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Chenhao Jin

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Yuan Yao

See next page for additional authors

Authors
Chenhao Jin, Qinlin Huang, Xiaorong Sun, Yunxi Hao, Yuan Yao, Xin He, Liangshuo Wang, and Shinae Jang

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Life-Cycle Building Carbon Emission Management Platform based on Building Information Modeling Technology

Chenhao Jin[1]
Qinlin Huang[2,*]
Xiaorong Sun[3]
Yunxi Hao[4]
Yuan Yao[5]
Xin He[6]
Liangshuo Wang[7]
Shinae Jang[8]

*Corresponding author
[1] Assistant Professor, Business School, Hohai University, Nanjing, China, cjin@hhu.edu.cn
[2] Research Assistant, Business School, Hohai University, Nanjing, China, 2698804628@qq.com
[3] Assistant Professor, School of Energy and Electrical Engineering, Hohai University, Nanjing, China, xsun@hhu.edu.cn
[4] Research Assistant, Business School, Hohai University, Nanjing, China, 965282108@qq.com
[5] Research Assistant, Business School, Hohai University, Nanjing, China, 1622641229@qq.com
[6] Research Assistant, Business School, Hohai University, Nanjing, China, 285623976@qq.com
[7] Research Assistant, Business School, Hohai University, Nanjing, China, 1612687836@qq.com
[8] Associate Professor in Residence, Department of Civil & Environmental Engineering, University of Connecticut, Storrs, CT, USA, shinae.jang@uconn.edu

ABSTRACT

Buildings produce 40% of annual carbon emissions among various sectors in modern society. One of the most challenging problems of carbon management is how to monitor and calculate a building's life-cycle energy consumption and carbon emission data during both construction and operation stages. The Building Information Modeling (BIM) technology provides a promising method to obtain and simulate buildings as-is status at different stages in the life cycle. This paper develops a framework for building a carbon emission management platform using the carbon emission factor method and BIM technology, which can derive corresponding carbon emission and measure carbon footprint with building geographic information to achieve precise positioning of carbon emission objects. The platform can achieve multi-role collaboration, equipment visualization, real-time carbon emission monitoring, and data analysis. The platform is applied to an existing building in Hohai University to assess the total carbon footprint of the building in its life cycle. This platform can greatly improve the calculation accuracy of the carbon footprint of buildings, improve data transparency, provide valuable information for building facility management personnel, and help achieve the goal of carbon neutrality.

Keywords: Building Information Modeling, carbon footprint, life-cycle assessment.

INTRODUCTION

As human activity produces more and more carbon emission, global warming is threatening human society and causing more and more problems. Many international organizations and governments of different countries have made a promise and plan to achieve the common goal of carbon neutrality. As one of the largest carbon contributors, buildings produce 40% of annual carbon emissions in the globe. Among the five stages of a building's life-cycle, i.e., design, construction, operation and maintenance, demolition, and recycling, the carbon emissions produced by the construction and operation maintenance stages account for about 90% of the carbon emissions of the whole life cycle. This means that improving the carbon footprint management of the public building and operation and maintenance stage, controlling the carbon emissions of the construction and operation and maintenance stage is very important to reduce the total carbon emissions and promote the upgrading of the energy structure system in the construction industry. For construction managers and building facility managers, carbon management is difficult to implement due to a lack of information and data about a building's carbon footprint data, especially for existing buildings. The building carbon footprint management platform, which can achieve accurate calculation of the carbon footprint, carbon data monitoring, and analysis, is in great need for building facility management.

With the advantages of integrating building information from various sources, BIM has the potential to play a key role in carbon reduction control in the construction, operation, and maintenance stages. In the construction stage, BIM acts as an information integration platform to evaluate and simulate carbon emissions on the network, assist in prefabricated construction without building physical facilities, also greatly reduce carbon emission (Hao *et al*., 2020). In the stage of construction operation and maintenance, a green transformation has become a new development trend and sustainable evaluation using BIM

(Lim *et al*., 2021). is mainly realized through data management to provide the building information required for performance simulation, real-time modification of the model using analytical feedback, and compatibility with performance simulation software. However, due to the practical difficulties of evaluation standard establishment, data acquisition, automation management, and interactive design, the practical application of BIM in building carbon reduction are rare. The current life-cycle assessment (LCA) approach has been considered feasible for potential theoretical guidance, and the current study has found that LCA combined with BIM has the potential to reduce the difficulty of classification and collection of carbon emission data. During the whole life-cycle of a construction project, uncontrollable factors such as construction period limit, environmental change, technical iteration, and material replacement all add difficulties to the practice of LCA, and the combination of BIM and LCA is expected to improve this situation (Yang *et al*., 2018). Moreover, carbon emission control and sustainable design in the existing building operation and maintenance stage urgently need to clarify the BIM workflow, but the lack of practice leads to the lack of high precision of the existing building BIM models and data, such as spatial data inside the building, operation data of energy consumption, and many others (Lim *et al*., 2021). To sum up, BIM technology is widely used in the construction and operation maintenance stage of low-carbon building research, but it still needs to improve the accuracy of carbon footprint calculation methods, optimize the working framework to be compatible with different simulation tools, and improve the level of automation to complex situations.

LITERATURE REVIEW

Research on Carbon Emission Related During the Construction Stage

At present, the following three methods are widely accepted in carbon footprint calculation. The first is the carbon emission factor method. Since the traditional inventory analysis method is more widely applied in the mature construction drawing design stage or with a detailed bill of quantities, this method is suitable for measuring carbon emissions in the design stage or after the end of the project. For example, the CO_2 emission due to the building materials consumption can be calculated by the data China Statistical Yearbook on Construction combined with the known carbon emission factors (Zhang & Wang, 2016). The Korea Life Cycle Inventory Database can be used to assess the carbon emissions for each material used in the project for a building complex combined with electric carbon emission factors (Seo *et al.*, 2016).

The second method is the method of Life Cycle Assessment (LCA) combined with carbon emission factors. The LCA is a method of assessing the environmental impact of products during their life cycle (Cang *et al.*, 2020). Currently, there are three carbon emissions calculation methods for building life cycle assessment (LCA), i.e., process-based LCA (P-LCA), input-output LCA (I–O-LCA), and hybrid LCA (H-LCA). Each method has its own characteristics and scope of application. Such methods as can be used to assess the environmental impact of buildings during the entire life cycle. They are often combined with carbon emission factors for the systematic measurement of building carbon emissions. The combined LCA approach and carbon emission factors are used to assess and compare emissions in different climates from different building and structural buildings (Luo & Chen, 2020).

The third method is the method using BIM combined with carbon emission factors. With BIM technology developing, it became possible to get building information model early in the design stage. BIM emerged as a solution, allowing one to measure real-time carbon emissions in the materialized phase. Bentley's Open Building Designer software is one of the tools to implement BIM technology. In the software, the engineering view can be presented in 2D and 3D views, and BIM software can export quantities data at any time node based on the project schedule plan. Based on the derived quantities data and combined with the known carbon emission factors, the carbon emission measurement in the materialization stage can be carried out with a simpler and more widely applicable method. Carbon emission measurement in the construction phase using BIM technology combined with carbon emission factors helps users save time and effort for the subsequent carbon reduction optimization design. Based on the above discussion, this paper uses BIM technology combined with the existing carbon emission factors to achieve real-time measurement of carbon emissions in the construction phase.

Table 1: Analysis of carbon emission calculation method in building chemical stage.

Methods	Advantages	Limitations	Applicable object	Application status
Carbon emission factor method	1. It is simple to calculate with high credibility; 2. Have a specific carbon emission factor database available; 3. Very wide application and mature system	The calculation results are rough, and the carbon emission factors of different statistical sources are quite different, and there is a gap from the standardized quantitative calculation	It is applicable to a national strategic level, and calculation of social and economic carbon emission sources are relatively stable	Widely used, high recognition, conclusion authority

LCA+ carbon emission factor method	Detailed calculation results can be given for specific assessed objects	Combining process analysis and input-output analysis produces multiple calculations; It needs more time and data; drawbacks in system boundary determination and data collection	It is applicable to government environmental decision-making management, economic evaluation, and social evaluation	Widely applied with credible conclusions
BIM + carbon emission factor method	1. The results are accurate, and building energy consumption data can be obtained directly 2. The method can be combined with carbon emission factors from different regions 3. Achieve the standardized quantitative calculation	BIM-related software is not mature. The building material carbon data are not accurate	Suitable for the carbon emission management of large public buildings or architectural complexes	No mature application in the building preliminary virtual simulation stage

Research on Carbon Emission Related in the Construction Operation and Maintenance Phase

There are three main methods for calculating carbon emissions in operation and maintenance stage. The first one is the emission factor method, which is widely used. Its basic idea is to construct the activity data and emission factors for each emission source according to the carbon emission list, and then take the product of the activity data and emission factor as the carbon emission estimation value of the emission project (Köne & Büke, 2019). In this method, the activity data is mainly derived from relevant national or regional survey data. The emission factors can use the reference value given by the global average level in the IPCC report (Eggleston *et al.*, 2006).

The second method is the quality balance method (Guo & Ma, 2019), which considers the direct emissions, indirect emissions, and the final generated carbon sink, that is, considering the full input and output to follow the law of quality conservation as the basic principle. This method is a quantitative analysis of the energy consumption and CO_2 emissions generated in the whole process.

The third method is the energy measurement method, which is based on the basic data of the field energy measurement in the construction operation and maintenance stage to collect the relevant carbon emissions. In the building energy consumption measurement work, the concept of classification should be adopted to measure various energy consumption such as air conditioning, electrical light, water, and power consumption.

Based on the above-related methods and literature review, this paper proposes the BIM + carbon emission factor calculation method, based on the BIM model and monitoring data, to transfer building-related energy consumption data to the background to summarize the relevant carbon emissions. This method can organically combine energy measurement method with computer internet of things technology and the application of carbon emission factor method.

Table 2: Analysis of the carbon emission calculation method in the construction operation and maintenance phase.

Methods	Advantages	Limitations	Applicable object	Application status
Carbon emission factor method	1. Simple to calculate with high credibility; 2. Specific carbon emission factor databases are available 3. Widely used application and mature system	The calculation results are rough, and the carbon emission factors of different statistical sources are quite different, and there is a gap from the standardized quantitative calculation	In the calculation of carbon emissions at the national strategic level, the social and economic carbon emission sources are relatively stable, ignoring their internal complexity	1. It is widely used 2. High recognition 3. Conclusion authority
Quality balance method	Clarify the relationship between various kinds of equipment and natural emission sources	Data acquisition is difficult. The method is not standardized. The data lack authority is not suitable for a single building	Social and economic development develops rapidly, and building carbon emission equipment is updated rapidly	1. No standardized measures were available 2. The conclusions are not universally accepted
Energy measurement method	The measurements are very accurate	Data is difficult to obtain, and it is difficult to investigate building carbon emissions at the overall social level.	Single building measurement, suitable for buildings with access to energy data	1. Difficult in obtaining data; 2. The scope of application is too narrow

BIM+ carbon emission factor calculation method	1. The results are accurate, improve the deficiency of energy measurement method, and directly obtain construction energy consumption data 2. Building structural factors were selected from the relevant carbon emission factor database 3. Realize the standardized quantitative calculation	The precise grasp of the results, this plan is limited to the analysis of carbon emissions in the operation and maintenance stage of single buildings and fails to realize the carbon emission analysis and survey of the whole city and even the whole society	Single large public building measurements	No universal application in the building preliminary virtual simulation stage

RESEARCH METHODOLOGY

For the calculation and monitoring of building in the entire life-cycle, a BIM-based collaborative management platform is designed to assist the units involved in carbon emission control and provide corresponding suggestions. Starting from the two stages of building materialization and operation and maintenance, the platform conducts the overall design with three basic functions: multi-role collaborative participation, real-time monitoring of carbon emissions, and visualization of existing facilities.

Platform Design Ideas

According to the actual practical requirements of public building carbon reduction in the construction field, three basic functions are designed, namely real-time monitoring of energy consumption, equipment visualization, and multi-role collaborative participation.

The first is to have the building's energy consumption monitored in a timely manner, which is mainly used in the operation and maintenance stage. Carbon emissions in operation and maintenance phase are mainly concentrated in energy consumption. Compared with the construction phase, the operation and maintenance phase does not have a very clear monitoring facility for energy consumption. In order to solve this problem, infrared sensors, power sensors, water flow sensors, remote control facilities, and RFID devices are embedded in each monitoring target in advance. After energy consumption data such as electricity and water consumption are obtained, and energy consumption data of equipment can be analyzed timely by integrated application of BIM and Internet of Things, and finally, BIM cloud database in operation and maintenance stage can be constructed. Based on the database, we designed the data processing function of the platform system. In order to obtain the carbon emissions, after the energy consumption database is obtained, the BIM+ cloud computing technology is used to process the energy consumption data in the database according to the pre-set calculation formula of carbon emissions. The BIM cloud carbon emission database at the operation and maintenance stage is obtained by integrating carbon emission data.

Then, visualize the device situation. After loading the sensor and obtaining the BIM cloud carbon emission database at the operation and maintenance stage, we encountered the problem that the obtained database information could not be transmitted synchronously to the BIM collaborative management platform system. To this end, this paper uses Navicat database software and its built-in data synchronization function to synchronize the BIM cloud carbon emission database information to Navicat database and then build a link between Navicat and the cloud server where the BIM collaborative management platform resides. At this point, the platform can extract the carbon emissions of the monitoring targets stored in the Navicat database and present them simultaneously on the platform management interface.

The third technical difficulty is multi-user collaborative participation. BIM technology is used to import the BIM model of the building into the platform and back it up to the cloud. With this model as a node, multiple users can be linked so that they can view the BIM model at the same time, and different projects, work details, and corresponding data can also appear in the platform interface. After the modification and saving of the corresponding data, the modification record is synchronized to the platform system interface of the decision-maker to realize the timely update of the data. After solving the above four technical keys, the platform realizes the three basic functions of this BIM-based collaborative management platform. The overall framework of the platform is shown in Figure1.

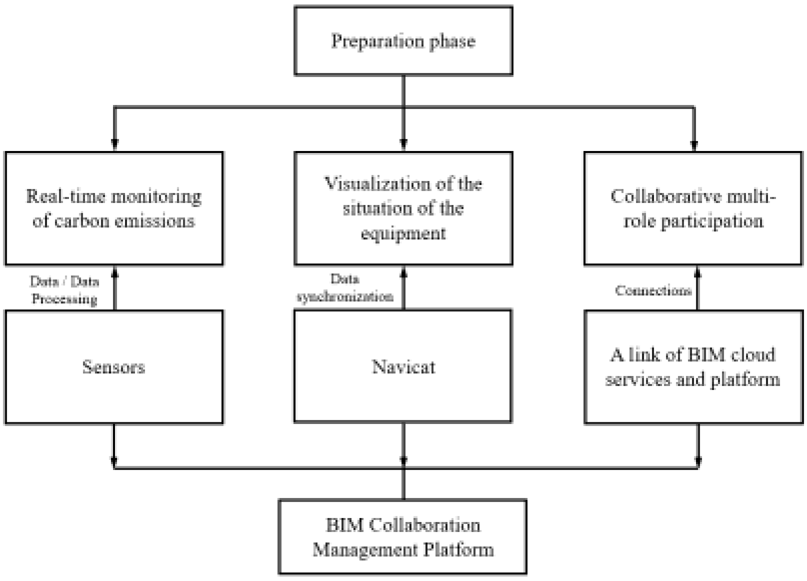

Figure 1: Research methodology.

Calculation Methods for Materialization and Operation and Maintenance Stage

Materialization stage

The calculation of carbon emissions in the production stage of materials refers to the calculation of carbon emissions produced by the mining production of raw materials and the transportation of building materials. Based on the basis of the consumption of all types of raw materials in the system analysis stage, the material consumption can be converted into carbon emissions through the emission coefficient method to obtain the total carbon emissions produced in each stage of the material production stage. After investigation and research, the indirect emission generated by the construction electricity and equipment electricity during the construction process is the largest emission source in the construction activities. Therefore, the electricity consumption during the materialized stage can be measured by the power carbon emission factor.

Table 3: Source of carbon emissions in the materialized stage.

The materialized stage	Carbon emissions sources
Material production stage	Carbon emission of raw materials and production of building materials
Construction stage	Carbon emissions from construction machinery operation during the construction period and carbon emissions from site processing of + materials

(1) Calculation model of carbon emission in the material production stage

The carbon emission calculation model (Eq. 1) in the material production stage is constructed as follows:

$$C = C_1 + C_2 \tag{1}$$

Type in: C: carbon emission in the building chemical stage;

C_1: Carbon emissions in the building materials mining and production stage;

C_2: Carbon emissions in the building materials transportation stage;

Carbon emission calculation formula (Eq. 2) is:

$$C_1 = \Sigma Qi \times Fi \times (1\text{-}s) \tag{2}$$

Type: C_1: Carbon emissions in the building materials mining and production stage;

Q_i: Type I building materials requirements for the cast-in-place project;

F_i: Type I th carbon emission factor of building materials;

s: The recovery coefficient of class i building materials.

For all kinds of building materials and equipment, the carbon emission factors of building materials have been given in the Building Carbon Emission Calculation Standard released by China in 2019.

The carbon emission calculation formula (Eq. 3) of the building materials transportation stage is:

$$C_2 = \Sigma\, Q_i \times L_i \times T_i \tag{3}$$

Type: C_2: Carbon emissions in the building materials transportation stage;

Q_i: Demand for type I building materials for cast-in-situ engineering;

L_i: Average transportation distance of type i building materials;

T_i: The carbon emission factor of transportation distance per unit weight for the transportation mode of type i building materials.

The acquisition method of demand for building materials in the formula is roughly the same as that of Q_i in the previous formula. It can be obtained through the purchase list and other materials, and the transportation distance of building materials can be obtained through the freight list and other materials. Carbon emission factors of various modes of transportation can be learned through consulting the Construction Carbon Emission Calculation Standards.

(2) The calculation of the carbon emission model in the construction stage
This model is proposed to adopt direct measurement, calculating the synchronous carbon emissions of various equipment during construction by directly monitoring the power consumption during construction. The synchronous monitoring model of carbon emission (Eq. 4) during the construction stage is constructed as follows:

$$P_d = E \times E_e \tag{4}$$

Type: E: power consumption (kw • h)
E_e: Electric Power Carbon Emission Factor (t /kw • h)

Power carbon emission factors can be obtained by consulting the construction carbon emission factor database (Song *et al.*, 2013).

Operation and maintenance stage
In the operation and maintenance stage, the carbon emission factor-based emission coefficient method is adopted as the carbon emission calculation method, and the basic principle can be expressed as "carbon emission = activity data × carbon emission factor." This system studies the carbon emissions in the process of construction operation and maintenance. The activity data used are mainly energy usage, and the carbon emission factors used are mainly energy carbon emission factors.

Table 4: Source of some energy carbon emission factor database.

International organizations	Data sources
Intergovernmental Panel on Climate Change (IPCC)	IPCC Guidelines for National Greenhouse Gas Inventories Emission Factors Database, EFDB
International Energy Agency (IEA)	CO_2 Emissions from Fuel Combustion database (International Energy Agency, 2013) IEA GHC CO_2 Emissions Database (Greenhouse Gas Protocol, n. d.)
World Resources Institute (WRI)	GHG Protocol Tool for Energy Consumption in China (Song & Yang, 2011)
Energy Information Administration, US Department of Energy (DOE/IEA)	Voluntary Reporting of Greenhouse Gases Program (Van der Heijden, 2018)

WORKFLOW DESIGN

In the materialization stage, in order to achieve the carbon emission measurement of the project, the construction quantity table needs to be exported. With the help of Bentley OpenBuilding Designer software, the construction quantity of the project at different time nodes can be exported in the form of Excel form according to the schedule of the project. Upload the quantities to the management platform, which can calculate the total carbon emissions of the project at this time node according to the embedded formula.

To upload the exported construction quantity data to the platform for analysis and calculation, Navicat database software is used in this project, and its built-in data synchronization function can synchronize the construction quantity data to the Navicat database. Navicat software is used to build a link with the cloud server where the carbon emission management platform is located, and the platform can extract the project quantity data stored in the Navicat database to calculate the carbon emission.

Using BIM+ cloud computing technology, the platform matches the data in the database with the corresponding computing model and processes it according to the pre-set carbon emission computing formula. Cloud computing technology can transfer the complex carbon emission computing work in BIM to the cloud to improve computing efficiency. With the help of the building collaborative management platform, the carbon emission data can be fed back to the users in real-time. And the interconnection between various terminal devices can be realized by using cloud computing technology. Users connect the cloud service via a computer or mobile to view the carbon emissions during the materialized phase. The materialized phase process is shown below in Figure 2.

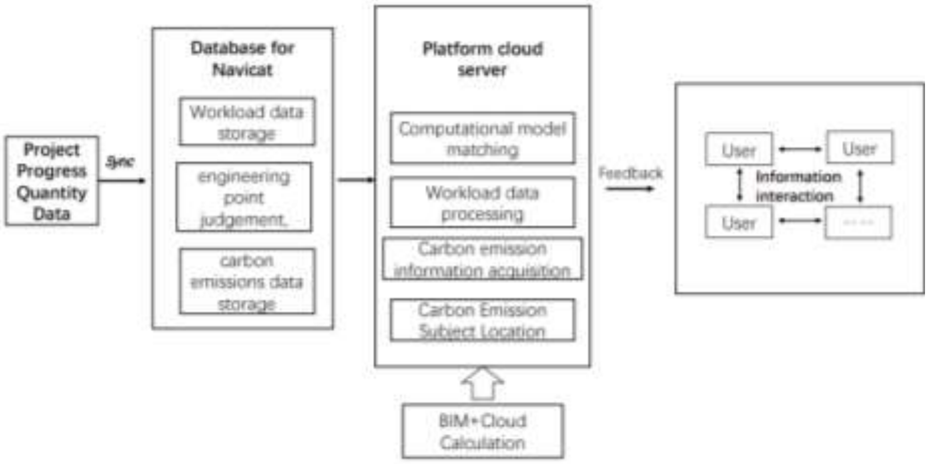

Figure 2: The process of the materialization stage.

As shown in Figure 3, in the operation and maintenance stage, remote control facilities and equipment such as infrared sensors, water flow sensors, and power sensors, and RADIO frequency identification devices are embedded in the monitoring target in advance. By relying on BIM+ Internet of Things technology, the power consumption and key operating parameters of the equipment are integrated into the building collaborative management platform, and data interconnection network and database are established. BIM+ cloud computing technology processes the energy consumption data in the database and feeds the carbon emission data to users in real-time through the platform interface, which can realize the interconnection between various terminal devices and facilitate users to view the carbon emission information of buildings in operation and maintenance stage. BIM +GIS technology is used to collect, store, manage, calculate, analyze, display, and describe geographic location distribution data in space, integrate geographic information into the platform, and combine with the spatial information in the model and the surrounding geographical environment, which clearly reflects the specific location of energy consumption equipment in the system. According to the *Energy Consumption Standard for Civil Buildings* issued by the Ministry of Housing and Construction in China, the platform can hold responsible persons of energy consumption equipment with excessive carbon emissions accountable in real-time. Based on this technology, the platform can accurately locate the machines with excessive carbon emissions, conduct a timely inspection, and analyze the equipment and its operation. The platform will then adopt the most energy-efficient way to control carbon emissions based on the carbon reduction database.

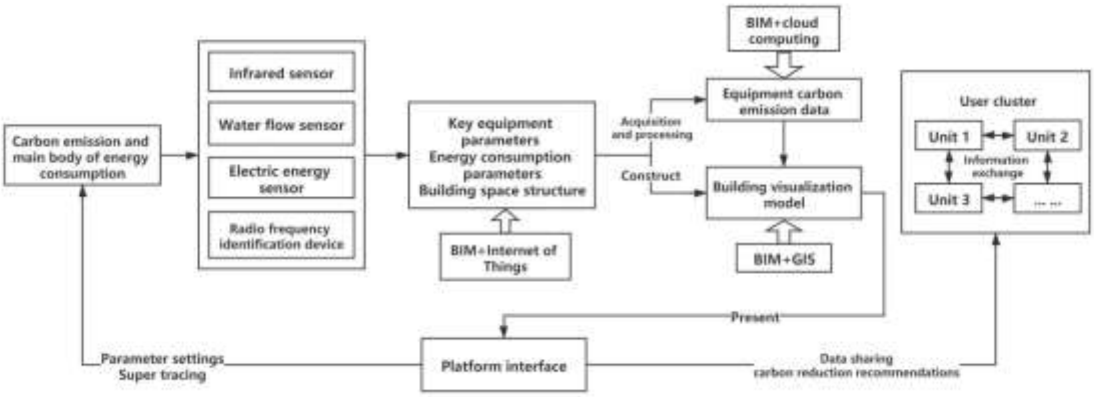

Figure 3: System operation process in the operation and maintenance stage.

The platform presents the corresponding content according to the user's permission. For non-management personnel in the building operation and maintenance stage, the interface only displays real-time building carbon emissions; for managers in the building operation and maintenance stage, the interface not only displays real-time carbon emissions of buildings but also positions equipment with excessive carbon emissions and energy consumption and provides relevant carbon reduction suggestions to control carbon emissions. In addition, the platform can undertake simple logical deduction and realize the simplification, intelligence, and humanization of operation and maintenance management. The framework chart of the platform is shown in Figure 4.

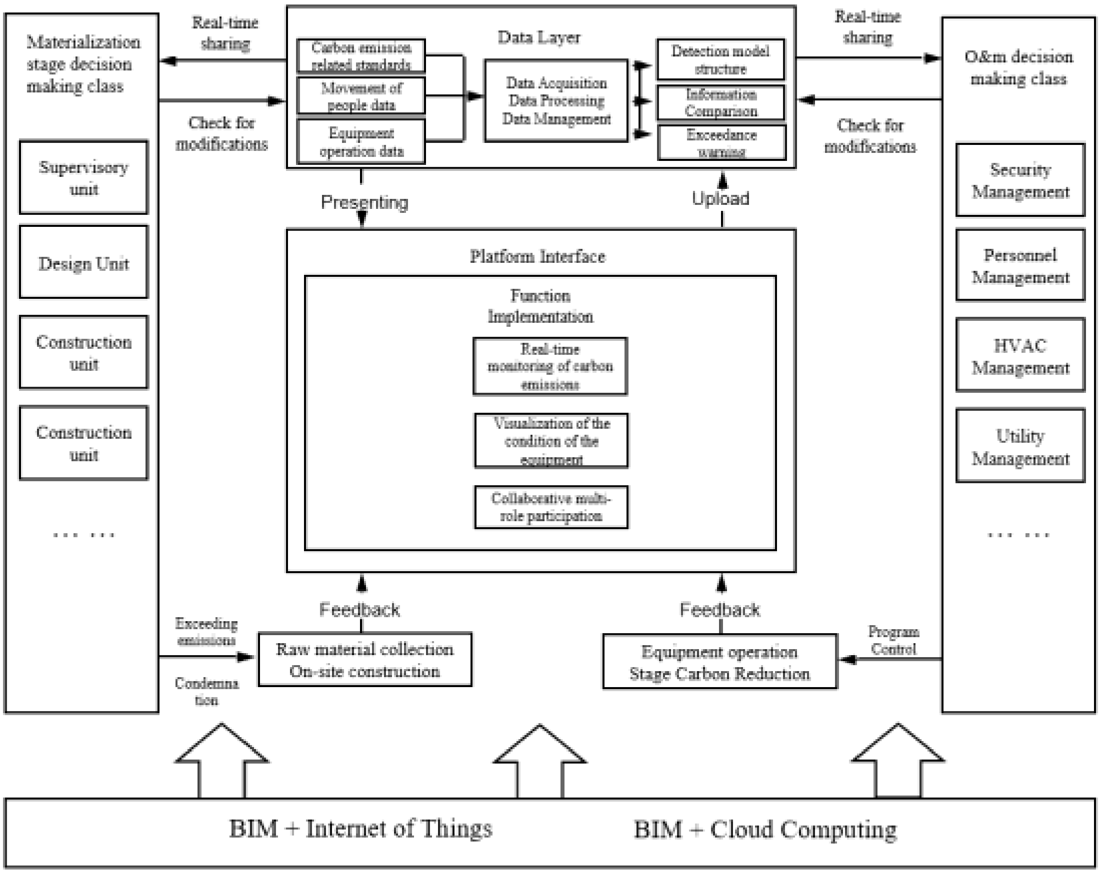

Figure 4: Platform framework.

FUNCTIONAL IMPLEMENTATION

First, multi-role collaborative participation. The BIM-based collaborative management platform shares internal data within the building, allowing departments to view it simultaneously. At the same time, the relevant data authority is authorized according to the professional and subordinate departments, and each professional department can only adjust or use part of the content, ensuring the coordination and management of each department and performing its own duties.

Secondly, real-time monitoring of carbon emissions. The front-end facility captures the carbon emission dynamic data in real-time and uploads it to the data layer at fixed points for processing. When the data is beyond the scope or becomes abnormal, activate the built-in alarm mechanism immediately to provide detailed alarm information and remind the responsible department. The platform regularly evaluates the construction safety and equipment safety during the operation and maintenance stage and carries out emergency management.

Thirdly, visualization of the existing facilities. The management center interface shows the internal spatial structure of the building and the real-time trend chart of carbon emissions of various departments. After the user layer makes the corresponding instructions to the application layer, the changes of the relevant equipment will also be immediately displayed on the interface. The data processing center supports the integration of the user's multiple instructions into a phase carbon reduction scheme and storage. When the user uses the scheme, the interface displays its past usage of it.

Fourthly, the intuitive embodiment of the BIM model. The platform is closely combined with the BIM model, viewing the content of the BIM model at any time when entering building information or performing other operations on this platform. Only need to enter the website of the platform server in the browser, enter the account, log into the building collaborative management platform, click the "building information" in the new project, the BIM model and data content can be seen. Among them, the platform subdirectory system is on the left, and the right is the data display and model operation interface. The operation interface is shown in Figure 5.

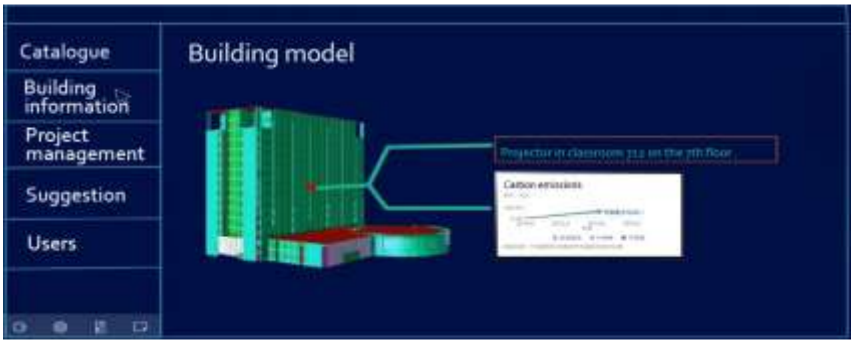

Figure 5: Operating interface diagram.

In addition, we find that the content and form of carbon emission data of public buildings have obvious dynamic characteristics. In order to better help users improve the efficiency of carbon emission reduction, it is necessary to adopt centralized management for dynamic data and configure relevant services centered on the data source (Ju & Chen, 2015). Therefore, in the operation and maintenance stage, the platform has established a carbon reduction measures database and extracted, integrated, and correlated the data sources according to the industry classification and external conditions so as to establish a carbon reduction measures retrieval directory according to the principle of source consistency (Shi *et al*., 2014). While ensuring the reliability of the information, it also meets the specific needs of different users under different conditions. Users can accurately search for carbon emission reduction measures according to corresponding external conditions and their own needs and realize information interaction with other users at the same time.

After sending the search command, the information is transmitted from the user layer to the data layer. The platform will automatically identify and transform the key data in the search command, form the search conditions, and locate it in the directory according to the conditions. Then, the retrieval results and corresponding carbon emission change values are exported from the Navicat database, and the two are combined into a data group for text display. It should be noted that the work experience and expert evaluation on carbon emission management in the construction operation and maintenance stage within three years will be included in the display results.

Users can view and select the search results. After the selection instruction is issued, the selected text is recognized, split, and reorganized by the data layer, and the application layer is contacted in the format of "equipment information + used power + running time period" to set one or more corresponding devices with one key. The above operations will be included in the carbon reduction measures library.

The processing rules of carbon emission data and carbon reduction operation data in the operation and maintenance stage are shown in Table 5 below.

Table 5: Data processing rules in the operation and maintenance stage.

Type	Data structure	Function
Search command	Retrieval time + user's unit + external conditions + carbon emission change value	Retrieving user commands
Search Results	Usage times + service time + historical operation + carbon emission of equipment + expert evaluation	Rendering search results
Application Commands	Number of devices + location of devices + Power of devices + Running time + Whether manual intervention can be performed	Managing device operation

PROJECT APPLICATION

The research of this project is applied to Boxue Buildings of Hohai University Jiangning Campus, which has one 15-story main building and one 5-story auxiliary building, with a total construction area of 37,544 square meters. The construction of the building structure started in 2008 and ended around July 2009. The civil works ended in December 2009 and were put into use after local decoration in 2010. The appearance of the Boxue Building is shown in Figure 6.

Figure 6: Full picture of Boxue Building.

BIM Modeling, Simulation, and Analysis

According to the BIM model of the main building and auxiliary building of Erudite Building, it is estimated that the average construction needs about 407 tons of concrete. According to the literature, for the same type of similar size buildings, the transport pump unit volume of concrete electricity consumption is 2.97 kWh/m^3. The average daily electricity consumption of the main structure construction stage is 68.4 kWh per day, and the average electricity consumption of the decoration construction stage is 44.3 kWh per day. According to the data, the average carbon dioxide emission factor of the Jiangsu Province power grid is 79,400 t/kWh. Carbon emission data can be estimated for the construction phase of Boxue Building.

Figure 7: Construction progress and BIM model simulation of the main building.

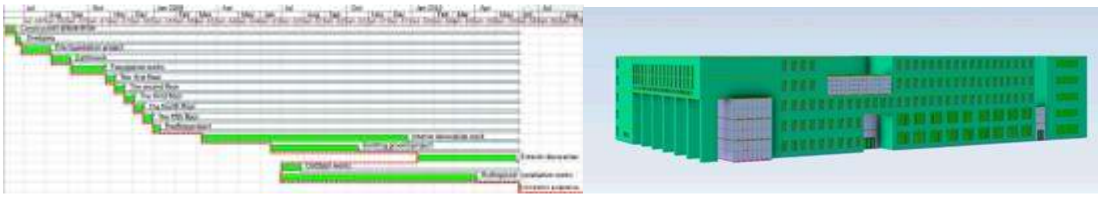

Figure 8: Construction progress and BIM model simulation of the auxiliary building.

In the example, the previous five floors conducted a detailed analysis. In order to achieve the estimation of the carbon emission in the materialized stage, only the amount of concrete and steel quantity derived in the current BIM model was studied, and the analogy method was adopted to calculate the power consumption data of the same type of construction devices of buildings with similar construction area.

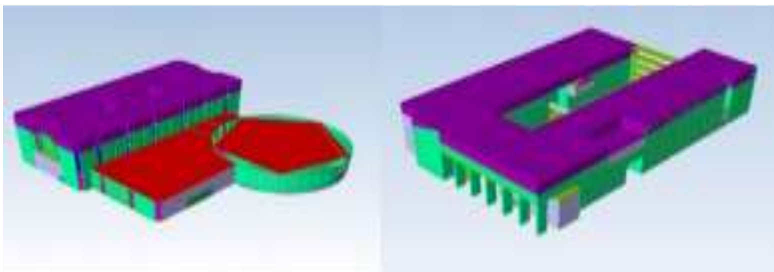

Figure 9: BIM construction progress simulation of Boxue building.

(Note: The left figure shows the construction of the main building on December 23, 2008. The right figure shows the construction progress of the auxiliary building on January 7, 2009.)

The construction quantity of Boxue Building is derived from Bentley software, and it can be concluded that 3376 m^3 of concrete and 501 tons of steel are used in the construction of the main building to the fifth floor. When the auxiliary building was built to the fifth floor, it used 9975 m^3 of concrete and 1482 tons of steel. Referring to the Building Carbon Emission Calculation Standard, the carbon emission factor of C30 concrete is 295kg/m^3, hot-rolled carbon steel reinforcement is 2340 kg/t. It can be calculated that during the material production phase, Boxue Building produced 2168.26 t CO_2 on the 5th floor of the main building and the auxiliary building produced 6410.505 t CO_2. For the construction stage, similar construction projects can reach the average daily power consumption of 68.4 kWh/day in the main construction stage, calculate the total electricity consumption of the main building and auxiliary building to the fifth floor is 8994.6 kWh. The power carbon emission factor in Jiangsu Province is 793 t/10000kWh. In conclusion, for Boxue Building, the total carbon emission in the construction phase is 8585.90 tons of carbon dioxide as calculated by carbon emission factor and analogy analysis.

Carbon Emission Analysis of the Project Operation and Maintenance Phase

System interface diagram in operation and maintenance phase

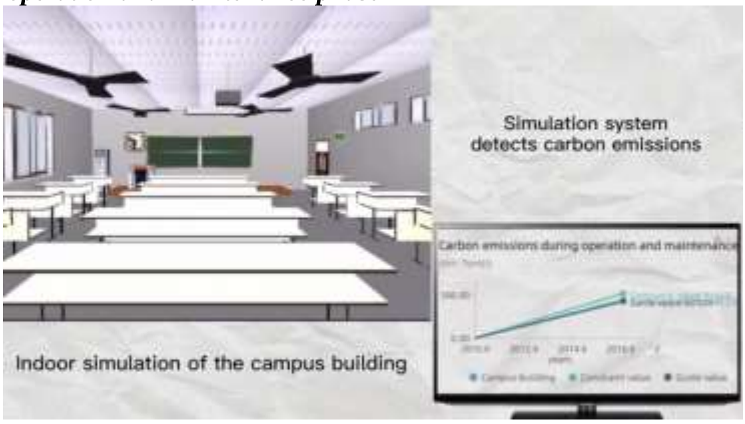

Figure 10: System display interface diagram in operation and maintenance stage.

The carbon emission data calculation in operation and maintenance stage

The constraint values and guide values in Table 6 refer to the relevant indicators of non-heating energy consumption of commercial office buildings in hot summer and cold winter areas in the Energy Consumption Standard for Civil Buildings. Erudite Building maintenance stage carbon emissions mainly come from HVAC, lighting, air conditioning, projection, and elevator equipment, the use of this equipment is directly related to the building personnel flow and climate change, equipment related energy consumption data from building collaborative management platform, through the platform internal automatic data acquisition, data processing, data accountability final feedback to the platform display page, for a cycle export the cumulative carbon emissions of the campus building, the maintenance stage carbon emissions database.

Table 6：Carbon emission calculation data during the campus construction operation and maintenance stage.

Cumulative carbon emissions (ton) / Time	Campus building	Constraints	Guide value	Note
2010.6	0	0	0	
2011.6	72.155	85	70	
2012.6	144.309	170	140	
2013.6	216.464	255	210	
2014.6	288.619	340	280	
2015 6	360.773	425	350	
2016.6	432.928	510	420	
2017.6	505.083	595	490	
2018.6	577.237	680	560	
2019.6	649.362	765	630	
2020.6	685.440	850	700	Due to COVID-19
2021.6	757.595	935	770	

CONCLUSIONS

Evaluating carbon emissions for public buildings during life-cycle stages is of great importance under the context of global carbon neutrality. With advanced information integration ability and 3D interactive visualizing function, the proposed method in this paper can improve the carbon emission calculation accuracy for existing buildings using its BIM model and real-time monitoring data. It can significantly reduce the cost of carbon footprint tracking and carbon emission data management, improve information accuracy and promote low-carbon buildings. The BIM-based carbon emission collaborative management platform proposed in this paper uses advanced information technology to provide a one-station solution for building owners and facility managers to have a better understanding about the carbon emission and provide evidence to make better solutions to achieve zero-carbon buildings.

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