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ENVIRONMENTAL BENEFITS OF GREEN BUILDINGS WITH BIM TECHNOLOGY

Abstract: Under accelerated urbanisation and rapid social and economic development, environmental pollution has become an important content of the construction industry. Therefore, the environmental benefit analysis of green buildings is of great significance to the effective use of energy and resources and to achieve the goal of protecting resources, reducing pollution and improving the ecological environment. The results show that the measured results of incremental environmental costs of the office building in Taiyuan City in land saving, energy saving, water saving, material saving, indoor environmental quality and operation management are decreased by 13.56 %, 11.02 %, 25.17 %, 14.43 %, and 15.25 %, respectively; incremental environmental benefits in land saving, energy saving, water saving, material saving, indoor environmental quality and operation management are increased by 23.15 %, 10.37 %, 19.30 %, 18.25 %, and 22.53 %, respectively. Those suggest that the BIM technology applied to the complete life cycle cost analysis of green buildings can test, measure and guide all the steps of building design, construction and maintenance and largely meet the criteria of resource-saving and energy-saving. The results of this paper provide a reference for further research on the environmental benefit analysis of green buildings based on BIM technology.

Keywords: green buildings, environmental benefit analysis, building information modelling, environmental protection

Introduction

Under accelerated urbanisation and rapid social and economic development, environmental pollution has become essential to the construction industry's work. The traditional construction industry faces development problems, such as high emissions, high consumption, difficulty in recycling, and low efficiency. This extensive development model has a significant impact on the development of the construction economy. Construction economic benefits are difficult to get real improvement [1]. The concept of green buildings requires the full use of resources in the construction process, focusing on environmental factors, and ensuring ecological balance, so that the natural environment, human beings and buildings between the formation of harmonious coexistence and sustainable development. Therefore, the environmental benefit analysis of green buildings is essential for effectively using energy and resources and achieving the goal of protecting resources, reducing pollution and improving the ecological environment [2]. The environmental benefits of green buildings can generally be optimised from indoor and outdoor environments. Indoor optimisation can be done by eliminating indoor pollution, while the outdoor environment can be optimised by reducing the production of pollutants

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and greenhouse gas emissions. The five aspects of the environmental benefits of green buildings, environmental benefits of green buildings mainly include five aspects, respectively energy-saving benefits, water-saving benefits, land-saving benefits, material-saving benefits and indoor environmental improvement benefits [3]. Therefore, the green building environmental efficiency analysis system contains seven major indicators: land saving and outdoor environment, energy saving and energy saving and energy saving and water saving and water resource utilisation, material and material resources utilisation, indoor environmental quality, construction management and operation management [4].

Building Information Model (BIM) is a multi-dimensional model information integration technology based on computer-aid design technology and other information technology, which can transmit information such as the three-dimensional geometry of buildings, the materials of building components, the price and the progress of construction of the project through digital information simulation [5]. The generation of BIM technology has changed the traditional calculation method, which simulates the reality of building carbon emissions at various stages through numerical information, which is conducive to understanding the effectiveness of green technology used in all stages of construction and provides technical support for setting the benchmark for green buildings [6]. By linking BIM to sustainability analysis, BIM technology can more effectively assess environmental impacts throughout the life cycle of a building or infrastructure. Typical project life cycle phases include planning and design, construction, commissioning, operation and maintenance, refurbishment and demolition. The BIM technology provides a decision support foundation for assessing critical sources of carbon emissions throughout the life cycle of buildings and exploring more environmentally sustainable measures to improve the building environment [7]. Applying BIM technology to construction is conducive to further promoting the realisation of green buildings, effectively controlling energy consumption, alleviating environmental pollution in construction, and effectively improving environmental efficiency. Applying BIM technology to the design phase of green buildings can effectively improve the scientific, efficient and rational design. Applying BIM technology to the construction phase of green buildings can control wastewater discharge and noise pollution, which is conducive to unifying green buildings' economic and environmental benefits [8].

Methods and materials

This paper takes an office building in Taiyuan City, Shanxi Province, Central China, as a study object and uses BIM technology to investigate the environmental benefits of green buildings. The project covers an area of 350,000 m^2, with a total construction area of 267,300 m^2, a volume ratio of 0.58 and a greening rate of 33.7 %. This study takes its 28th building to carry out energy consumption simulation; the total land area of this building is 9,800 m^2, and the total construction area is 9,850.64 m^2 with 9,416.34 m^2 above ground, 434.30 m^2 underground, and 20.40 m height. Five floors above ground, one floor beneath, concrete frame structure, one to five floors for shops, offices, conference rooms, innovative workshops, and the ground floor for the garage. The project uses regional hot and cold sources, and the host uses three ground source heat pump units and three cold typhoon inverter multi-online units. The power consumption ratio of the hot water circulation pump of the central heating system is 0.01050; the ratio of the circulating water supply and the cooling ratio of the circulating water pump of the air-conditioning hot and cold water system is 0.100100; the air-conditioning system fan unit air consumption power is 0.20; and the new wind system fan unit air consumption power is 0.21. The transition season makes full use of self-heating resources to reduce energy consumption, effectively ensure the air conditioning effect, and significantly improve the air conditioning area's air quality. The new air inlet and its access are configured according to the new wind, and the new duct of the air treatment unit is equipped with a regulator valve.

There are two essential points to the entire life cycle cost of a construction product: first, it refers to the sum of all the costs of the whole life cycle consumed by the construction product and directly related to the construction product; second, the calculation of the full life cycle cost takes into account the value of the fund time, i.e. the annual value of the cost or the present value of all expenses incurred during the life cycle. The standardisation of raw data is sometimes also standardised as raw data, the role of which is to reduce all the original data according to the corresponding proportion [9]. According to the corresponding proportion, all the indicator data can be reduced to a fixed interval so that different units and scales can bind the original data. Different units of values have a comparable. The incremental cost of the environmental benefits of green buildings refers to the increase in cost caused by increasing a particular output under the technical and production conditions of the BIM. Incremental costs are defined in practice: as full-service incremental costs and full-factor incremental costs. Full-business incremental cost refers to the increased cost of a business class, which is generally used with an appropriate bonus since it does not include expected costs. Complete element incremental cost refers to allocating the increased cost and part of the standard cost of a particular element. An appropriate bonus is needed to compensate for the remaining standard cost.

In the construction phase, BIM technology is essential for the visualisation and intelligent management after the construction project is completed. The BIM technology allows project participants to extract and track relevant, valuable data, such as component conditions, specification modules, maintenance and operation guides, and warranty calibration. Therefore, BIM technology can enable it to participate in the design of the whole life cycle of the construction project. The construction project can achieve reasonable real-time control at all stages, including the construction project design, by the management personnel through the building information management platform [10]. Operational activities throughout the life cycle allow project participants to extract construction data information and visualise their projects' progress throughout the project's life cycle. At the same time, the application of building information model technology can integrate the various areas of expertise of the model into a building model during the design phase. Setting the corresponding detection rules in BIM technology can carry out the corresponding collision verification, export detailed inspection reports, and efficiently find the components and position of the collision pipe and line frame. The collision verification can find the probability point of the pipe intersection and the appropriate height of the air conditioning pipe, avoid unnecessary errors before construction, save human and material resources, significantly improve the control accuracy of collision verification, and improve the modification and changes that may occur in the construction project process.

A series of environmental impact category reports can be formed through the green building life cycle assessment, resulting in the value of the building's environmental impact under different schemes. Because the green technology adopted at different stages is different, it is necessary to correct it by setting its parameters, comparing and analysing the carbon emissions of projects under different schemes, and finally proposing effective emission reduction measures [11]. Carbon emissions from construction waste's demolition and recycling phases are mainly divided into carbon emissions from the demolition phase and carbon emissions from the recovery and treatment phases. This phase focuses on green technologies such as recycling and using them to make new building materials to reduce carbon emissions. The carbon emissions in the demolition phase mainly come from the energy use of the operation of the construction equipment on site, and the carbon emissions from the construction waste treatment phase mainly come from the energy use of the on-site recycling equipment and transportation equipment.

Analysis of results

Based on the five aspects of the environmental benefits of green buildings based on BIM technology, the environmental benefits of green buildings mainly include five aspects: energy-saving, water-saving, land-saving, material conservation, and indoor environmental improvement benefits. Conservation of building materials for green buildings, including selecting materials according to local conditions, purchasing prefabricated concrete, using recycling technology for building waste, and using renewable building materials [12]. The model reduces the environmental pollution and material loss caused by building materials in the long-distance transportation process, and green buildings can also use green renewable materials, recycled building materials, such as bubble board technology, renewable insulation board technology in order to reduce waste and improve the efficiency of building materials. The greening rates of light, noise, wind, thermal and air environment of the green office building in Taiyuan City are 0.104, 0.496, 0.405, 0.148 and 0.486, respectively, which are parallel to that of carbon emission factors which are 0.539, 0.591, 0.372, 0443 and 0.216, respectively (Table 1). The green building based on BIM technology can optimise the indoor construction layout to achieve local sound insulation in the room, reduce noise interference, and improve the acoustic environment. Secondly, the green building in the construction process, or through the sound insulation material, the construction of its room peripheral protection structure, to achieve the purpose of sound insulation through the enclosure structure.

Greening rate is typically estimated by calculating the percentage of an area that is covered by vegetation, such as trees, shrubs, and grass. This can be done using satellite imagery, aerial photography, or on-the-ground surveys. The formula for calculating greening rate is: (total area covered by vegetation / total area) · 100 %.

Table 1

Analytical results of environmental indicators for building elements of the office building in Taiyuan City, Shanxi Province

Building elements	**Advantage weight [-]**	**Greening rate [-]**	**Power consumption [kWh]**	**Carbon emission factor [-]**	**Volume ratio [-]**
Light environment	0.231	0.104	0.324	0.539	0.473
Noise environment	0.474	0.496	0.417	0.591	0.279
Wind environment	0.237	0.405	0.362	0.372	0.208
Thermal environment	0.248	0.148	0.483	0.443	0.585
Air environment	0.564	0.486	0.384	0.216	0.262
System control	0.314	0.654	0.539	0.353	0.426
Performance maintenance	0.053	0.496	0.215	0.403	0.220

Power consumption is usually measured in units of kilowatt-hours (kWh) or megawatt-hours (MWh). The reason why it is often presented without a unit is because it may be used as a relative measure, such as when comparing the energy efficiency of different buildings or appliances. In such cases, the focus is on the ratio of power consumption before and after implementing energy-saving measures, rather than the absolute value of power consumption.

Suppose the BIM technology is combined with green buildings. In that case, designers can choose more natural energy-saving and environmental protection materials according to the structure. Construction personnel can also control the proportion of materials used scientifically during construction, thus effectively reducing the problem of environmental pollution and waste of resources and genuinely realising green buildings' environmental, economic and social benefits [13]. Comprehensive analysis in energy conservation is to obtain more energy-saving benefits; in the use of the whole life cycle process, the need for scientific and reasonable evaluation is to find out the key technology from the perspective of environmental value. In order to choose an optimal technology solution, the model needs to improve the green building project key technology evaluation level [14]. The BIM technology needs to be analysed from the dynamic protection of green technology and considered from the perspective of energy-saving expenditure in the whole life cycle of green key technology to improve the level of green technology and promote the environmental benefits of green buildings. The increase of green building technology needs to work from the internal rate of return perspective by studying the difference in net cash flow each year. The specific implementation process needs to evaluate the environmental and environmental benefits and improve the level of green building life technology research. In the process of green building environment implementation, it is necessary to realise the cost value, analyse the ecological benefits, evaluate the resources consumed, and promote the continuous development of the green building industry from the perspective of sustainable development.

The difference between green buildings based on BIM technology and traditional buildings is that green buildings use environmentally friendly materials, thus effectively avoiding adverse environmental impacts on buildings. The environmental impact of buildings is mainly reflected in two aspects: the indoor and outdoor environment. The effect of greenhouse gases on the indoor environment is mainly reflected in the pollution of materials, including building, decoration, and furniture materials. Compared with traditional buildings, green buildings have the benefit of resource conservation, which is reflected in saving land resources, water resources, materials and energy. The greening rates in the planning, design, construction, debugging, operation, maintenance and renovation stages of the green office building in Taiyuan City are 0.263, 0.597, 0.143, 0.283, 0.414, 0.302 and 0.632, respectively, which are parallel to that of carbon emission factor which are 0.473, 0.696, 0.765, 0.071, 0.245, 0.212 and 0.347, respectively (Table 2). Building green buildings based on BIM technology realises the rational use of land resources. To protect land resources, designers should use industrial waste such as slag and fly ash and use as little or no clay brick as possible. In dismantling traditional buildings, the efficiency of recycling rebar and high-priced aluminium is high, so there is no proper recycling of other building materials. The advantage of green building is that all building materials can be developed and utilised to a certain extent, reducing the cost of cleaning up developers and ensuring the economic benefits of enterprises [15].

Table 2
Analytical results of environmental indicators for whole life cycle of the office building in Taiyuan City, Shanxi Province

Whole life cycle	**Advantage weight [-]**	**Greening rate [-]**	**Power consumption [kWh]**	**Carbon emission factor [-]**	**Volume ratio [-]**
Planning	0.373	0.263	0.203	0.473	0.475
Design	0.048	0.597	0.492	0.696	0.587
Construction	0.203	0.143	0.037	0.765	0.234
Debugging	0.173	0.283	0.278	0.071	0.196
Operation	0.384	0.414	0.386	0.245	0.446
Maintenance	0.232	0.302	0.121	0.212	0.139
Renovation	0.523	0.632	0.373	0.347	0.475

The environmental benefits of green buildings based on BIM technology are creating healthy, comfortable and safe indoor spaces for people and creating outdoor spaces that can be coordinated and harmonious with the surrounding ecological and social environment. The environmental benefits of green buildings can generally be optimised from indoor and outdoor environments. Indoor optimisation can be done by eliminating indoor pollution, while the outdoor environment can be optimised by reducing the production of pollutants and greenhouse gas emissions [16]. The influence of the enclosure structure of green buildings based on BIM technology on the energy consumption of a building is mainly reflected in the energy consumption of heating and cooling insulation. The incremental environmental benefits measurement of the energy-saving technology of green building enclosure structure should be measured from the two aspects of coal-saving environmental benefits in winter heating period and environmental benefits saving of summer air conditioning. Environmental costs are directly related, and indirect costs are associated with environmental impacts at all product life cycle stages. These include environmental costs of acquiring raw materials, manufacturing and processing environments, production environment costs, use, circulation and consumption processes, recycling environment costs, and environmental waste costs.

In green building design, many complex problems make obtaining scientific calculation results from traditional calculation methods challenging. BIM technology can easily and quickly obtain the ideal, standard-compliant coordination results. The use of the BIM technology first requires the builder to provide the building’s three-dimensional design, architectural effects, architectural design requirements, building floor plan and other particular information and then requires a third party to do an excellent job in advance lighting test to provide the correct analysis report [17]. The main contents of the report are to detail the relationship between the surrounding buildings and the design space, and the curtain wall document should provide a detailed description and analysis of the description of light pollution. Its format is converted from model to wind environment analysis software readable format. After a simple adjustment, it can simulate the wind environment and obtain results to judge the wind speed requirements of walking areas. If there is an inappropriate place, it can be adjusted appropriately to make the subsequent construction smooth. After all the data information obtained above into the BIM, and then by adjusting the analysis data into the format supported by the sun analysis program for simple adjustment, it is easy to simulate the sun to get the analysis report, which can not only prevent errors in the manual calculation but also effectively save a lot of unnecessary resources, to achieve the original intention of green building.

Analysis of the environmental benefits of green buildings based on BIM technology

By linking BIM to sustainability analysis, environmental impacts can be assessed more effectively throughout the life cycle of a building or infrastructure. Typical project life cycle phases include planning and design, construction, commissioning, operation and maintenance, refurbishment and demolition. Designers believe BIM has the potential to be applied at every stage to promote sustainable construction. On the other hand, this technology provides detailed physical and functional features of buildings that can be combined with various environmental modelling methods to achieve the overall design and evaluation of sustainable low-carbon buildings. The cost reduction rates of light, noise, wind, thermal and air environment of the green office building in Taiyuan City are 0.091, 0.367, 0.405, 0.144 and 0.264, respectively, which have a roughly negative relationship to that of benefit growth rates which are 0.635, 0.389, 0.606, 0223 and 0.385, respectively (Table 3). The technology provides a decision support base for assessing critical sources of carbon emissions throughout the life cycle of buildings and exploring more environmentally sustainable measures to improve the building environment, for example, using the BIM framework for concrete and operational carbon quantification and analysis. By combining the green building assessment program with BIM technology, designers can use its data to evaluate and obtain green building scores to facilitate the evaluation process [18]. Many countries are developing full integration and automation of green building assessments to enhance the use of BIM in green building certification. The model combines this technology and network map service technologies for site location and transportation analysis. Its use of BIM technology can help automate and optimise building sustainability assessments and greatly simplify the green building assessment process and certification.

Table 3

Analytical results of environmental benefits of the office building in Taiyuan City, Shanxi Province

Analytical elements	**Cost reduction rate [-]**	**Benefit growth rate [-]**	**Energy efficiency [-]**	**Resource utilisation rate [-]**
Light environment	0.091	0.635	0.295	0.546
Noise environment	0.367	0.398	0.686	0.274
Wind environment	0.144	0.606	0.168	0.574
Thermal environment	0.264	0.223	0.435	0.619
Air environment	0.335	0.385	0.384	0.843
System control	0.190	0.684	0.119	0.444
Performance maintenance	0.482	0.484	0.322	0.246

The design of green buildings based on BIM technology is mainly reflected in energy conservation, which fully uses solar energy for heating, reduces air conditioning and collective heating, and ultimately achieves energy conservation. Peripheral protection structure is the most important content of building energy-saving design. Peripheral protection structure energy-saving measures refer to the roof, exterior walls, doors and windows and other aspects to take adequate measures to insulation, such as by increasing the area of doors and windows to increase lighting and ventilation area, improve the material’s insulation and insulation and improve the closed doors and windows. Green buildings use renewable energy sources, usually solar and geothermal, and are the most accessible renewable energy sources. Intelligent technology energy saving is to air-conditioning units, new wind units, refrigeration units and lighting facilities to implement optimal control to maximise the reduction of building power consumption. As for building energy consumption, lighting is significant; indoor and outdoor lighting systems should consider energy-saving light sources, lamps and accessories. In order to save energy consumption, green buildings usually use efficient new energy-saving lamps, public areas of lighting using high-efficiency light sources, and high-efficiency lamps and delay or voice control switches while paying attention to natural lighting site energy-saving measures. The system should control the energy efficiency ratio of equipment and the transmission efficiency of the pipe network system. Buildings with centralised heating or air conditioning systems can install new wind systems to recycle energy and achieve relatively objective economic and environmental benefits [19, 20].

Conclusion

This paper takes an office building in Taiyuan City, Shanxi Province, Central China, as a study object and uses BIM technology to investigate the environmental benefits of green buildings. This study conducts the selection of an analytical index system, implements the construction of a systematic evaluation method, proposes a quantitative combined evaluation framework of the environmental benefits of green buildings, analyses the measurement of the incremental environmental cost, performs the measurement of incremental environmental benefits, and finally discusses the analysis of environmental benefits of green buildings based on BIM technology. The BIM technology provides a decision support base for assessing critical sources of carbon emissions throughout the life cycle of buildings and exploring more environmentally sustainable measures to improve the building environment, for example, using the BIM framework for concrete and operational carbon quantification and analysis. Environmental costs are directly related and indirect costs associated with environmental impacts at all stages of the product’s life cycle, including the acquisition of raw material environmental costs, manufacturing and processing environment costs, production environment costs, use, circulation and consumption process environmental costs, recycling environment costs, and environmental waste costs. The results show that the measured results of incremental environmental costs of the office building in Taiyuan City in land saving, energy saving, water saving, material saving, indoor environmental quality and operation management are decreased by 13.56 %, 11.02 %, 25.17 %, 14.43 %, and 15.25 %, respectively; incremental environmental benefits in land saving, energy saving, water saving, material saving, indoor environmental quality and operation management are increased by 23.15 %, 10.37 %, 19.30 %, 18.25 %, and 22.53 %, respectively. Those suggest that the BIM technology applied to the complete life cycle cost analysis of green buildings can test, measure and guide all the steps of building design, construction and maintenance and largely meet the criteria of resource-saving and energy-saving. The results of this paper provide a reference for further research on the environmental benefit analysis of green buildings based on BIM technology.

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References

[1] Nguyen TP, Nguyen VA, Pham DD, Do HQ. Intergrating building information modeling (BIM) and tools with green building certification system in designing and evaluating water efficiency of green building for sustainable buildings. IOP Conf Ser: Materials Sci Eng. 2021;1079(3):32063. DOI: 10.1088/1757-899X/1079/3/032063.

[2] Taiwo EM, Yahya KB, Haron Z. Utilisation of building information modelling for indoor environmental quality assessment - A review. IOP Conf Ser: Earth Environ Sci. 2019;220(1):12051. DOI: 10.1088/1755-1315/220/1/012051.

[3] Lu Y, Wu Z, Chang R, Li Y. Building Information Modeling (BIM) for green buildings: A critical review and future directions. Automat Constr. 2017;83:134-48. DOI: 10.1016/j.autcon.2017.08.024.

[4] Uddin MN, Wei HH, Chi HL, Ni M, Elumalai P. Building information modeling (BIM) incorporated green building analysis: An application of local construction materials and sustainable practice in the built environment. J Build Rehabil. 2021;6(1):1-25. DOI: 10.1007/s41024-021-00106-5.

[5] Jiménez-Roberto Y, Sebastián-Sarmiento J, Gómez-Cabrera A, Castillo GL. Analysis of the environmental sustainability of buildings using BIM (Building Information Modeling) methodology. Ing Compet. 2017;19(1):241-51. Available from: http://www.scielo.org.co/scielo.php?pid=S0123-30332017000100241&script=sci_arttext&tlng=en.

[6] Cedeño-Laurent JG, Williams A, MacNaughton P, Cao X, Eitland E, Spengler J, et al. Building evidence for health: Green buildings, current science, and future challenges. Annu Rev Public Health. 2018;(1):291-08. DOI: 10.1146/annurev-publhealth-031816-044420.

[7] Kauskale L, Geipele I, Zeltins N, Lecis I. Environmental and energy aspects of construction industry and green buildings. Latv J Phys Tech Sci. 2017;54(2):24-33. DOI: 10. 1515/lpts-2017-0010.

[8] Eisenstein W, Fuertes G, Kaam S, Seigel K, Arens E, Mozingo L. Climate co-benefits of green building standards: Water, waste and transportation. Build Res Inf. 2017;45(8):828-44. DOI: 10.1080/09613218.2016.1204519.

[9] Balaban O, de Oliveira JAP. Sustainable buildings for healthier cities: Assessing the co-benefits of green buildings in Japan. J Clean Prod. 2017;163:68-78. DOI: 10.1016/j.jclepro.2016.01.086.

[10] Lo CL. Environmental benefits of renewable building materials: A case study in Taiwan. Energy Buildings. 2017;140:236-44. DOI: 10.1016/j.enbuild.2017.02.010.

[11] Su Y, Wang L, Feng W, Zhou N, Wang L. Analysis of green building performance in cold coastal climates: An in-depth evaluation of green buildings in Dalian, China. Renew Sust Energy Rev. 2021;146:111149. DOI: 10.1016/j.rser.2021.111149.

[12] Wang B, Luo L, Wang F. Research on the incremental cost and benefit of green building based on the whole life cycle. IOP Conf Ser: Earth Environ Sci. 2015;580(1):12015. DOI: 10.1088/1755-1315/580/1/012015.

[13] Nan C, Jie Z. Estimation of environmental damages of cement building and environmental benefits of prefabricated building: A case study based on a residential project in Henan Province, China. Nature Environ Pollut Technol. 2020;19(2):721-8. DOI: 10.46488/NEPT.2020.v19i02.027.

[14] Alsulaili AD, Al-Matrouk MF, Al-Baghli RA, Al-Enezi AF. Environmental and economic benefits of applying green building concepts in Kuwait. Environ Dev Sust. 2020;22(4):3371-87. DOI: 10.1007/s10668-019-00352-1.

[15] Beccali M, Cellura M, Fontana M, Longo S, Mistretta M. Energy retrofit of a single-family house: Life cycle net energy saving and environmental benefits. Renew Sust Energy Rev. 2013;27:283-93. DOI: 10.1016/j.rser.2013.05.040.

[16] Arrigoni A, Zucchinelli M, Collatina D, Dotelli G. Life cycle environmental benefits of a forward-thinking design phase for buildings: the case study of a temporary pavilion built for an international exhibition. J Clean Prod. 2018;187(187):974-83. DOI: 10.1016/j.jclepro.2018.03.230.

[17] Mao G, Chen H, Du H, Zuo J, Pullen S, Wang Y. Energy consumption, environmental impacts and effective measures of green office buildings: A life cycle approach. J Green Build. 2015;10(4):161-77. DOI: 10.3992/jgb.10.4.161.

[18] Poon S. Deconstructing sustainability perceptions: Investigating technological innovation-environmental interaction in green buildings and the influence of architectural design. Int J Built Env Sust. 2020;8(1):91-101. DOI: 10.11113/ijbes.v8.n1.621.

[19] Wu CH, Tsai SB, Liu W, Shao XF, Xia YK, Wacławek M. Green environment and sustainable development: methods and applications. Ecol Chem Eng S. 2021;28(4),467-70. DOI: 10.2478/eces-2021-0030.

[20] Liu W, Tsai SB, Wu CH, Shao X, Wacławek M. Corporate environmental management and sustainable operation: theory and application. Ecol Chem Eng S. 2022;29(3):283-5. DOI: 10.2478/eces-2022-0020.