x 600 (Concrete), Metsec-172213 (Steel), and KingspanStructuralProducts_Multideck_60V3_1.0mm (Steel). Below this table is another table with columns: Embodied Carbon (kgCO₂e/FU), Unit, Functional Unit (FU), Mass/FU (kg/FU), EPD, Density I, Density II, and Density (kg/m). This table provides detailed carbon factor data for the materials listed above.

Material	Volume	ICE Material I	ICE Material II
UC203x203x46 - (22)	1	3	4
Metal - Steel 50-355	0.2964	Steel	Steel, UO Pipe
400 x 600 - (5)			
Concrete - Cast-in-Place Concrete	1.441	Concrete	General
Concrete - Cast-in-Place Concrete - RC 40/50	0.427	Concrete	General
Metsec-172213 - (15)			
Metal - Steel 50-355	0.07241	Steel	Steel, UO Pipe
Metal - Steel - Light Gauge	0.01611	Steel	Steel, UO Pipe
KingspanStructuralProducts_Multideck_60V3_1.0mm - (4)			

Embodied Carbon (kgCO ₂ e/FU)	Unit	Functional Unit (FU)	Mass/FU (kg/FU)	EPD	Density I	Density II	Density (kg/m)
3.02	kg	1	1		Steel	stainless steel, 5% Ni	7850
2.64	kg	1	1		Concrete	aerated, Wm-1k-1 (1.16)	500
2.64	kg	1	1		Concrete	aerated, Wm-1k-1 (1.16)	500
3.02	kg	1	1		Steel	stainless steel, 5% Ni	7850
3.02	kg	1	1		Steel	stainless steel, 5% Ni	7850

Figure 2: Overview of automated materials extraction and carbon calculation system

To estimate the time efficiency of using the automated carbon calculator, a manual calculation was done on the case study project to compare the time spent on both the experimental and control group. As shown in Table 1 below, manual carbon

calculation took approximately 12 hours (718 minutes) compared to 21 minutes spent while using the automated carbon calculator. This represents a 97% reduction in the time used for manual carbon calculation.

Table 1: Results for AutoBIM Carbon Calculator Performance Evaluation

Group	Time Spent
Manual Calculation	718
AutoBIM Calculation	21

In addition to carbon calculation, the system facilitates the identification of key carbon hotspot that contributes the highest proportion of the embodied carbon, as shown in Figure 3. This enables the designers to understand the elements that could be replaced with alternative materials to reduce the whole building embodied impact.

Using the carbon hotspot as a decision support mechanism on the case study project, an alternative design was proposed for the structural frame as shown in Figure 4. Based on a new calculation for the alternative design, a carbon reduction of 14% was achieved, suggesting the potential for driving embodied carbon mitigation through the AutoBIM carbon calculator. In addition, the system facilitates the side-by-side comparison of the alternative designs to identify key areas of improvement as the designs change.

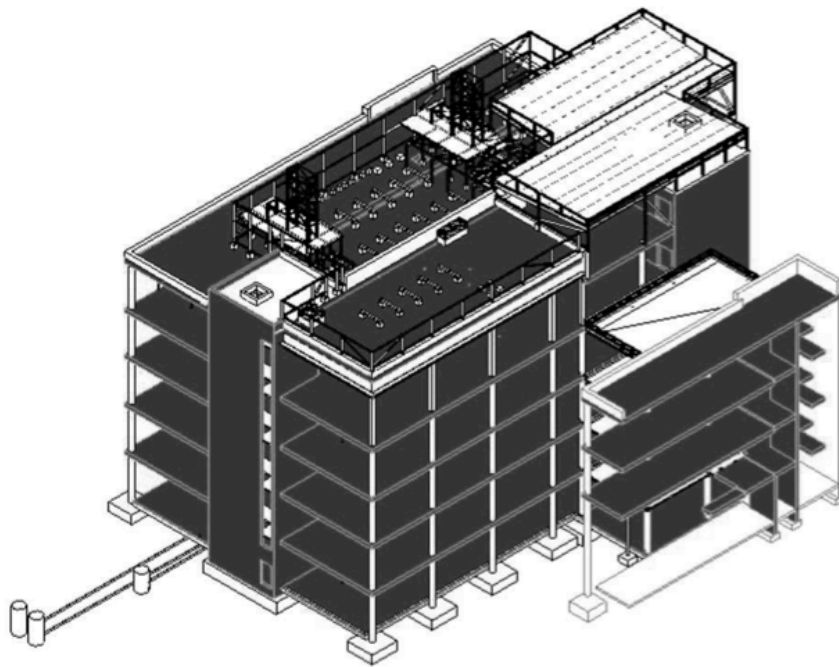


Figure 3: Carbon hotspot analysis

CONCLUSIONS

The construction industry has long faced challenges relating to sustainability, productivity and overall efficiency, and the need to enhance the industry's challenges has been recognised by governments, researchers and other key stakeholders. BIM as a transformative technology was envisioned as a potential approach to addressing the challenges facing the construction industry. In line with the current development in BIM, this paper introduces AutoBIM Carbon Calculator, a BIM-based plugin that was

designed to estimate and support decision relating to embodied carbon management on construction projects.

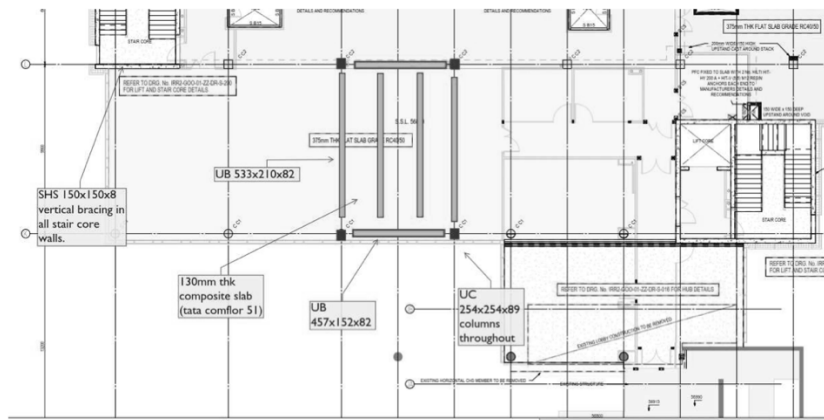


Figure 4: Alternative design based on initial calculation and carbon hotspot

As evident in the case study analysis, traditional carbon estimation is labour-intensive and may comprise various errors undermining a precise estimation process. With the AutoBIM carbon calculator being able to extract data directly from BIM model, this reduces the risks of over estimation or underestimation, ensuring that the embodied carbon is accurately estimated. In addition to carbon estimation, the system helps in identifying carbon hotspots, which supports the designers to explore alternative materials and design to lower embodied carbon, thereby promoting sustainability.

Overall, the results can be seen to advocate the effectiveness of plugins in significantly enhancing the relative productivity. Findings from the case study analysis show that the use of AutoBIM Carbon Calculator reduced the time used for carbon calculation from 12 hours when done manually to just 21 minutes. Such radical reduction in time is associated with critical automation benefits, allowing professionals to allocate their time more effectively. The results expand the findings of Saad *et al.*, (2022) who infer that BIM-based plugin solutions are enhancing productivity through automation.

Additionally, the results also showed that the use of automated calculator supported 14% reduction in carbon emission from the case study project. This is significant, and it underscores the potential of technology in contributing to carbon effectiveness of the construction industry, an industry that is very significant to achieving the global sustainability target (Ajayi *et al.*, 2015). Such a finding supports the study of Jalaei *et al.*, (2019), which emphasizes plugins' potential in allowing the optimisation of life cycle environmental assessments. Hence, this study illuminates the effectiveness of plugins in performing carbon-related tasks, and it encourages future research to rely on comparable technologies to reduce carbon emission of construction projects.

With the successful validation of the AutoBIM Carbon Calculator highlighting the potential for similar technologies in the construction industry, future studies that adopts other methodologies than case studies, can explore the broader application of BIM-based plugins in addressing sustainability challenges of the industry beyond the embodied carbon. In addition, the potential of plugins in enhancing construction productivity could be explored by developing solutions that optimise resource use, enhance efficiency, and improve safety. This is especially as the AutoBIM calculator demonstrates the potential for addressing multifaceted challenges facing the construction industry through technology-driven solutions.

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