Research on Sustainable Management of Civil Engineering Cost Based on Life Cycle Cost Analysis

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Abstract: Based on life cycle cost analysis (LCCA), this paper constructs a framework for sustainable management of civil engineering cost, aiming at achieving the synergy between the optimal life cycle cost and the goal of sustainable development. The main innovations include the concept model of "three-dimensional sustainable cost": environmental cost (carbon emission, pollution control) and social cost (health impact, community effect) are brought into the scope of cost management, forming a multi-dimensional and dynamic cost evaluation system. A dynamic cost prediction equation including initial cost, operating cost, environmental cost and social cost is established, in which the discount rate is integrated with sustainable factors such as carbon price, which provides a scientific decision-making tool for civil engineering that takes into account economic, environmental and social benefits. Through the integrated design of BIM model, cost list, energy consumption simulation data, building materials carbon footprint database and operation and maintenance history big data, it provides full-cycle, structured and visual data input for LCCA model. Real-time monitoring of building energy consumption, indoor environmental quality and other data using Internet of Things (IoT) sensors, and regular input of LCCA model for comparative analysis, forming a closed-loop management, guiding long-term building management and optimization. The empirical study shows that: comparing the green scheme with the traditional scheme, although the initial construction cost of the green scheme is high, its significant savings in operation, environment and social costs reduce the total life cycle cost by 16.6%, which proves that the decision based on sustainable LCCA can achieve the best long-term comprehensive benefits.

1. Introduction

At present, the cost management of civil engineering is facing the dilemma of "emphasizing construction and neglecting operation", which leads to high operation and maintenance costs and huge energy consumption in the whole life cycle of buildings, and it is difficult to meet the requirements of sustainable development under the "double carbon" strategy. With the development of BIM technology and big data, life cycle cost analysis (LCCA) can be accurate, which provides technical support for integrating construction, environment and social costs, realizing the transformation from short-term cost control to full-cycle and multi-dimensional cost management, and promoting the construction industry to move towards green, efficient and sustainable development [1-2].

The purpose of this study is to solve the contradiction between economy and sustainability in traditional cost management, and to realize the synergy between the whole cycle cost optimization and the sustainable development goal by constructing a dynamic management system based on LCCA. In theory, the concept model of "three-dimensional sustainable cost" is innovatively put forward, and environmental cost (carbon emission, pollution control) and social cost (health impact, community effect) are included in the cost management category, and a dynamic cost prediction equation including initial cost, operating cost, environmental cost and social cost is established, in which the discount rate integrates sustainable factors such as carbon price, which provides a scientific decision-making tool for civil engineering with both economic, environmental and social benefits.

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2. Construction of LCCA analysis model

The core innovation of the Total Life-Cycle Cost (TLCC) model constructed in this study lies in breaking through the traditional limitation of only considering economic costs, internalizing environmental and social costs, and forming a multidimensional and dynamic TLCC evaluation system [3].

The dynamic cost prediction equation is proposed as follows:

$$TLCC = C_I + \sum_{t=1}^{N} \frac{C_{O,t} + C_{Env,t} + C_{Soc,t}}{(1+r)^r} \quad (1)$$

Where $TLCC$ represents the total life cycle cost. It is the final core index of decision-making, and pursues its minimization or optimization, not just the lowest initial construction cost. C_I stands for initial construction cost. Refers to all expenses incurred in the decision-making, design, bidding and construction stage of the project, including land acquisition, survey and design, Jian 'an project fees, equipment purchase fees, etc. $C_{O,t}$ stands for the operation and maintenance cost in the t year. Including energy costs (water, electricity, gas), routine maintenance, regular maintenance, equipment replacement, property management and other costs generated during the use stage of the building.

$C_{Env,t}$ stands for the environmental cost in the t year. This is one of the "three-dimensional sustainable costs" included in this study. Refers to the economic value converted by the negative impact of the project on the environment during the whole life cycle, mainly including:

1．Carbon emission cost: The carbon emissions from building materials during the construction phase, transportation, as well as direct (boiler, air conditioning) and indirect (purchased electricity) energy consumption during the operation phase. Its monetization is calculated by multiplying carbon emissions (tCO_2e) by carbon prices (yuan/tCO_2e).

2．Pollution control cost: the treatment cost to deal with the waste water, waste gas and solid waste generated during construction and operation.

$C_{Soc,t}$ stands for the social cost in the t year. This is another dimension of "three-dimensional sustainable cost". Refers to the economic value converted from the negative impact of the project on the well-being of human society, mainly including:

1．Health impact cost: the loss caused by poor indoor air quality, poor light environment, noise pollution, etc., which leads to the damage to the health of the occupant and the decline in work efficiency. It can be estimated by "disease cost method" or "willingness to pay method", for example, medical expenses and lost work due to increased incidence [4-5].

2．Community effect cost: the interference and noise impact on the surrounding traffic during the construction period, as well as the negative effects such as landscape damage and neighborhood estrangement that may be caused after the completion.

N is the project life cycle. Refers to the total life of the project from construction to scrapping and dismantling, which is usually set to 50 years or 70 years according to the building type and structural durability. r is the dynamic discount rate [6]. In this study, it was improved sustainably. It not only reflects the time value and social preference of funds, but also integrates sustainable factors. Its composition can be expressed as:

$$r = r_{base} + r_{risk} - r_{carbon} \quad (2)$$

Among them, r_{base} is the benchmark discount rate, and social discount rate or industry benchmark rate of return can be adopted. r_{risk} is the project-specific risk premium. r_{carbon} is a carbon preference adjustment factor. This is the key to innovation, and it is a function that is positively related to the expected increase of carbon price in the future. This means that the expectation of tighter carbon constraints and higher carbon prices in the future will reduce the actual discount rate, thus increasing the present value weight of future operating, environmental and social costs, and making decision-making more inclined to choose technologies and schemes that may have higher initial investment but are greener and more efficient in the long run.

Based on BIM technology, in the design stage, the cost and energy consumption information are integrated by standards such as COBie and gbXML to build a simulated digital asset, and EnergyPlus and other tools are used to predict energy consumption and carbon emissions, so as to accurately estimate the operating and environmental costs; On this basis, the life cycle assessment (LCA) method is used to calculate the carbon footprint and monetize the environmental cost in combination with the carbon market price, and the social cost is estimated by the health impact data of WHO and other institutions and the local medical cost. Although there are quantitative challenges, the relative comparison between the schemes still provides an important basis for sustainable decision-making.

3. Sustainable management framework of civil engineering cost

The framework is a dynamic cycle system that runs through the whole life cycle of the project, and its core is the above LCCA model, as shown in Figure 1 below.

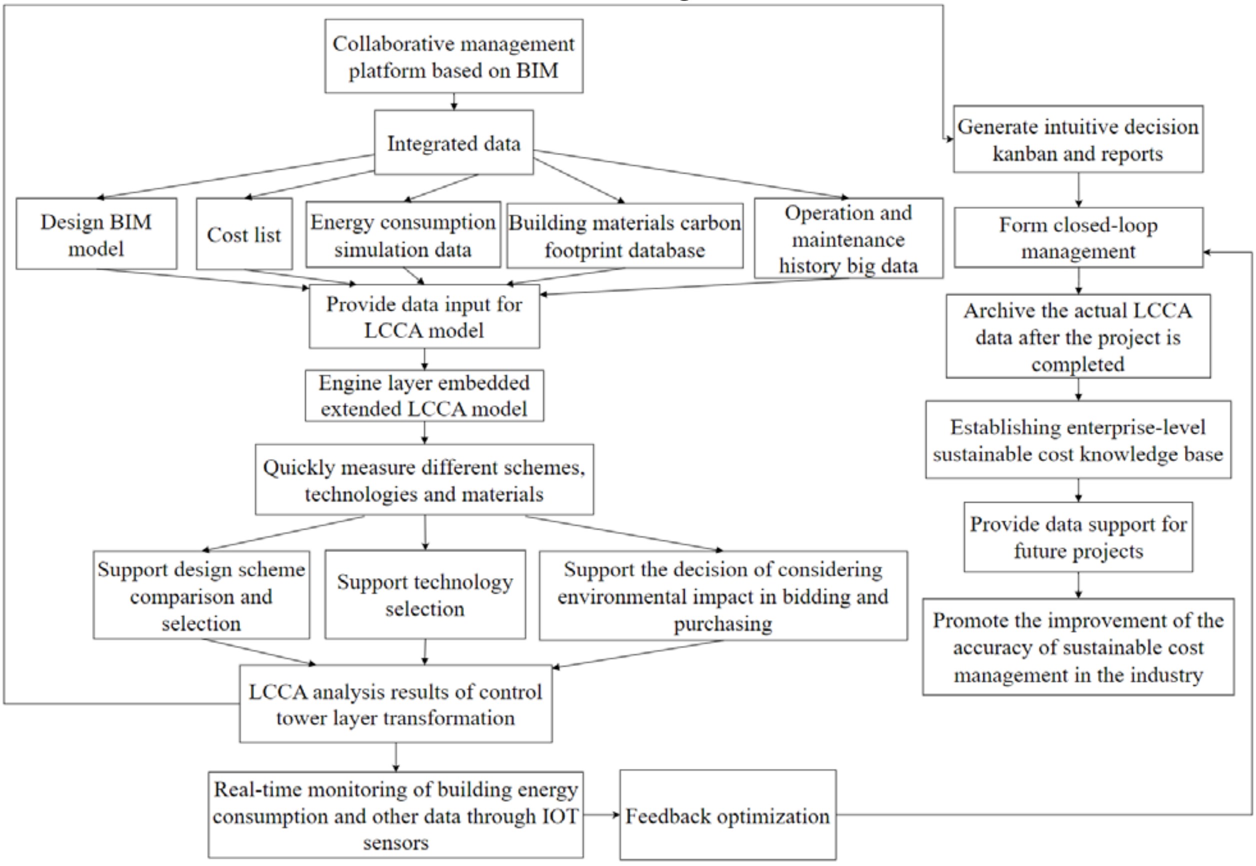

Figure 1 Sustainable management framework of civil engineering cost

On the first floor, a collaborative management platform based on BIM is established, and BIM model, cost list, energy consumption simulation data, carbon footprint database of building materials and historical big data of operation and maintenance are integrated and designed. Through this method, it provides full-cycle, structured and visual data input for LCCA model, and ensures the accuracy and reliability of cost prediction. As the foundation of the whole framework, this level supports the data collection and integration required for subsequent analysis and decision-making.

The second layer embeds an extended LCCA model to quickly calculate LCCA for different schemes, technologies, and materials at various key decision-making points such as design, bidding, and construction. This includes not only the comparison of design schemes, such as the comparison between glass curtain wall systems and high-performance masonry exterior wall systems, but also the evaluation of technical selection, such as the comparison between traditional air conditioning systems and ground source heat pump systems. In addition, during the bidding and procurement stages, contractors are required to provide Environmental Product Declarations (EPD) for the main building materials, which will be used as one of the technical scoring items in the evaluation process to promote the greening of the supply chain [7]. This layer serves as the core of the entire framework, providing scientific basis for various decisions.

At the final level, the analysis results of LCCA are transformed into intuitive decision-making kanban and report to support owners and managers to make sustainable decisions. In the operation stage, the Internet of Things (IoT) sensors are used to monitor the data of building energy consumption and indoor environmental quality in real time, and the LCCA model is regularly input for the comparative analysis of "planned value and actual value", forming a closed-loop management of "prediction-monitoring-feedback-optimization". After the project is completed, the actual LCCA data are archived to form an enterprise-level "sustainable cost knowledge base", which provides valuable data support for future project investment estimation and design optimization, thus continuously improving the accuracy of sustainable cost management in the whole industry. This layer aims to turn theory into practice and guide long-term building management and optimization.

4. Empirical research design

A newly-built public office building project is selected as the research object, and two comparison schemes are designed for its external protection structure system: Scheme A is the traditional scheme of combining ordinary glass curtain wall with traditional air conditioning system, and Scheme B is the green scheme of adopting high-performance thermal insulation glass curtain wall, building integrated sunshade component and ground source heat pump system; Although the initial construction cost of Scheme B is obviously higher than that of Scheme A, it is expected to significantly reduce the energy consumption level in the operation stage and improve the indoor thermal comfort, which provides a basis for the subsequent comparative analysis of TLCC and sustainability based on LCCA model.

The project life cycle is set to 50 years, and two discount rates are used for comparison. The traditional discount rate is 5% (only reflecting the time value of funds), while the dynamic sustainable discount rate is set to 4% to reflect the impact of future carbon price increase expectations on investment decisions; The carbon price benchmark takes the current market price of 100 yuan/ton of carbon dioxide equivalent, and assumes an annual growth rate of 5%; The social cost mainly considers the loss of health and work efficiency. According to the relevant research of WHO, the cost of productivity loss caused by indoor thermal discomfort is set as 200 yuan/person-year, and the cost is higher in the scheme with poor performance, so as to quantify the differences of different schemes in non-economic dimensions.

Using BIM energy consumption simulation software to simulate the hourly energy consumption of the two schemes within 50 years, and input them into LCCA model for calculation. The expected results are shown in Table 1 and Figure 2 below. Although the initial construction cost of scheme B (green scheme) is as high as 185 million yuan, which is significantly higher than that of scheme A's 150 million yuan, it has obvious advantages in operation and maintenance, environment and social costs, with the operation and maintenance cost reduced from 122 million yuan to 68 million yuan, the environmental cost reduced from 35 million yuan to 12 million yuan, and the social cost reduced from 180 million yuan. 1 million yuan, about 16.6% lower than the 325 million yuan of Scheme A, indicating that the green scheme has significant long-term advantages after comprehensively considering economic, environmental and social benefits.

Table 1 Comparative analysis of present value of TLCC (unit: RMB 10,000)

Cost category	Scheme A (traditional scheme)	Scheme B (green scheme)
Initial construction cost (C_I)	15,000	18,500
Operation and	12,200	6,800

maintenance cost (PV)		
Environmental cost (PV)	3,500	1,200
Social cost (PV)	1,800	600
LCC	32,500	27,100

Note: PV is the present value; Environmental costs are mainly carbon emission costs; The social cost is mainly the loss of health productivity.

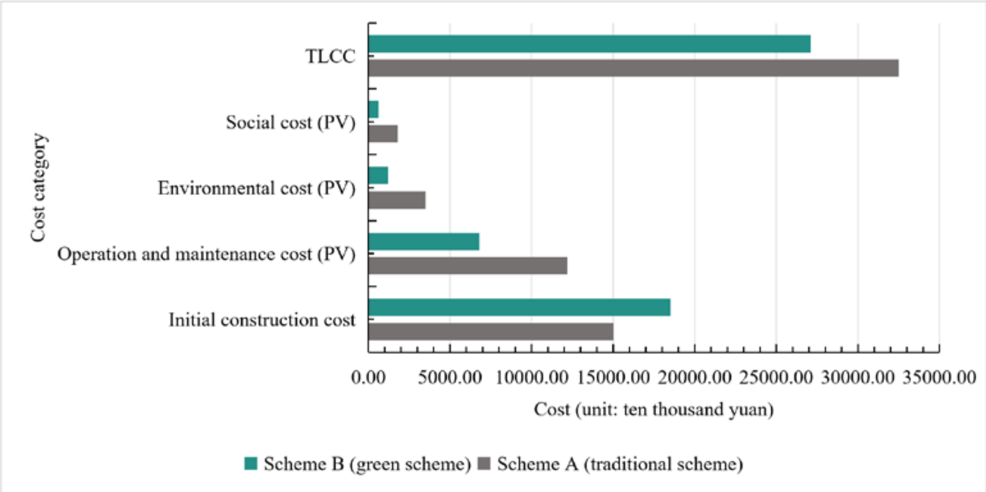

Figure 2 Comparison of LCC structure between two schemes

The empirical results show that, although the initial construction cost of green scheme (B) is 23.3% higher than that of traditional scheme (A), its remarkable savings in operation, environment and social costs reduce the total life cycle cost by 16.6%, which fully proves that decision-making based on sustainable LCCA can break through the cognitive misunderstanding of "high input is uneconomical" and realize the optimization of long-term comprehensive benefits. Sensitivity analysis further shows that the advantage of Scheme B may be weakened when the discount rate exceeds 6%, which highlights the key impact of carbon constraint mechanism on green investment under the guidance of policies, and the increase of carbon price will further enhance its economic competitiveness, thus effectively verifying the scientific and necessary to systematically incorporate sustainable factors into project cost decision.

5. Conclusion

The dynamic management system based on LCCA aims to solve the contradiction between economy and sustainability in traditional civil engineering cost management, and realize the synergy between the optimal full-cycle cost and the sustainable development goal. The research shows that bringing environmental cost and social cost into the category of cost management and forming a conceptual model of "three-dimensional sustainable cost" can effectively improve the scientific and comprehensive decision-making. Based on the sustainable management framework of civil engineering cost of LCCA, through BIM technology and big data analysis, the successful transformation from short-term cost control to full-cycle and multi-dimensional cost management has been realized, which provides important theoretical support and practical guidance for promoting the green, efficient and sustainable development of the construction industry.

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