International Journal for Housing Science and Its Applications
Publish August 10, 2025. Volume 46, Issue 4 Pages 3476-3488

https://doi.org/10.70517/ijhsa464477a

# Analysis of the Dual Benefits of Green Building Technology Integration in Urban Residential Development on Project Cost and Environmental Sustainability

**Xiaoye Xu[1,*], Shengnan Sun[2] and Xiaoguang Zhao[1]**
[1] Department of the Economics and Management, Hebei University of Environmental Engineering, Qinhuangdao, Hebei, 066102, China
[2] Office (Audit), Hebei University of Environmental Engineering, Qinhuangdao, Hebei, 066102, China
Corresponding authors: (e-mail: hhyxxy20@163.com).

**Abstract** Green building technology applied to urban residential development can produce significant economic and ecological benefits. In this paper, green design and construction of urban residential buildings is carried out from the perspective of floor area and other aspects. The Nanjing CF project is selected as the research object to analyse the impact of green building technology on its project cost and environmental sustainability. A fuzzy exponential smoothing model is constructed based on fuzzy mathematical theory and exponential smoothing method to estimate the project cost of the CF project. Carbon emissions during the whole life cycle of the building, including the production of building materials, are measured to illustrate the environmental sustainability of the green building technology.The green building technology used in the CF project results in a significant reduction in the cost of roofing materials and maintenance costs compared to conventional roofing. With a base year of 2023, the CF project will pay for itself in full in 25 years, both in terms of construction and maintenance costs. Compared with traditional buildings, the green building in the CF project has reduced carbon emissions at all stages of the whole life cycle, and the total building carbon emissions are 9.72% lower than those of traditional buildings.

**Index Terms** green building technology, fuzzy mathematics, exponential smoothing method, carbon emission, project cost estimation

## I. Introduction

The history of the development of the construction industry is a milestone in the creation of material civilisation by mankind, but it is also a history of the destruction of the natural environment. Buildings emit a large amount of carbon dioxide and produce a large amount of construction waste in the process of construction, which affects the comfort and well-being of urban residents' lives [1]-[3]. In the context of the era of global sustainable development and the concept of green health is gradually taking root in people's hearts, green building has become the mainstream trend of this era.

A green building is a building that maximises resource conservation, protects the environment and reduces pollution during its whole life cycle, provides people with healthy, suitable and efficient use of space, and lives in harmony with nature [4]-[6]. And green buildings are often realised through the integrated application of multiple green technologies. Green technology is a general term for technologies, processes or products that can reduce environmental pollution, energy saving and consumption [7], [8]. For buildings, green technologies include energy-saving and rational use of energy technologies, land-saving and outdoor environment control technologies, water-saving and rational use of water resources technologies, material-saving and rational use of material resources technologies, and indoor environmental quality control technologies [9]-[12]. Green building should start from the pre-project stage, and be controlled in accordance with relevant requirements in all stages of planning, design, construction, completion and operation of the project, following the principle of sustainable development and reflecting the concept of green balance [13]-[15]. Through scientific overall design, integration of natural ventilation, natural lighting, low-energy enclosure structure, solar energy use, water use and other green technologies, the construction and operation of green buildings are realised to achieve the harmonious unity of humanities and architecture, environment and science and technology [16]-[19].

This paper applies green building technologies to urban residential buildings in terms of floor area, building drainage system layout and main building parts. An urban residential building in a CF project located in Nanjing is selected as the research object to analyse the project cost and environmental sustainability benefits of green building technology in the development process. The fuzzy mathematical theory is combined with the exponential smoothing method to construct a fuzzy exponential smoothing estimation model for estimating the project cost. By comparing the results of this model with the prediction method of project cost estimation based on support vector machine and the project cost estimation method based on improved case-based reasoning, the adaptability of this model is verified in practice. The project cost estimation model is used to calculate the construction and maintenance costs of roofing materials in CF projects, and the financial net present value (NPV) calculation method is introduced to explore the project cost benefits of green building technologies in CF projects. The life cycle of a building is divided into five stages: production of building materials, transport of building materials, construction, operation and demolition, and the carbon emissions of the whole life cycle of the building are measured. Comparing the carbon emissions of the green residential building in the CF project with those of the traditional building, the environmental sustainability benefits of the green building technology are demonstrated.

## II. Strategies for the application of green building technologies in urban housing

This section will focus on exploring how green building technologies can be effectively applied to urban residential development. Through the use of multiple green building technologies in the building area, building drainage system, and the main part of the building, the effect of technology integration can be achieved, thus achieving a significant improvement in the low-carbon greening effect of urban residential buildings.

### *II. A. Floor space design*

In the concept of green building, the most important thing is to save land. Therefore, in residential design building projects, attention must be paid to saving land. In the early construction of green building, the construction cost should be considered to save land as much as possible. At the same time, under the guidance of the green building concept, site-specific green building design techniques and standards should be adopted to maximise the saving of land resources.

### *II. B. Layout design of building drainage system*

#### II. B. 1) Design of domestic water supply system

In order to ensure that the building water supply and drainage system is effectively integrated into the concept of green building design, the workers need to carry out scientific design of the living water supply system, to meet the residents' water needs while avoiding the unreasonable waste of water pressure control, water supply noise and other problems. In addition, it is also necessary to enhance the utilisation rate of rainwater through green recycling technology on the design, which can well alleviate the problem of water shortage, and then let the water resources can be better recycled, so that the building has a more in-depth green environmental protection concept.

#### II. B. 2) Hot water system design

The design of hot water system is also a key element in the green design of building water supply and drainage. When designing the water supply and drainage project, the building engineering department can incorporate circulating pipes in the hot water centralised water supply system, so that the remaining hot water can be quickly transferred back to the return pipe, thus improving the utilisation rate of water resources and realising energy saving effects.

### *II. C. Design of the main part of the building*

#### II. C. 1) Green construction design for roofs

The development of urban housing begins with a study of construction materials. Since roofing construction is quite different from traditional construction, constructors should not use water-absorbent materials during the work process, otherwise the service life of the whole house will be affected. Green building materials should be used innovatively to enhance the livability of urban housing while reducing construction costs and carbon emissions.

#### II. C. 2) Green construction design for windows and doors

In the process of work to increase the inspection of door and window materials, select a number of products combined with better green energy-saving materials. At the same time to take into account the impact of the environment on the construction site, especially in the north is cold all year round, strengthen the sealing of doors and windows is necessary, some places to build doors and windows should also be equipped with double glazing to reduce the temperature of the side of the house in winter, which can bring the benefits of energy saving and consumption reduction.

#### II. C. 3) Green energy-saving design of construction equipment

Greening living furniture and other equipment can enhance the environmental protection and energy conservation of building construction. (1) Secondary construction should be carried out for architectural lighting, and when

installing and other light fittings, lighting brightness, range, light colour and other needs should be taken into account, so as to optimise the installation space of the lighting equipment, and thus improve the protection of the environment.
(2) Effective management of all construction equipment, the creation of a consent system with the ability to integrate, in order to improve the efficiency of individual resource allocation, effectively preventing the occurrence of resource waste.

## III. Cost-benefit analysis of green building technology projects

### *III. A. Project overview*

(1) Project Location

The NJCF project site is located in the southeast of Nanjing, connecting Kirin Science and Technology Park in the northeast and Jiangning University Town in the south, seamlessly connecting with the main urban area, which is a key area to be built and upgraded by the City of Nanjing in the future. The project location is shown in Figure 1. The project is surrounded by rich industrial resources, only 3 kilometres from Kirin Science and Technology Park in the north, 1.8 kilometres from Jiangning University Town in the south, and 2.3 kilometres from Jiangning High-Tech Zone. The surrounding area of the project site belongs to the Outer Qinhuai Green Scenic Belt, which is a key area in Nanjing, and at the same time echoes with the Qinglong Mountain Scenic Area of Kirin Science and Technology Park, which has a beautiful landscape and pleasant environment.

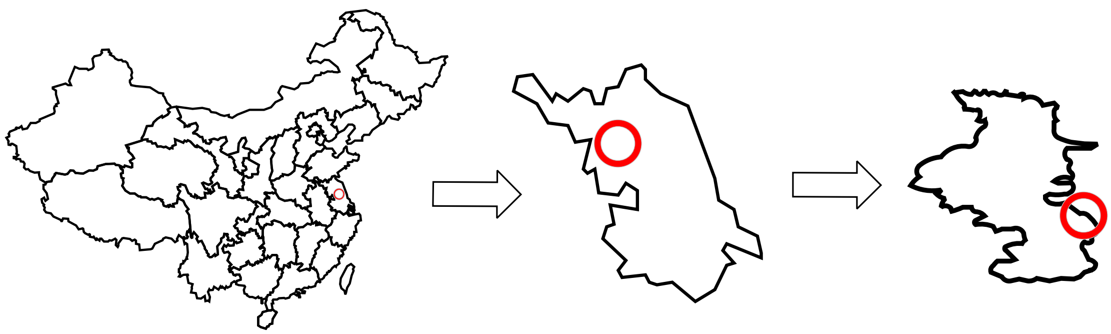

Figure 1: Project location

(2) Project Traffic

The project is located at the intersection of the Bypass Expressway and the Ninghang Expressway, and can quickly reach the main areas of the city through the 'Dongqi Road - Ninghang Expressway - Bypass Highway'. After completion, the project will be 21.8 km away from the core CBD area of the main city of Nanjing and 9.64 km away from the centre of the district, with convenient traffic. It is only 6.2 kilometres from Nanjing South Station, the city's transport hub, and 23 kilometres from Lukou Airport. Longmian Avenue Station is about 1.4 kilometres away from the project. There are also Metro Line 3, Metro Line 10 East Extension and Metro Line 11 in the pipeline around the project. With the opening of the most convenient road into the city, the project can be directly connected to Nanjing's Inner Ring Road and quickly reach the city centre. The traffic to the main locations in the city is faster.

(3) Project Supporting Facilities

CF project is adjacent to Dongshan Old Town and Kirin Science and Innovation Park, with more mature education, medical and commercial facilities in the neighbourhood. The Shangfang area where the project is located has fewer supporting facilities, but it can fully enjoy the supporting facilities of the two surrounding areas.

(4) Project Development Plan

The project site area is 3.97 square kilometres, and the transferable operational land covers an area of 1,287,300 square metres, corresponding to a planned floor area of 3,489,200 square metres, of which 2,850,900 square metres is residential floor area and 680,000 square metres is commercial floor area, with an average plot ratio of approximately 2.6. The CF project is positioned for development as a green residential area, and the requirements of the project plan are set out in accordance with the planning conditions and the site conditions. The overall layout of the project moves according to the mountainous terrain, and the elevation is reasonably set. In order to reduce the amount of earth excavation and lower the cost of earth transport, the site is divided into a number of terraces with different elevations from the south to the north. The high-rise residential buildings are arranged along the project near the direction of Dongqi Avenue, forming a development space with the opposite direction of Qinglong Mountain.

It is initially planned in the project development programme that the construction of the area within the development scope will take shape within two years after the establishment of the project company, 80% of the project within the development scope will take shape within five years, and the development of the project will be completed within seven years.

## *III. B. Estimation methodology*

### III. B. 1) Modelling

(1) Fuzzy Mathematics

The theory of fuzzy mathematics is based on fuzzy set theory, and two crucial concepts in the theory are fuzziness and closeness [20]. The closeness is a quantitative index describing the degree of similarity (closeness) of any two fuzzy sets, which can be derived using Eq.

(2) Exponential Smoothing

Exponential smoothing method as a time series forecasting method is developed on the basis of moving average method [21], and the formula is:

$$S_i = \propto y_i + (1-\propto) S_{t-1} \tag{1}$$

where, $S_t$ is the smoothed value at time $t$. $y_t$ is the actual value at time $t$. $S_{t-1}$ is the actual value at time $t-1$. $\alpha$ is the value of the smoothing coefficient, $\alpha \in [0,1]$, the value of the smoothing coefficient $\alpha$ is crucial, which determines the degree of model smoothing and the degree of response of the predicted value to the actual value.

(3) Estimation model construction based on fuzzy exponential smoothing method

According to the exponential smoothing method and the related theory of fuzzy mathematics, the construction project cost estimation model can be constructed, the process is as follows:

Let the number of constructed typical construction project (sub)projects be $n$, denoted as $A_1, A_2, \cdots, A_i$, $i=1,2,\cdots,n$; let the number of characteristic elements of constructed typical construction project (sub)projects be $m$, then the set of characteristic elements of projects $T=\{t_1,t_2,\cdots,t_j\}$, $j=1,2,\cdots,m$.

The fuzzy subset of the $i$ th constructed typical construction project (sub)project is denoted by Zander notation:

$$T = \frac{t_{i1}}{t_1} + \frac{t_i}{t_2} + \cdots + \frac{t_i}{t_j} \tag{2}$$

As a result, the fuzzy subset of constructed typical construction project (sub)project characteristics corresponding to the proposed project is then expressed as:

$$T_o = \frac{t_1^*}{t_1} + \frac{t_2^*}{t_2} + \cdots + \frac{t_i^*}{t_j} \tag{3}$$

Estimation of the cost of the proposed project based on the exponential smoothing method:

$$\begin{aligned} E_x = \lambda \Big[ & \alpha_1 E_1 + \alpha_2 (1-\alpha_1) E_2 + \alpha_3 (1-\alpha_1)(1-\alpha_2) E_3 \\ & + \frac{1}{3}(1-\alpha_1)(1-\alpha_2)(1-\alpha_3)(E_1+E_2+E_3) \Big] \end{aligned} \tag{4}$$

where, $E_x$ is the estimated cost of the proposed project. $\lambda$ is the adjustment factor. $E_1$, $E_2$, $E_3$ is the estimated cost of the constructed construction project. $\alpha_1$, $\alpha_2$, $\alpha_3$ for the ranking of the first three typical projects and the proposed construction project of the closeness of the project (degree of affiliation), $\alpha_1 \geq \alpha_2 \geq \alpha_3$. Closeness (degree of affiliation) $\alpha$ is exactly the index smoothing coefficient, the greater the value of closeness (degree of affiliation) $\alpha$, the higher the similarity between the constructed typical project and the proposed project, and the more accurate the results of cost estimation of the proposed project.

### III. B. 2) Selection of model parameters

(1) Selection of characteristic factors

Assuming that the characteristic factor of the project is $r_j$, its corresponding fuzzy set of characteristic factor selection is:

$$R = \{r_j, j=1,2,\cdots,m\} \tag{5}$$

where $R$ represents the fuzzy set of characteristic factors and $m$ represents the number of characteristic factors. In order to further enhance the accuracy of the final project cost estimation results, the key characteristic factors of the project cost are listed as shown in Table 1.

Table 1: Key features of project cost

| No. | Characteristic factor | Item characteristics |
|---|---|---|
| 1 | Construction project | Quantity of engineering, Geologic condition, Construction period |
| 2 | Earth excavation | Excavation, Equipment type, Site position, Construction period |
| 3 | Electromechanical installation | Equipment type, Installed capacity, Construction period |
| 4 | Template engineering | Template material, Template structure, Vertical support |
| 5 | Borehole grouting and anchorage | Perforated mass, Perfusion, Mud pump, Construction period |

(2) Affiliation calculation

The affiliation degree of fuzzy set is generally based on the criterion of ‘the affiliation degree of elements with complex structure, high construction difficulty, high cost, long duration and other characteristics is larger’. According to the above basic principle, the affiliation degree is calculated by normalising the specific value of the affiliation degree, and the affiliation degree of the fuzzy subset is obtained:

$$V = \{v_1, v_2, \cdots v_j, \cdots v_m\} \tag{6}$$

where $V$ represents the set of affiliation degrees of fuzzy subsets. In this paper, a new method based on quantitative eigenvalues is proposed, i.e., the ratio of the residual value to the average of the quantitative eigenvalues is based on the average of the quantitative eigenvalues. Through the above discussion, a set of evaluation index system for evaluating project cost estimation can be established as a way to determine the degree of project cost estimation.

The project characteristic vector is set to $R$, and the factors included in $R$ are set to $r_1, r_2, \cdots r_m$. The affiliation degree of each factor in $R$ is set to $e_1, e_2, \cdots, e_m$. Based on the above assumptions, it is determined that the fuzzy characteristic variables of the project can be further described by the following equation:

$$R = \frac{e_1}{r_1} + \frac{e_2}{r_2} + \cdots + \frac{e_m}{r_m} \tag{7}$$

(3) Weight division and calculation of adjustment factor

After determining the affiliation degree of each key feature element, weighting is carried out to achieve a reasonable division of weights. In the weight division, binary comparison method can be combined and engineering experience and expert advice can be integrated to obtain the engineering weight set:

$$O = \{V_1, V_2, \cdots, V_m\} \tag{8}$$

where $O$ represents the set of engineering weights, and $V_1, V_2, \cdots V_m$ represents the weights corresponding to different characteristic factors.

In the process of project cost estimation, it is necessary to calculate the adjustment coefficient according to the actual situation of the project, so as to ensure that the final estimation results are closer to reality. The calculation of the adjustment factor can be combined with the following empirical formula:

$$I = 1 + \frac{1}{m}[1.5(\frac{T'}{T_{a1}} - 1) + 0.8(\frac{T'}{T_{a2}} - 1) + 0.2(\frac{T'}{T_{a3}} - 1)] \tag{9}$$

where, $I$ represents the adjustment factor. $T'$ represents the fuzzy correlation in the engineering programme and also the ratio of the value of the degree of affiliation to the maximum value of the sum of the degrees of affiliation. $T_{a1}, T_{a2}, T_{a3}$ represents the corresponding fuzzy correlation coefficient in the engineering programme, which can also be obtained from the ratio of the value of the degree of affiliation to the maximum value.

(2) Project cost prediction and estimation

Assume that a project contains a total of $n$ similar project and the project affiliation to be estimated. The affiliations are listed in descending order, and the unilateral project cost of the corresponding similar project can be calculated. Assuming that the estimated unilateral cost of the $j$ nd similar project is $Z^*{}_j$, its estimation error can be expressed as $Z_j - Z_j^*$. Combined with the exponential smoothing method, the estimation result of the unit project cost of the $j-1$ th similar project can be written:

$$Z_{j-1}^* = Z_j^* + p_j(Z_j - Z_j^*) \tag{10}$$

where $Z_{j-1}^*$ represents the estimate of the unilateral cost modification for the similar $j$ nd project. Multiply the estimation error in the $j$ rd similar project by the related items in that project and the degree of affiliation in the project to be estimated as a compensation value for correcting the estimate. Use this method to estimate the unilateral cost of the $j-1$ th similar project. Going one step further, an estimate of the project cost is obtained.

### III. B. 3) Analysis of model adaptation

The model is applied to the urban residential construction projects selected in this paper to verify the adaptability of the project cost estimation model constructed in this paper. When testing the method of this paper in obtaining similar projects, the checking rate of the characteristic factors of the construction project is shown in Fig. 2, in which r1-r5 represents five kinds of characteristic factors. Analysing Fig. 2, it can be seen that when this paper's method is used to obtain similar projects, the check completeness and check accuracy of the five characteristic factors are greater than 0.98, and the performance of characteristic factor extraction is better.

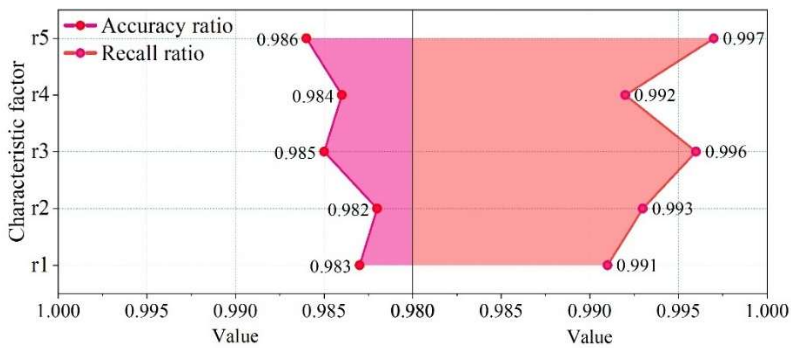


Figure 2: Test results of accuracy and recall rate

After estimation, the result of project cost estimation of NJCF project is $6,327,100,000. The hanging beam method is batch sample training, and the assessment index during the training process is the mean square error of the sample, which is calculated by the formula shown below:

$$E = \frac{1}{q}\sum_{k=1}^{l}(d_k - o_k)^2 \tag{11}$$

where $q$ is the number of groups of training samples, $d_k$ is the desired output value of the $k$ rd output neuron, $o_k$ is the network output value of the $k$ th neuron, and $l$ denotes the number of output neurons, i.e., the dimensions of the output vector. The evaluation results are shown in Fig. 3, where ICR denotes the Improved Case Reasoning method. Larger dots indicate larger mean square error. Analysing the data in the figure, it can be seen that the estimation result of this paper's method has the lowest mean square error among the three methods selected in this paper, and the 10 cost management personnel think that the estimation accuracy of this paper's method is the highest, and the estimation effect of this paper's method is the best, compared with the prediction method of project cost estimation based on the Support Vector Machines, and the estimation method of project cost estimation based on the Improved Case-based Reasoning.

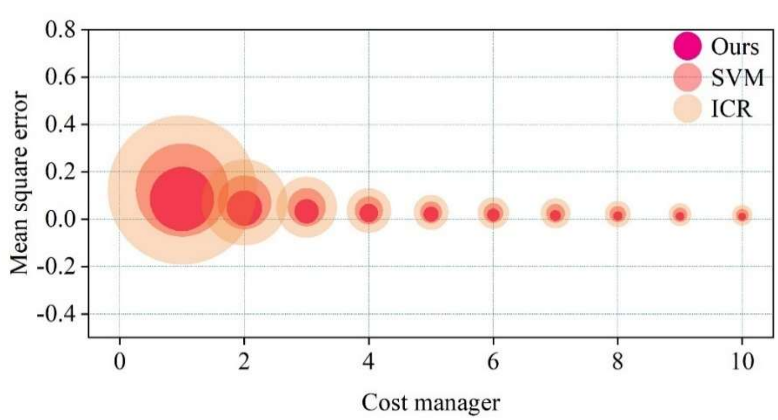


Figure 3: Estimation effect evaluation

The estimation accuracy of different methods for CF project cost is tested, and the results are shown in Table 2. Analysing the data in Table 2, it can be seen that there are obvious gaps in the estimation accuracy of the three estimation methods on the project cost, and the estimation accuracy of this paper's method is always greater than 95% along with the increase of the project samples, and the average accuracy is higher than 96%, which is a higher estimation accuracy for the cost of CF projects. It shows that the method of this paper has better adaptability in practical application and can be applied to the subsequent estimation of project cost-effectiveness analysis of green building technology.

Table 2: Estimation accuracy of three methods

| Sample number of estimating | Ours | SVM | ICR |
|---|---|---|---|
| 20 | 0.953 | 0.894 | 0.836 |
| 40 | 0.968 | 0.883 | 0.854 |
| 60 | 0.961 | 0.902 | 0.842 |
| 80 | 0.972 | 0.917 | 0.863 |
| 100 | 0.983 | 0.908 | 0.881 |

## *III. C. Project cost-benefit analysis*

Based on the architectural design requirements of the CF project and the application of green building technologies as well as the results of the project cost estimation based on the fuzzy exponential smoothing method, this section analyses the project cost-effectiveness of the CF project in Nanjing with an eye on the roof portion of the urban residence.

### III. C. 1) Construction cost analysis

(1) Material construction costs

The residential roofs of the Nanjing CF project are constructed with lawn-style green roofs to highlight green building technology. Traditional roofs mainly include root blocking layer, storage and drainage layer, filter layer, soil substrate layer, plant layer and construction. The lawn-style green roof in the CF project mainly includes prefabricated planting containers, soil substrate layer, plant layer and construction. According to the project cost estimation results, the unilateral cost comparison between the two is shown in Table 3. As can be seen from the table, the average unilateral cost of the lawn-type green roof in the traditional roof and CF projects is 151 yuan/m² and 103 yuan/m², respectively. Since the roof area of the CF project is 4238m², and in order to meet the future maintenance management and user living needs, the roof greening rate is now controlled at about 70%, that is, the construction area is 2967m². The basic material cost and construction cost of the two construction methods are 407247 yuan and 305601 yuan respectively.

Table 3: Project construction unilateral costs (yuan/m²)

| Roof type | Barrier layer | Drainage layer | Filter layer | Soil matrix layer | Plant layer | Total unilateral cost |
|---|---|---|---|---|---|---|
| Traditional roof | 8-9 | 22-28 | 6-9 | 38 | 72 | 146-156 |
| Roof type | Prefabricated planting container | | | Soil matrix layer | Plant layer | Total unilateral cost |
| CF project green roof | 32-42 | | | 32 | 34 | 98-108 |

(2) Post-maintenance costs

Nanjing has four distinct seasons and moderate rainfall, so the maintenance of plants only needs to be regularly inspected and weeded, etc., and the maintenance is low. In addition, the modular design of the green roof of the CF project is more intelligent than the drainage and irrigation system of the traditional roof, and the future maintenance is cheaper and more convenient. According to the estimation results, the annual maintenance cost of the traditional roof is 8 yuan/m², and the annual maintenance cost of the lawn green roof of the CF project is 3 yuan/m². Finally, it is concluded that the annual maintenance costs of the traditional and CF lawn green roofs in this case are 23,736 yuan and 8,901 yuan, respectively.

### III. C. 2) Analysis of benefits

In order to analyse the project cost effectiveness of green roofs and conventional roofs used in the CF project, a financial NPV calculation method is introduced, which is shown in equation (12). In this case, the nodal cost of the green roof is used as the cash inflow. The construction cost cost and post maintenance cost required by the two different construction methods are used as cash outflows to obtain a quantitative analysis of the two construction methods in terms of project cost effectiveness:

$$FNPV = \sum_{t=1}^{n} (CI_t - CO_t)(1+i)^{-t} \tag{12}$$

where $CI_t$ is the cash inflow in year $t$. $CO_t$ is the cash outflow in year $t$. $n$ is the calculation period of the technical programme. $i$ is the standard discount rate for the construction industry, which is 3 per cent.

Taking 2023 as the first year, according to the formula, the financial net present value of the traditional roof with a calculation period of $n$ year is: $FNPV=\sum_{t=1}^{n}(34579-17028\times1.0251^t)(1+0.03)^{-t}-407247$, of which 34,579 yuan and 17,028 yuan are respectively the electricity cost saved by the green roof of the CF project and the maintenance cost of the introduction of the consumer price index. Similarly, the CF project has a $n$-year financial NPV of $FNPV=\sum_{t=1}^{n}(34579-17028\times1.0251^t)(1+0.03)^{-t}-305601$. In this paper, the financial net present value of traditional roofs and CF green roofs is obtained over a 30-year cycle, as shown in Figure 4. As can be seen from the figure, the traditional roof construction method cannot recover all the construction and maintenance costs on a 35-year cycle, but the green roof construction method in the CF project can recover all the construction and maintenance costs after the 25th year. In the next 10 years, the financial net present value of green roofs will be 127,522.7 yuan more than that of traditional roofs, 365073 yuan more in the next 20 years, and 585,873.7 yuan more in the next 30 years. It can be seen that with the development of time, the gap between traditional roofs and green roofs in terms of financial net present value is getting bigger and bigger, indicating that the use of green building technology for urban residential development has significant project cost benefits.

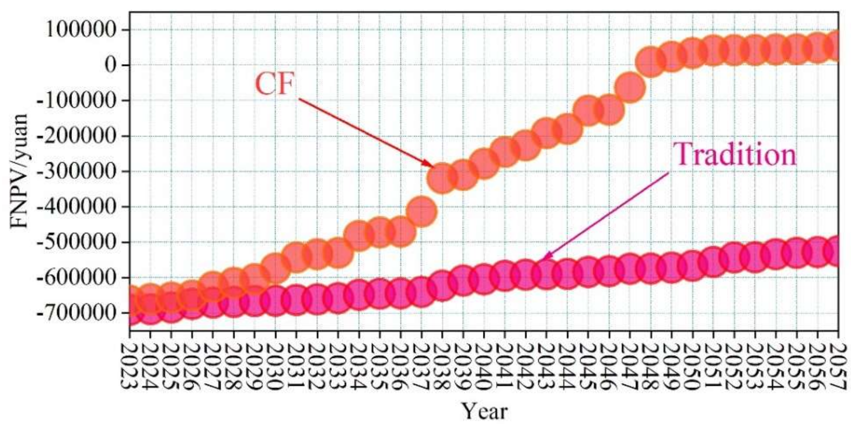


Figure 4: Net present value of two ways of building

# IV. Analysis of environmental sustainability benefits of green building technologies

## *IV. A. Whole Life Cycle Carbon Modelling of Buildings*

According to the characteristics of residential buildings, the boundary of carbon emission measurement [22] is as follows: building material production stage, building material transport stage, construction stage, operation stage, and dismantling stage.

### IV. A. 1) Stages of building materials production

The formula for calculating carbon emissions at the building materials production stage is as follows.

$$C_{SC}=\sum_{i=1}^{n}M_iF_i \tag{13}$$

where $C_{SC}$ is the carbon emission from the production stage of building materials $(kgCO_2)$. $M_i$ is the consumption of building materials $i$. $F_i$ is the carbon emission factor of building materials ($kgCO_2$/unit quantity of building materials). Among them, the consumption of building materials can be obtained by checking the design drawings, bill of quantities and bill of materials.

### IV. A. 2) Building materials transport phase

The formula for calculating carbon emissions from the transport of building materials is as follows:

$$C_{yx}=\sum_{j=1}^{m}\sum_{i=1}^{n}M_i\times D_{i,j}\times ET_j \tag{14}$$

where, $C_{yx}$ is the carbon emissions from the transport of building materials $(kgCO_2)$. $M_i$ is the consumption of major building materials of category $i$, $(t)$, determined on the basis of the relevant technical information of the project. $D_{ij}$ is the average transport distance $(km)$ for Category $i$ building materials using transport mode $j$, based on the location of the supplier to the construction site. $ET_j$ is the carbon emission factor $kgCO_2/(t \cdot kg)$ per unit weight of transport distance for transport mode $j$.

### IV. A. 3) Construction phase

In this paper, the construction process energy consumption estimation method is used. The specific calculation formula is as follows:

$$CE_{JZ} = \sum_{i=1}^{n}\left(E_{JZ,i} \times EF_i\right) \tag{15}$$

where, $CE_{JZ}$ is the carbon emissions generated during the construction phase, $kgCO_2$. $E_{JZ,i}$ is the total amount of energy type i consumed during the calculation cycle, $kg/a$, $m^3/a$. $EF_i$ is the carbon emission factor, $kgCO_2/kg$, $kgCO_2/m^3$.

$$E_{jz} = E_{fx} + E_{cx} \tag{16}$$

where $E_{JZ}$ is the total energy consumption of the construction phase. $E_{fx}$ is the total energy consumption of the component works, $E_{cx}$ is the total energy consumption of the measure works, and the electricity emission factor is:

$$E_{fx} = \sum_{j=1}^{n} Q_{fx} f_{fx,i} \tag{17}$$

$$f_{fx,i} = \sum_{j=1}^{m} T_{i,j} R_j + E_{jj,i} \tag{18}$$

where, $Q_{fx,i}$ is the engineering quantity of the $i$ project in the sub-project $f_{fx,i}$ is the energy consumption coefficient of the $i$ th project in the sub-project project, $T_{i,j}$ is the consumption of the $j$ th construction machinery shift (Taiwan class) of the $i$ th project unit engineering quantity, $R$, is the energy consumption of the $j$ th construction machinery unit of the $i$ th project, when there is empirical data, the value can be taken according to the empirical data, $E_{jj,i}$ is the $i$ th project, the small construction machinery does not list the consumption of the mechanical shift, but the energy consumed by it is part of the energy consumption of the human material, $i$ is the project serial number in the sub-project project, $j$ is the serial number of the construction machinery:

$$E_{cx} = \sum_{i=1}^{n} Q_{cx} f_{cx,i} \tag{19}$$

$$f_{cx,i} = \sum_{j=1}^{m} T_{A-i,j} R_j \tag{20}$$

In the formula, $Q_{cx,i}$ for the measures of the project in the project volume $i$, $f_{cx,i}$ for the measures of the project in the $i$ th project energy consumption coefficient, $T_{A-i,j}$ for the $i$ th project unit volume of the $j$ th type of construction machinery shift consumption (shift), $R$ for the $i$ th project of the $j$ th type of construction machinery unit shift of energy consumption, $i$ for the measures of the project serial number, $j$ for the construction machinery serial number.

### IV. A. 4) Building operation phase

Carbon emissions during the operation phase of a building depend on the amount of carbon emissions caused by energy consumption during the operation of the building and the amount of carbon sequestered in greenfield carbon sinks. The formula is as follows:

$$C_m = \left[\sum_{i=1}^{n} EF_i \sum_{j-1}^{n}\left(E_{i,j} - ER_{i,j}\right) - C_j\right] y \tag{21}$$

where $C_m$ is the carbon emission during the operation phase of the building $(kgCO_2)$. $i$ is the type of energy. $j$ is the type of energy-using system. $E_{ij}$ is the amount of type i energy consumed by type $j$ system (unit/a). $ER_{i,j}$ is the amount of type $i$ energy provided by renewable energy for type $j$ systems (unit/a). $C_\rho$ is the green carbon sink $(kgCO_2/a)$. $y$ is the building design life $(a)$.

### IV. A. 5) Building demolition phase

Due to the lack of data related to the building demolition stage and the absence of relevant calculation standards, the following building demolition formulas were obtained by referring to relevant literature:

$$Y = X + 1.99 \tag{22}$$

where $X$ is the number of strata above ground and $Y$ is the carbon emissions per unit area.

## IV. B. Results of analysing carbon emissions from green buildings

### IV. B. 1) Material production and transport phase

The carbon emission calculation results of the production stage of building materials and the transport stage of materials in the development process of the CF project selected in this paper are shown in Table 4 and Table 5, where M1-M²1 denote different types of building materials, respectively. From the table, it can be seen that the total tan emissions of building materials in the production and transport stages are 2775.72 tCO2e and 1017.70 tCO2e, respectively. Among them, the carbon emissions of building materials M3 and M4 in the production and transport stages account for the highest proportion among all building materials.

Table 4: Carbon emissions in building materials production stage

| | Type of building materials | Dosage | Unit | Production factor (tCO2e) | Carbon emission (tCO2e) |
|---|---|---|---|---|---|
| 1 | M1 | | t | 2.347 | |
| 2 | M² | | m3 | 0.268 | |
| 3 | M3 | 1401.26 | m3 | 0.724 | 1017.31 |
| 4 | M4 | 1864.38 | m3 | 0.253 | 483.96 |
| 5 | M5 | | t | 0.385 | |
| 6 | M6 | | t | 1.134 | |
| 7 | M7 | 1093.29 | t | 0.124 | 132.47 |
| 8 | M8 | 14.68 | t | 5.023 | 72.69 |
| 9 | M9 | 335.84 | m² | 0.257 | 83.71 |
| 10 | M10 | 3621.41 | t | 2.841 | 82.49 |
| 11 | M11 | 1.24 | m² | 0.296 | 817.64 |
| 12 | M12 | 41.83 | t | 0.718 | 2.84 |
| 13 | M13 | 10.82 | m3 | 0.952 | 11.31 |
| 14 | M14 | 4.31 | m3 | 5.231 | 6.97 |
| 15 | M15 | 3.86 | t | 0.258 | 4.13 |
| 16 | M16 | 31.98 | t | 0.736 | 18.26 |
| 17 | M17 | 22.36 | m3 | 20.882 | 7.24 |
| 18 | M18 | 21.03 | m3 | 1.831 | 15.48 |
| 19 | M19 | 0.78 | t | 5.021 | 14.37 |
| 20 | M²0 | 1.56 | t | 3.414 | 2.68 |
| 21 | M²1 | 0.41 | t | 0.863 | 2.17 |
| 22 | Total | | | | 2775.72 |

Table 5: Carbon emissions during building materials

| | Type of building materials | Dosage | Unit | Mode of transport | Transport factor {[tCO2e/(t·km)]×10-4} | Carbon emission (tCO2e) |
|---|---|---|---|---|---|---|
| 1 | M1 | | t | Wagon | 3.18 | |
| 2 | M² | | $m^3$ | Wagon | 3.18 | |
| 3 | M3 | 1401.26 | $m^3$ | Wagon | 3.18 | 408.13 |
| 4 | M4 | 1864.38 | $m^3$ | Wagon | 3.18 | 454.82 |
| 5 | M5 | | t | Wagon | 3.18 | |
| 6 | M6 | | t | Wagon | 3.18 | |
| 7 | M7 | 1093.29 | t | Wagon | 3.18 | 13.68 |
| 8 | M8 | 14.68 | t | Wagon | 3.18 | 1.87 |
| 9 | M9 | 335.84 | m² | Wagon | 3.18 | 9.86 |
| 10 | M10 | 3621.41 | t | Wagon | 3.18 | 4.03 |
| 11 | M11 | 1.24 | m² | Wagon | 3.18 | 112.58 |
| 12 | M12 | 41.83 | t | Wagon | 3.18 | 0.21 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 13 | M13 | 10.82 | m$^3$ | Wagon | 3.18 | 1.06 |
| 14 | M14 | 4.31 | m$^3$ | Wagon | 3.18 | 2.84 |
| 15 | M15 | 3.86 | t | Wagon | 3.18 | 0.71 |
| 16 | M16 | 31.98 | t | Wagon | 3.18 | 0.65 |
| 17 | M17 | 22.36 | m$^3$ | Wagon | 3.18 | 6.38 |
| 18 | M18 | 21.03 | m$^3$ | Wagon | 3.18 | 0.11 |
| 19 | M19 | 0.78 | t | Wagon | 3.18 | 0.23 |
| 20 | $M^{2}0$ | 1.56 | t | Wagon | 3.18 | 0.06 |
| 21 | $M^{2}1$ | 0.41 | t | Wagon | 3.18 | 0.48 |
| 22 | Total | | | | | 1017.70 |

### IV. B. 2) Construction phase

According to the carbon emission formula, the carbon emission per unit area in the construction stage can be estimated, and then combined with the floor area, the total carbon emission of the whole construction process can be calculated. Using the formula, the carbon emission per unit area of the CF project is 4.87kgCO2e/m², and the total area of the CF project is 2,850,900 square metres, so the total carbon emission of the CF project during the construction phase is 13,886.6tCO2e.

### IV. B. 3) Operational phase

This paper calculates the carbon emissions generated by the maintenance and replacement activities of a building in the course of its use, based on maintenance records or maintenance plans. Based on the service life of the building and the service life of the building materials, the number of maintenance and replacement of building materials is calculated, and the carbon emissions from the production and transport of building materials generated by the maintenance and replacement of building materials are counted.

The calculation method of maintenance times and carbon emissions from maintenance is as follows: the service life of building materials is the same as the service life of the building by default, if the service life of building materials is inputted by custom, the number of times of use will be calculated as the service life of the building/customised service life of building materials and rounded to the nearest whole number, and the number of maintenance times = the number of times of use - 1. If the customised service life inputted by custom is 20 years, the number of times of use will be 60/20 = 3 times and the number of times of maintenance will be 2 times. The carbon emissions from the maintenance of building materials is the cumulative value of (carbon emissions from the production of each building material + carbon emissions from the transport of each building material) x the number of maintenance times. Reduction of carbon emissions in the operation phase of the building. The comparison of carbon emissions between the design building and the baseline building is shown in Figure 5, and the summary of carbon emissions in the operation phase of the building is shown in Table 6. In this paper, the carbon emission intensity of the green building is reduced by 116.51% compared to the conventional building, and the carbon emission is reduced by 9.91kgCO2e/(m²·a).

Table 6: Carbon emission at construction operation phase

| Type | Optimized ratio (%) | Annual reduction in carbon emissions per unit area[kgCO2e/(m²·a)] |
|---|---|---|
| Air Conditioning | 62.79 | 0.27 |
| Heating | 32.23 | 0.39 |
| Lighting | 21.49 | 2.66 |
| Renewable Energy | | 6.59 |
| Total | 116.51 | 9.91 |

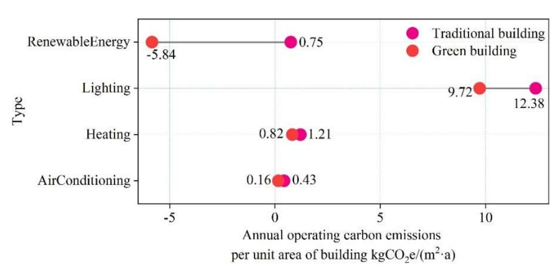


Figure 5: Carbon emission contrast

#### IV. B. 4) Dismantling phase

In the absence of detailed demolition-related data, the empirical formula method was used for calculation. The carbon emissions per unit area in the demolition phase were estimated by the empirical formula, and then the total carbon emissions of the whole demolition process were calculated by combining the building area. Since the CF project is still in operation, the emission per unit area of the CF project in the demolition stage is 0.86kgCO2e/m² by the empirical formula, and the total carbon emission of the CF project can be measured to be 2459.10tCO2e according to the total building area of the CF project.

### *IV. C. Analysis of environmental sustainability benefits*

The results obtained by summarising the previous calculations of carbon emissions over the whole life cycle of the building are shown in Table 7. It can be seen from the table that the carbon emissions of CF projects based on green building integration technology are lower than those of traditional buildings in all stages, and the total carbon emissions are reduced by 9.72% compared with those of traditional buildings. This indicates that green building integration technology has significant ecological and environmental benefits, and its large-scale application in urban residential development can significantly improve environmental sustainability.

Table 7: Building carbon emission summary

| | Stage | S1 | S2 | S3 | S4 | S5 |
|---|---|---|---|---|---|---|
| Traditional building | Carbon emission (tCO2e) | 3978.44 | 1239.61 | 14503.74 | 908.29 | 2671.38 |
| | Carbon emissions per unit area (kgCO2e/m²) | 1.40 | 0.43 | 5.09 | 0.32 | 0.94 |
| | Annual carbon emissions (kgCO2e/m²·a) | 4.08 | 1.39 | 0.41 | 5.04 | 0.67 |
| Green building | Carbon emission (tCO2e) | 2775.72 | 1017.70 | 13886.60 | 897.31 | 2459.10 |
| | Carbon emissions per unit area (kgCO2e/m²) | 0.97 | 0.36 | 4.87 | 0.31 | 0.86 |
| | Annual carbon emissions (kgCO2e/m²·a) | 3.61 | 1.27 | 0.32 | 4.84 | 0.03 |

## V. Conclusion

This paper proposes the application strategy of applying green building to urban residential development, and selects the Nanjing CF project to explore the project cost benefits and environmental sustainability benefits of green building technology through fuzzy index smoothing estimation model, financial net present value calculation, carbon emission measurement and other methods.

(1) Green building technology reduces the cost of materials, construction and post-maintenance of roof construction by 101646 yuan and 14,835 yuan respectively compared with traditional roof construction methods. Taking 2023 as the base period, the green roof of the CF project will be 127,522.7 yuan more than the traditional roof in 10 years, 365073 yuan more in the next 20 years, and 585,873.7 yuan more in the next 30 years. At the same time, after 25 years, the CF project can recover all the construction and maintenance costs, while the traditional construction method cannot fully recover all the construction and maintenance costs in the 35-year cycle. It shows that the application of green construction technology has significant project cost benefits.

(2) The carbon emissions of green buildings at all stages of the life cycle are 2775.72 tCO2e, 1017.70 tCO2e, 13886.60 tCO2e, 897.31 tCO2e and 2459.10 tCO2e, respectively. The total carbon emissions are reduced by about 9.72% compared with traditional buildings. Demonstrate good environmental sustainability.

## References

[1] Darko, A., Chan, A. P. C., Ameyaw, E. E., He, B. J., & Olanipekun, A. O. (2017). Examining issues influencing green building technologies adoption: The United States green building experts' perspectives. Energy and Buildings, 144, 320-332.
[2] Darko, A., Zhang, C., & Chan, A. P. (2017). Drivers for green building: A review of empirical studies. Habitat international, 60, 34-49.
[3] Olanipekun, A. O., Xia, B., Hon, C., & Darko, A. (2018). Effect of motivation and owner commitment on the delivery performance of green building projects. Journal of Management in Engineering, 34(1), 04017039.
[4] Hwang, B. G., Zhu, L., & Ming, J. T. T. (2017). Factors affecting productivity in green building construction projects: The case of Singapore. Journal of Management in Engineering, 33(3), 04016052.
[5] Chan, A. P. C., Darko, A., Olanipekun, A. O., & Ameyaw, E. E. (2018). Critical barriers to green building technologies adoption in developing countries: The case of Ghana. Journal of cleaner production, 172, 1067-1079.
[6] Darko, A., & Chan, A. P. (2017). Review of barriers to green building adoption. Sustainable Development, 25(3), 167-179.
[7] Doan, D. T., Ghaffarianhoseini, A., Naismith, N., Zhang, T., Ghaffarianhoseini, A., & Tookey, J. (2017). A critical comparison of green building rating systems. Building and Environment, 123, 243-260.
[8] Kuhn, T. E., Erban, C., Heinrich, M., Eisenlohr, J., Ensslen, F., & Neuhaus, D. H. (2021). Review of technological design options for building integrated photovoltaics (BIPV). Energy and Buildings, 231, 110381.

[9] Geng, Y., Ji, W., Wang, Z., Lin, B., & Zhu, Y. (2019). A review of operating performance in green buildings: Energy use, indoor environmental quality and occupant satisfaction. Energy and Buildings, 183, 500-514.

[10] Bradu, P., Biswas, A., Nair, C., Sreevalsakumar, S., Patil, M., Kannampuzha, S., ... & Gopalakrishnan, A. V. (2022). Recent advances in green technology and Industrial Revolution 4.0 for a sustainable future. Environmental science and pollution research international, 1.

[11] Eleftheriadis, S., Mumovic, D., & Greening, P. (2017). Life cycle energy efficiency in building structures: A review of current developments and future outlooks based on BIM capabilities. Renewable and Sustainable Energy Reviews, 67, 811-825.

[12] Biyik, E., Araz, M., Hepbasli, A., Shahrestani, M., Yao, R., Shao, L., ... & Atlı, Y. B. (2017). A key review of building integrated photovoltaic (BIPV) systems. Engineering science and technology, an international journal, 20(3), 833-858.

[13] Mayrand, F., & Clergeau, P. (2018). Green roofs and green walls for biodiversity conservation: a contribution to urban connectivity?. Sustainability, 10(4), 985.

[14] Song, Y., Wang, X., Tan, Y., Wu, P., Sutrisna, M., Cheng, J. C., & Hampson, K. (2017). Trends and opportunities of BIM-GIS integration in the architecture, engineering and construction industry: A review from a spatio-temporal statistical perspective. ISPRS International Journal of Geo-Information, 6(12), 397.

[15] Feng, W., Zhang, Q., Ji, H., Wang, R., Zhou, N., Ye, Q., ... & Lau, S. S. Y. (2019). A review of net zero energy buildings in hot and humid climates: Experience learned from 34 case study buildings. Renewable and Sustainable Energy Reviews, 114, 109303.

[16] Besir, A. B., & Cuce, E. (2018). Green roofs and facades: A comprehensive review. Renewable and Sustainable Energy Reviews, 82, 915-939.

[17] Manso, M., Teotónio, I., Silva, C. M., & Cruz, C. O. (2021). Green roof and green wall benefits and costs: A review of the quantitative evidence. Renewable and Sustainable Energy Reviews, 135, 110111.

[18] Sharifi, A. (2021). Co-benefits and synergies between urban climate change mitigation and adaptation measures: A literature review. Science of the total environment, 750, 141642.

[19] Liu, Z., Liu, Y., He, B. J., Xu, W., Jin, G., & Zhang, X. (2019). Application and suitability analysis of the key technologies in nearly zero energy buildings in China. Renewable and Sustainable Energy Reviews, 101, 329-345.

[20] Zong Bin Liu,Wei Shui Fei,Pei Guan Wu & Fei Chen. (2011). The Research on Building up the Hierarchy Process and Fuzzy Evaluation Model and Evaluation System about the Cement Concrete Pavement on the Basis of the Fuzzy Mathematics Theory. Advanced Materials Research(255-260),3228-3233.

[21] Benjamin Salomon Diboma,Flavian Emmanuel Sapnken,Mohammed Hamaidi,Yong Wang,Prosper Gopdjim Noumo & Jean Gaston Tamba. (2024). Improved exponential smoothing grey-holt models for electricity price forecasting using whale optimization. MethodsX102926-102926.

[22] Shengdong Cheng,Xin Zhou & Huan Zhou. (2023). Study on Carbon Emission Measurement in Building Materialization Stage. Sustainability(7).