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Evaluating Construction Cost of Green Building Based on Life-cycle Cost Analysis: An empirical analysis from Nanjing, China

Hongmei Liu*

School of Architecture Engineering, Jiangsu Open University, Nanjing, 210036, China
184858472@qq.com

Abstract

With the economic development, energy consumption is increasingly serious, land resources becoming scarcer and scarcer. Green building can effectively solve the problem of resource shortage; however, the development of green buildings in China is very slow because of its higher cost, compared with conventional buildings.. In this paper, we analyze the construction cost of green building based on life-cycle cost method, and try to find out the key factors that affect the cost. Through the empirical analysis, the results prove that there are six main factors that influence the cost of green building, such as green building technology, policy support, project positioning, construction technology, building materials prices and local conditions. On this basis, we put forward relevant policy suggestions.

Keywords: *Construction cost; green building; life cycle model; architectural design*

1. Introduction

With the continuous growth of the global population, the wasted water and land problems caused by energy use has become more and more serious, such as the greenhouse effect, acid rain, global warming, etc. Global energy crisis and environmental degradation make a profound impact on human survival and development [1]. The European Union measurement standards shows that the construction process will have a serious impact on resource and environment , waste rate of energy is as follows: 42% energy,50% water resources , 48% raw material , 50% arable land, 50% gas emissions and 50% solid waste. [2]. At the same time, most people are gradually aware that the rapid development of human civilization cannot be at the expense of the environment. Therefore the development of low-carbon economy is very important, pushing the building energy conservation has become a global consensus.

According to statistics from China Building Materials Market Association, among China's current buildings, more than 95% are high-energy buildings [3]. In accordance with the current pace of construction, 16 million to 20 million square meters construction will be completed in the year of 2016, and the high energy consumption construction accounted for more than 80% [4].So that, energy consumption is 2~3 times more than that in developed countries, the current construction industry is in a high input, high consumption, high emission and low efficiency state. In order to deal with the global climate change, the development of green building is imperative. In view of this, the national implementation of the green building development strategy is very necessary.

According to Deng and Wu [5], the cost of green building is the key factor that hinders its popularization. Compared with the conventional buildings, we added green element to the construction of green building, it may lead people mistakenly believe that the cost of green building will be higher. On the one hand, the supply of green building materials is less, the market is not standardized, the price of green building materials is generally

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higher than the conventional materials; on the other hand, the conventional construction technology is mature, and the green building technology is not mature enough to meet the need of customers.

Over the past few decades, scholars all over the world have carried out many researches on the theory of green building and the whole life cycle cost. However, most of the research on green building mainly focused on the concept [5-6], green building efficiency and green building evaluation system, etc., lack of the study of whole life cycle of green building cost. According to the research, the green building cost is the key factor to hinder the promotion of green building. Combined with the above analysis, this paper will focus on the construction cost and the life cycle theory, and make comprehensive analysis of the various aspects of the green building cost.

2. Literature review

2.1. Green Building

In 1992, the United Nations Environment and development conference was held in Rio De Janeiro, Brazil. At the meeting, the concept of green building was firstly put forward. Since then, green building has become a research system, not only concerned about the environment, but also related to living comfort and health. Many countries began to practice the green building, and then green building becomes the world's construction industry trends.

Hammad (2014) pointed out that green building means the respect of nature and strives to design sustainable building by using efficient resources [7]. The essential idea of green design is to pursue the design method which could minimize the impact on natural environment as well as to prevent deterioration of natural environment [8]. Its purpose is neither to be defeated nor to retreat from nature. Green design is a kind of positive behavior, which is expected to be a positive contribution to the natural environment.

Green building is emphasized in the whole life cycle of building. It includes building materials production, planning, design, construction, operation and maintenance and removal, recycling scrap the whole process, all links can be efficient use of building resources, land saving, energy saving and water saving[4]. When Green building achieves the relevant performance requirements, it will increase investment of initial construction, but from the perspective of whole life cycle, the future operation and maintenance costs will be reduced. According to the existing experience, green building need to use green materials and green technology, etc. so that the initial cost will increase 5%-10%, but will save the long-term running costs for 50%-60%[3].

2.2. Life Cycle Cost Analysis

In China's current construction industry, the green building is still in an initial stage, it has not been vigorously promoted, and the practical experience is insufficient [9]. The research on the whole life cycle cost of green building is very limited. Castellano (2014) presented the concept of building cost in the whole life cycle of the green building, and analyzed the economic externality of green building [10].

Li *et al.*, (2014) made comprehensive analysis of factors that affect the whole life cycle cost of green building, and put forward the methods of controlling the cost of green building[11]. Kim (2013) used the cost benefit analysis to make the evaluation index system of green building, and evaluate the economic performance of project [12]. Based on relevant literatures, the main research is the cost benefit evaluation of green building, but lack of whole life cycle cost management. Therefore, it is essential to research life cycle cost theory of green building, which will have certain theoretical and practical significances.

3. Research Model

Cost estimation is another problem to be explored; the life cycle cost estimation is an important part of project cost. Therefore, this article will firstly analyze existing estimation methods and whole life cycle cost estimation to do further research, so as to put forward the whole life cycle cost estimation model as well as carry out empirical estimation.

3.1. Cost estimation based on fuzzy recognition theory

Firstly, we establish n index for analyzing characteristics of a specific project, because residential projects can usually use base type, the main structure form, indoor and outdoor decoration, building floors, floors, walls, roof, floor, stairs, doors and windows type, marked as $T=\{T_1, T_2, T_3 \ldots T_n\}$. And confirm the membership degree by using construction cost statistics and expert evaluation.

To determine the fuzzy nearness method, similar approach degree is mainly used:

$$d_H(A,B) = 1 - \frac{1}{n}\sum_{i=1}^{n} \left| A(u_i) - B(u_i) \right| \tag{1}$$

And Maximum-minimum method:

$$r_{ij} = \frac{\sum_{k=1}^{n} (x_{ik} \wedge x_{jk})}{\sum_{k=1}^{n} (x_{ik} \wedge x_{jk})} \tag{2}$$

In the formula, R_{ij} means the similarity coefficient of T_i and T_j; X_{ik} and X_{jk} are the corresponding membership values. And Wang's close degree as:

$$r_{ij}(A,B) = 1 - \frac{1}{2}\left[A \times B + (1 - A \oplus B) \right] \tag{3}$$

According to the second steps of proposed project, three typical projects are selected to estimate the cost of project. Finally to estimate project cost by exponential smoothing method, in which P_1, P_2 and P_3 represent the typical engineering fuzzy closeness degree respectively, D_1, D_2 and D_3 represent the cost of the project, According to the exponential smoothing method, three typical engineering projects are selected to construct the model of S initial cost calculation model:

$$\begin{aligned} Ds &= P_1 \cdot D_1 + P_2 \cdot (1 - P_1) \cdot D_2 + P_3 \cdot (1 - P_1) \cdot (1 - P_2) \cdot D_3 \\ &+ \frac{1}{3} \times (1 - P_1) \cdot (1 - P_2) \cdot (1 - P_3) \cdot (D_1 + D_2 + D_3) \end{aligned} \tag{4}$$

Construction time may be difference in typical project, , it is necessary to introduce adjustment coefficient as β , and β is used to improve the accuracy of the estimation.

$$\beta = 1 + \frac{1}{\mu}\left[1.8\left(\frac{T_{bg}}{T_{\rho 1}} - 1 \right) + 0.8\left(\frac{T_{bg}}{T_{\rho 2}} - 1 \right) + 0.4\left(\frac{T_{bg}}{T_{\rho 3}} - 1 \right) \right] \tag{5}$$

Finally, the construction cost of the project S is estimated:

$$Ds = \beta \times \{ P_1 \cdot D_1 + P_2 \cdot (1 - P_1) \cdot D_2 + P_3 \cdot (1 - P_1) \cdot (1 - P_2) \cdot D_3 + \frac{1}{3} \times (1 - P_1) \cdot (1 - P_2) \cdot (1 - P_3) \cdot (D_1 + D_2 + D_3) \} \quad (6)$$

3.2. Life Cycle Cost Estimation Model

In this paper, future cost is calculated according to operation cost, maintenance cost and value to the division formula, as:

$$LCC = C_0 + \sum_{t=0}^{T} OPV_{sum} + \sum_{t=0}^{T} M \times PV_{sum} - S \times PV \quad (7)$$

$$PV_{sum} = \frac{(1 + r) \cdot t - 1}{r \cdot (1 + r) \cdot t} \quad (8)$$

$$PV = \frac{1}{(1 + r) \cdot t} \quad (9)$$

Where C_0 means the initial construction cost, O means operating costs, M means maintenance costs, S means residual value, PV_{sum} means present value and, T means life cycle, t means time variable, R means discount rate and, PV means discount factor.

According to the above analysis, we present a model for the whole life cycle cost of the green building as:

$$D = \beta \times \{ P_1 \cdot D_1 + P_2 \cdot (1 - P_1) \cdot D_2 + P_3 \cdot (1 - P_1) \cdot (1 - P_2) \cdot D_3 + \frac{1}{3} \times (1 - P_1) \cdot (1 - P_2) \cdot (1 - P_3) \cdot (D_1 + D_2 + D_3) \} + \sum_{t=0}^{T} OPV_{sum} + \sum_{t=0}^{T} M \cdot PV_{sum} - S \cdot PV \quad (10)$$

In general, fuzzy identification method is adopted to calculate the cost of green building. However, variable probability distribution is difficult to be determined because it is difficult to obtain whole life cycle cost of a specific project. Therefore, it is only practical to estimate its initial construction cost and provide the basis for the project investment decision-making, but the full life cycle cost model still need to be further studied.

4. Empirical Analysis

4.1. Index Selection

Each phase of green building project is not independent but mutually influenced. Therefore, it is necessary to choose high ranked factors as research objects. This article sets up following principles for establishing the index system of green building's whole life cycle cost. According to analysis in Section 3 and comprehensive results; this section combines characteristics and development of green building, then selects the initial 24 factors in green building’s life cycle cost, as shown in Table 1.

Table 1. The Life Cycle Cost Factors of Green Building

Number	Factor	Number	Factor
A1	Enterprise green consciousness	A 13	consumption assessment
A 2	Green construction technology	A 14	Green building project type
A 3	Green building goals	A 15	Construction supervision
A 4	Water saving design	A 16	Waste harmless treatment
A 5	Consumer awareness	A 17	materials prices
A 6	Green construction scheme	A 18	Basic research on green building
A 7	Energy saving design	A 19	Green building assessment
A 8	Land saving design	A 20	Waste recycling
A 9	Industry standard	A 21	Project local conditions
A 10	Material saving design	A 22	Operation management technology
A 11	Green design pattern	A 23	Government green awareness
A 12	Policies and regulations	A 24	Engineering design change

4.2. Sample and Statistical Analysis

In this paper, the key factors are extracted by using principal component analysis method based on the questionnaire survey. In order to reflect the status of the green building market, we ultimately determine to choose the relevant professionals as the object of the questionnaire survey, the professionals includes government personnel, developers, contractors, managers from construction design companies and related experts. The investigation time was from January 2015 to June 2015, in Nanjing city. Then we make statistical analysis of the sample, as shown in table 2. From table 2, we can get that there are male174, accounting for 58%; female 126, accounting for 42%.In the aspect of age, we can find that 44 people younger than 30, 102 people aged between 30 and 40, 61 people older than 50, it shows that young people accounted for more than 50% .

4.3. Validity Analysis

When using principal component analysis, KMO and Bartlett test were used to test the model. If the KMO value is less than 0.5, it means the correlation is not significant. The test results of this paper are as follows: KMO value is 0.683, more than 0.5, and Bartlett's test of sphericity is significant, so it is suitable for the empirical analysis.

Table 2. The Statistical Analysis of the Sample

Item	Content	number	Percent
Gender	Male	174	58.0%
	Female	126	42.0%
Age	Under 30	44	14.66%
	31-40	102	34.0%
	40-50	93	31.0%
	More than 50	61	20.33%
Position	employees	201	67.0%
	First-line managers	76	25.33%
	Middle managers	23	7.66%
Working year	Less than 1year	25	8.34%
	1-5 year	101	33.66%
	6-10 year	80	26.67%
	More than 10 years	94	31.33%

Table 3. The Result of KMO Statistical Test

Kaiser-Meyer-Olkin		0.683
Bartlett's test	Approximate chi-square	132.554
	df	16
	Sig.	0.000

4.4. Principal Component Analysis

From Table 4, we can see that the first principal component is A4, A7, A11, A22, and the second principal component is A12, A19, the third principal components includes A3, A14;the fourth principal components includes A15, A6 and A2, and the fifth principal component includes A7, the sixth principal component includes A21. Therefore, we selected 6 key factors from 24 factors. At the same time, we find out the variable coefficient of the load of each principal component, and the main components are as follows:

$$F1=0.654A4+0.737A7-0.666A11-0.740A22$$

$$F2=0.641A3+0.738A14$$

$$F3=0.780A4+0.799A14$$

$$F4=0.640A2+0.683A6+0.718A15$$

$$F5=-0.745A7$$

$$F6=0.768A21$$

By analyzing the main component, the key influence factors are divided into six types, the factors indicators of full life cycle cost as shown in table 5. According to analysis results, we obtain key factors that influence whole life cycle cost of green building In fact, with the promotion of green building, the technical level of the green construction cost is mainly reflected by following points: first is the defect of technical scheme; second is lack of technical refinement, the design process is not comprehensive, energy saving and new materials has not been considered; third is the technology foundation is not solid, the whole process control level is insufficient; fourth is the lack of core competitiveness; fifth is the cost control ability is very poor.

Table 4. Factor Loading Matrix after Orthogonal Rotating

	1	2	3	4	5	6
A1	-.204	.285	-.127	.394	-.495	.075
A2	.063	-.415	.352	.640	.140	.135
A3	.179	.040	.780	-.032	.001	-.095
A4	.654	-.087	.149	-.156	.414	-.058
A5	-.596	-.236	.042	.019	.308	-.075
A6	-.106	.210	.135	.683	.003	-.413
A7	.737	-.292	.102	.104	-.094	.285
A8	.114	-.398	.581	.408	.025	.141
A9	-.049	.030	-.116	-.080	.086	.001
A10	.465	-.201	.115	-.202	.132	.244
A11	-.666	-.179	-.083	.317	-.203	-.112
A12	-.025	.641	-.116	-.038	.060	.223
A13	.236	-.584	.192	-.242	.108	.094

A14	.031	-.067	.799	-.032	.132	-.017
A15	-.132	.164	-.267	.718	.089	.139
A16	-.025	.710	.021	.119	.256	.067
A17	-.041	-.134	-.027	-.362	-.734	.064
A18	.050	.097	.037	-.079	.047	-.133
A19	.140	.738	-.042	-.021	-.121	-.031
A20	-.008	.240	-.176	-.320	.432	.225
A21	.043	.230	-.052	.060	-.026	.768
A22	-.740	-.064	-.223	-.146	.065	.362
A23	-.052	.097	-.440	-.040	.360	.299
A24	.248	-.218	.541	-.077	-.242	.431

Table 5. Index classification of Green construction Costs

	Influence factors	Index
1	A4 Water saving design ; A7 Energy saving design; A11 Green design pattern; A22 Operation management technology	Green building technology
2	A12 Policies and regulations; A19 Green building assessment	Policy support
3	A3 Green building goals; A14 Green building project type	Project positioning
4	A2 Green construction technology; A6 Green construction scheme; A15 Construction supervision	Construction technology
5	A17 materials prices	Building materials prices
6	A21 Project local conditions	Local conditions

5. Conclusion

Adhering to sustainable development has become a consensus of the world; China is also actively promoting the sustainable development of construction industry. However, people's understanding of the cost of green building is bound to hinder its development. In view of this, we research the theory of life cycle cost, combined with the status of green building, then analyze the whole life cycle cost of green building, and make empirical analysis. The factors that affect the cost of green building are complex. In this paper, we use main components analysis method and determine the six key factors, which are green building technology, policy support, project positioning, construction technology, building materials prices and local conditions. On this basis, we put forward relevant policy suggestions.

5.1. Improve the Idea of Green Building

Most people think green building is a high-end residential house, but in fact green building does not mean high cost. A lot of so-called “green buildings” in China use a lot of high technology and equipment terminals, which have not only greatly increased the initial investment, but also been invisible to increase the follow-up property maintenance costs, therefore it would increase the maintenance costs of the owners in operation stage.

5.2. Clear the Goal of Green Building Projects

Different green objectives will lead to different levels of cost, it is therefore necessary to pay attention to effectiveness of project, there is a higher demand, which is reducing the post operational energy consumption, focusing on energy efficiency.

5.3. Residential industrialization

Using the applicable technology, we may achieve the standard of green building, and save the cost. According to the different regions of the climate, building materials should be different. Through these practices, we can achieve low cost, and also realize local natural harmony.

5.4. Improve Laws and Regulations

The relevant departments of the State shall revise and improve the evaluation standards of green building. Government should provide more financial support for the assessment and practice of domestic green building, such as tax benefits, special fund, reducing the additional spending, improving the concern and recognition of green building.

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