Research of Low-carbon Campuses Development Based on BIM Technology under the "double carbon" strategy in China

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Abstract—China is vigorously advocating social and economic development transformation to green, sustainable, and low-carbon implementation after announcing the "double carbon" strategy. Universities have always had high energy consumption and carbon emission, and reduction of energy consumption can produce considerable economic and environmental benefits. In this paper, the importance of universities' participation in the low-carbon campus construction is clarified, and the strategies of domestic and foreign universities for green campuses and the practice of low carbon campuses are listed. The existing problems during the low-carbon campus development are summarized and the solutions based on BIM technology were proposed and practised. The use of BIM technology combined with other emerging technologies can realize carbon monitoring and emission statistics of a campus building or the whole campus, providing theoretical and practical support for the construction of a green campus, which applies to the goal of sustainable development.

Keywords- "double carbon" strategy; BIM technology; green campus; low-carbon

1. Introduction

In the global warming environment, it is critical for all the countries in the world to find ways to adapt to severe climate changes. Scientists estimate that limiting global warming to 1.5 degrees Celsius will reduce the chances of triggering climate change's most dangerous and irreversible effects. A 2020 report by the McKinsey Global Institute shows that the risk of natural disasters and nonlinear socioeconomic upheaval is rising as further warming is inevitable over the following decades [1]. Based on these theories, the source of causing global climate change is the significant emission of greenhouse gases such as carbon dioxide. Therefore, mitigating climate change from decarbonization is the central challenge part.

As a country with a large population, rapid economic development, and improving people's living standards, China's energy consumption has been increasing, and now it has become the world's largest carbon emitter [2]. In response to this, it is repeatedly stated by the government that China's carbon dioxide emissions strive to peak by 2030 and strive to achieve carbon neutrality by 2060 [3][4]. This concept of the "double carbon" strategy means that China's carbon

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dioxide emissions will no longer increase by 2030 and will gradually decrease after reaching the peak. Carbon neutrality is offsetting the total greenhouse gas emissions produced directly or indirectly by enterprises, groups, or individuals within a certain period through plantation and reforestation, energy conservation, and emission reduction to achieve "zero emission" of carbon dioxide [3].

Colleges not only assume the function of education but also have social responsibilities and obligations. It is reported that there were 3,012 higher education schools in China in 2021, and the full scale of all forms of higher education enrolment reached 44.3 million [5]. The volume of the college campus is enormous, calculated on acres. Furthermore, some universities possibly include several different school campuses with various study and research facilities providing living facilities such as dormitories and cafeterias, which are densely populated and have substantial social energy consumption [6]. Data indicate that the energy consumption of colleges in China accounts for 10% of the total energy consumption of society, and the per capita energy consumption of university students is four times that of the per capita energy consumption of residents [7]. Consequently, the development and construction of a low-carbon college campus are imperative.

2. Low-carbon Campuses Development

In 2019, China's Ministry of Housing and Urban-Rural Development released the "Green Campus Evaluation Standards" marking the promotion of the construction work of conservation-oriented campuses. In 2020, the General Office from the Ministry of Education and the National Development and Reform Commission jointly issued the "Action Plan for the Creation of Green Schools", which requires practicing the concept of green development in depth and establishing a long-term mechanism for ecological civilization education. The releases of all these policies imply that the low-carbon, green campus construction and development are closely related to the national development strategy.

2.1. Low-carbon Campus Development of Foreign Universities

The awareness and action of low carbon campuses, carbon neutral, and sustainable development started earlier in foreign universities. In 1900, "The Talloires Declaration" was signed by the presidents of 22 universities, who pledged to take positive actions in 10 areas, including enhancing awareness of environmental sustainability and promoting campus ecology. The declaration focuses on exploring sustainable campus construction practices, reducing campus carbon emissions, and building a low-carbon, zero-carbon campus through multiple ways, such as green building design, low-carbon facilities, green energy, and setting carbon reduction target policies [2][8]. In 2006, Second Nature, a US NGO, promoted 12 universities to sign the American College and University Presidents' Climate Commitment (ACUPCC) to achieve "climate neutrality" in college operations, integrating climate change and sustainable development into their operations. In 2007, ACUPCC expanded to include 336 colleges, and in 2015, they established the Presidents' Climate Leadership Commitments (PCLC). It aims to address climate change and sustainability in colleges and universities, including greenhouse gas emissions reductions, direct emissions (e.g., electricity, heating, cooling, and vehicle emissions), and indirect emissions. It also focuses on climate adaptation and community construction [8].

In 2009, the UK government published a White Paper on Low-Carbon Transition Development Plan, which set out the national emissions reduction targets. In 2010, the Higher Education Funding Council for England (HEFCE), the Universities UK (UUK), and the GuideHE consortium all responded to this target by requiring all UK universities set carbon reduction targets. HEFCE requires universities to reduce their carbon emissions by 34% of their 2005 baseline by 2020 and 80% by 2050. All major UK universities have published Carbon Management Plan (CMP) [8]. In recent years, more and more countries and universities have responded to them, and have also upgraded their CAP to Carbon Neutrality Plan, which specifies the time plan and pathway. The University of Melbourne's Advancing Melbourne 2030 demonstrates their partnering in the future of Melbourne and deal with the critical challenges of worldwide sustainability on carbon neutrality [9].

2.2. Low-carbon Campus Development in China

As early as 1998, the president of Tsinghua University made a speech about building a "green university", and proposed the idea of "green campus" demonstration projects [10]. In 2011, Tongji University, Zhejiang University, South China University of Technology, China Architecture Design and Research Group, and ten other units in China jointly established the "China Green University Network (CGUN)". Since then, China Green Campus Design Alliance and China Green Campus Association Alliance have been founded and played an essential leading role in the green sustainable development of Chinese universities [6].In 2013, the Ministry of Education issued the "Notice on Running Education Diligently and Building Thrifty Campuses", which carries out the construction of thrifty campuses in six aspects and requires paying attention to discovering and summarizing advanced experiences [4]. During the 13th Five-Year Plan, China proposed the "National Environmental Publicity and Education Action Plan (2016-2020)", which suggests promoting environmental education in colleges and universities, incorporating environmental education into teaching plans as a vital element of quality education for college students, and organize the creation of green universities [6]. After the "double carbon" target was proposed, Chinese universities responded positively, for instance, Tsinghua University established the "Global Alliance of Universities on Climate" consisting of 12 universities from 9 countries; Peking University and Sichuan University set up carbon-neutral research institutes; Tongji University held the "3060 Double Carbon Target and Path for Higher Education Campus" forum and over 44 universities signed the "Declaration on Carbon Neutral Action for China's Higher Education Campuses" [8]. More and more campus implements low-carbon environmental protection strategies and puts them into practice. For instance, in the East Campus of the Renmin University of China's master plan, the water system is designed as "zero net water", which means the required water resources are collected from rain and snow water or used lakes, streams, and rivers as functional water bodies, building an efficient landscape water circulation system; promoting the use of green technology equipment and facilities; creating a green culture on campus; establishing a sense of conservation and practicing low-carbon life [7].

3. Existing Problems about the Low-carbon Campus Development and Corresponding Solutions

3.1. Existing Problems with the Low-carbon Campus Development

There are many areas for improvement in allocating and managing internal resources in colleges and universities during low-carbon campus construction. For instance, the low-carbon consciousness of college students and teachers is still weak, wastefulness on campus is serious, and high energy consumption buildings are spread all over the campus. Data shows that the energy consumption of college buildings accounts for 83.2% of the total energy consumption of colleges [7]. Some of the universities have a long history, and the existing campus construction is far from reaching the green campus standard due to the limits of the original environment, materials, and other conditions. Although nearly 300 colleges and universities participated in the national demonstrations of conservation campuses in China, most universities stayed at the level of implementing the projects easier to achieve (such as lighting system renovation). Therefore, there needs to be scientific and reasonable planning to promote the long-term goals of low-carbon campus development to be achieved.

From the technology perspective, it is crucial to use scientific tools to design, monitor and maintain the campus facilities to reach the low carbon target. Researchers around the world make great efforts to develop design tools, build numerical models, and put their designs into practice. However, different tools have their own advantages and disadvantages, and there still needs to be a consistent opinion about the most suitable one.

3.2. Solutions based on BIM Technology

For campus construction, planning comes first. According to the report "Buildings and Climate Change" published by United Nations Environment Programme (UNEP) in 2009, energy consumption in the building sector accounts for 40% of global energy consumption and 1/3 of global greenhouse gas emissions. The energy consumption per unit of public buildings is 5-15 times higher than residential buildings [11]. The whole life cycle of buildings is divided into four stages: decision planning, design, construction, and operation [12]. Previously, the attention focused more on the construction stage. However, studies have shown that carbon emissions from the production of building materials and the use of facilities account for 90% of the total carbon emissions from buildings, with the operational phase emitting twice as much carbon as during production [13][14]. Usually, the life of buildings is 50-100 years, while some university campus buildings span longer. Consequently, the carbon emissions during the use process of buildings, i.e., the operation and maintenance stage, deserve more attention.

As stated above, colleges and universities need to transform into low-carbon and green campuses to become pioneers and leaders in addressing climate change in China and globally. Building Information Modelling (BIM) technology can help us reach that goal. In recent years, either the construction industry or the government has vigorously promoted the use of BIM technology applied in the whole life cycle of buildings, which has the advantage of using digital models to support collaborative workflows for virtual design and construction and can streamline project delivery workflows and improve building performance with features such as visualization and collaborative creation. BIM-based energy efficiency analysis can help design teams check and create optimized energy efficiency and predict the building's use process, thus

minimizing its environmental impact throughout its life cycle and facilitating energy conservation and emission reduction in campus construction [14]. BIM technology can be used to carry out building energy analysis, ventilation analysis, lighting analysis, sound environment analysis, thermal environment analysis, and systematic design optimization to achieve green building standards [15].

For instance, lighting, heating, and cooling are inseparable from electrical equipment. Thus, electricity occupies high energy consumption on campus. If the building envelope has good lighting and shading functions, that can significantly reduce the frequency of air conditioning and higher or lower temperature settings. Additionally, BIM technology allows the radiation of sunlight in the area to be effectively simulated. According to the environmental analysis of the sun, designers can optimize the use of solar energy in the design stage, effectively design the installation position and angle of solar energy equipment, which can reach the maximum benefit and storage of solar energy and replace natural gas and other energy sources with solar energy as a renewable energy source, thus achieving the goal of saving resources. Meanwhile, indoor lighting can also reasonably design with BIM technology to maximize the use of sunlight instead of artificial lighting and reduce electricity consumption. With the help of BIM technology, designers can calculate the energy consumption of the building according to the environment in which the building locates and adjust the design scheme by comparing and analyzing the lighting and heating conditions under different layout designs of the building to determine the system with lower energy consumption for low-carbon campus construction [16].

The life cycle of building materials is divided into four stages: production, transportation, operation, and recycling. The carbon dioxide emitted by materials in the operation stage accounts for the most, and the recycling phase accounts for nearly 15% [14], thus, the longevity of green building materials is preferred for sustainability. For example, inputting carbon emission factor, material service life, quotation, and construction volume into BIM software, can provide a comprehensive analysis and consideration for decision-making (Table 1).

Table 1. Test in the Design phase.

Construction phase	Building materials	Integrated carbon (CO_2) emission factor Ci/(kg/unit)[a]	Longevity, year[b]	BIM technology	Suggestions
Wall	Hollow brick wall, block wall	434.713	50	test in Virtual construction; use Autodesk Revit energy analysis	√
	Aerated concrete block wall	319.18	35		
Roof waterproofing	Roof coating waterproofing	2.753	10	test in Virtual construction; use Autodesk Revit energy analysis	
	Roof membrane waterproofing	1.49	20		√

[a] The Integrated carbon (CO_2) emission factor Ci/(kg/unit) calculated from the formula:

$$Ci = [\sum pC_{per} + \sum qC_{mat} (1 - \mu) + \sum rC_{mach}] (1 + \eta)$$

Ci is the integrated carbon emission factor of a sub-project; p, q, r are the quantity of labor, material, and machinery in each type of unit project; C_{per}, C_{mat}, C_{mach} are the carbon emission factors respectively; μis the material recycling rate; η is the maintenance rate of building components [13].

[b] Material longevity calculates in year [14].

BIM technology has the potential to combine with other digital technologies, such as IoT and GIS, to build out different integrated operation and maintenance management platforms, which can play the role of real-time guidance and monitoring for spatial management, asset management, and emergency management of the campus and boost the construction of a sustainable green campus [11][12].

4. Case Study: Application of BIM in the Low- carbon Campus Development

Taking a typical college in China as an example (Fig 1), we use BIM technology, coupled with the Internet of Things and digitalization, to build a low-carbon campus construction scheme in operation phase.

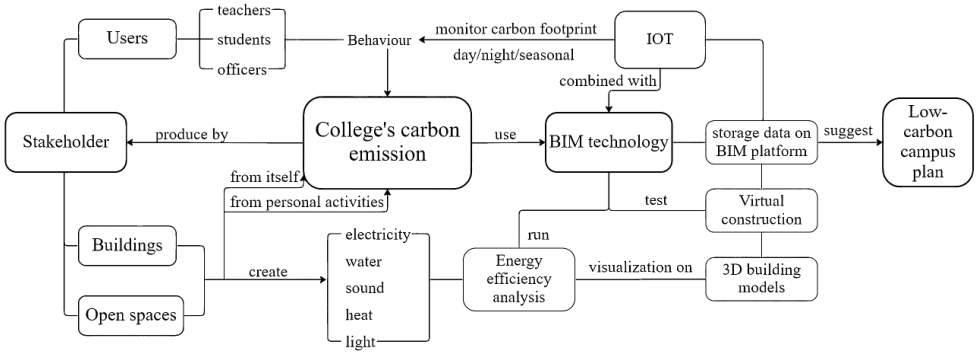

Fig 1. Case Study: the workflow of analysis

1) Using BIM technology to build a three-dimensional model of the campus buildings to visualize its situation.

2) Analysing the energy consumption of the buildings on campus and their corresponding carbon dioxide emissions and proposing improvement measures, such as design renovation on buildings, sustainable development education for the stakeholders, and other plannings.

3) For carbon emission and carbon footprint tracking and monitoring, using real-time monitoring data, establishing digital models, and analyzing the carbon emissions of the campus in different time zones (day/night/seasonal), for example, electricity consumption, water consumption, sound, heat and light, and personnel activities of a particular campus building,

then visualizing the results with “Green Campus Evaluation Standards”for comparison and suggestions (Table 2).

Table 2. Use BIM technology in the Operation phase.

Reduction on	Analysis by	Implementation	Benefit	Points[a]
electricity	Autodesk Revit Energy Analysis/ Ecotect Analysis/ GBSWARE BESI2020/ IOT：CCTV monitor system	reduce use of manual lighting equipment and replacement of energy-efficient lighting equipment	the proportion of electricity provided by renewable resource ≥2%. the reduction rate of energy consumption per student on campus per academic year 4.58%	10
		add solar photovoltaic power generation system on the roof		
		add remote control switches for high floors		
water	Autodesk Revit Energy Analysis/ Ecotect Analysis/ GBSWARE BESI2020	landscape water maintenance, campus rainwater collection and reuse	all rainwater on campus is collected and reused and the utilization rate of recycled water reaches 3%; the proportion of use renewable resource ≥25%;	18
		use solar power for hot water production		
sound	Autodesk Revit Energy Analysis/ Ecotect Analysis/ GBSWARE SEDU2018	replace old wooden doors in the lecture room	reduce the indoor noise level and promote sound insulation performance of the enclosure structure	12
		add greenery around the No. 10 teaching building to reduce the noise near the street		
heat and lighting	Autodesk Revit Energy Analysis/ Ecotect Analysis/ GBSWARE Dali 2018/ Weather tool	remote control of ventilation and heating system switches	energy efficiency optimization of heating and air conditioning system; ensure that the lighting factor is greater than 80% in building rooms	8
		add and change high quality curtains and other enclosure measures		
		arrange the location of seats in the classroom and office for better sunlight		
personal activities	Autodesk Revit Energy Analysis/ Ecotect Analysis/ IOT：energy consumption monitor system	plan for waste classification, ensure timely waste removal and set a waste recycling rate of more than 95%	establishment of green campus operation and management organization and set standards.	12
		develop green campus planning in the student handbook		

		printing monitoring system counts the amount of paper used and notices users	strengthen sustainable development education efforts. establish a campus energy consumption monitoring platform for permanent use and adjust energy-saving and emission-reduction strategies promptly	
		publicize energy consumption in departments and departments seasonally		

[a] Points on "Green Campus Evaluation Standards [17]".

5. Conclusion

Students' enrolment volume is massive in colleges and universities, and the social use of energy is enormous. Although many colleges and universities have set sustainable development targets positively, merely a tiny amount of them have made actual progress, and even fewer of them to develop fundamental construction programs that ensure low-carbon campus realization. The construction of low-carbon campuses in colleges and universities needs all to participate. In this paper, solutions based on BIM technology were proposed. It is suitable for the new campus planning and the renovation of old regions, to test changes in virtual construction and calculate materials in advance to select the optimal construction plan. It also analyzes the energy consumption of campus buildings in the operation phase to customize the carbon emission reduction plan. Coupling the BIM technology with the IoT and digital visualization technology, we can monitor the campus's real-time carbon footprint and visually analyze campus buildings' energy consumption and then timely put forward proper evaluation and corresponding improvement measures to reach the green campus.

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