Technical application and economic benefit analysis of green construction concept in municipal road engineering

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Abstract: With the goal of "double carbon" and the promotion of ecological civilization construction, the concept of green construction is gradually applied to municipal road engineering, aiming at solving the problems of resource waste and environmental pollution brought by traditional construction mode. This paper discusses the application of green construction technology in municipal road engineering and analyzes its economic benefits. First of all, the paper combs the key technologies such as energy saving, environmental protection materials, water saving and environmental protection and intelligent management, and focuses on the technological principles and applicable scenarios of warm mix asphalt and recycled aggregate concrete. Secondly, based on the life cycle cost method (LCC), an evaluation model including initial investment, operation and maintenance, and environmental governance costs is established, and the key variables are identified through sensitivity analysis. Finally, taking a municipal road project as an example, the cost-benefit difference between traditional and green construction schemes is compared, and the economic feasibility of green construction scheme is verified. The research results show that, although the initial investment of the green construction scheme is high, by reducing the long-term operation and maintenance costs and the external environmental costs, it can produce remarkable economic benefits in the whole life cycle of the project and has good environmental benefits. This study provides theoretical basis and practical reference for promoting the application of green construction technology in municipal road engineering.

1. Introduction

The traditional municipal road construction mode has long relied on the technical path of high energy consumption and high pollution, which leads to the increasingly prominent problems of resource waste and environmental pollution. Driven by the goal of "double carbon" and the construction of ecological civilization, the concept of green construction is permeating from the field of architecture to municipal engineering. In 2022, the Ministry of Housing and Urban-Rural Development issued the Construction Industry Development Plan of the 14th Five-Year Plan, which clearly required that the carbon emission intensity of municipal projects should be reduced by 15% in the whole life cycle, and promoted the large-scale application of low-carbon technologies such as warm-mixed asphalt and recycled aggregate. However, the promotion of green construction technology in municipal road engineering still faces challenges: on the one hand, the initial investment cost is 20%-30% higher than the traditional model, and the enthusiasm of enterprises is limited; On the other hand, the lack of quantitative evaluation tools leads to frequent technical and economic disputes [1] Therefore, a systematic analysis of the applicable scenarios and benefit boundaries of green construction technology has become a key proposition to promote industry transformation.

The existing research mostly focuses on the application of green construction in the field of housing construction, and the systematic analysis of municipal road engineering is still insufficient. Municipal engineering has the characteristics of linear distribution, long construction period and high environmental sensitivity, and its technical selection and benefit evaluation need to consider special constraints such as traffic diversion and underground pipeline protection [2]. This study

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combs the key technologies from four aspects: energy saving, water saving, environmental protection materials and intelligent management, and focuses on the technological principles and applicable scenarios of warm mix asphalt and recycled aggregate concrete. Based on life cycle cost method (LCC), an evaluation model including initial investment, operation and maintenance, and environmental governance costs is established, and key variables are identified through sensitivity analysis. Taking a municipal road project as an example, the cost-benefit difference between traditional and green construction schemes is compared to verify the technical and economic feasibility.

2. Technical system of green construction concept in municipal road engineering

Municipal road engineering has the characteristics of linear distribution, open-air operation, long cycle and close interaction with the surrounding environment. Its green construction technology system needs to be built around the core ideas of "energy saving, material saving, water saving, land saving and environmental protection" ("four festivals and one environmental protection") and combined with the characteristics of the project itself.

2.1 Energy saving and consumption reduction technology

Apply Warm Mix Asphalt (WMA) technology. The mixing and paving of asphalt mixture is achieved through physical or chemical means at lower temperatures (usually 20-30 ℃ lower than hot mix asphalt). This technology significantly reduces fuel consumption, reduces emissions of asphalt smoke, carbon dioxide, and harmful gases, improves the working environment for workers, and is a key technology for achieving the "dual carbon" goal in road engineering [3]. Energy saving transformation and scientific scheduling of construction machinery, using frequency conversion equipment, optimizing construction processes to reduce idle energy consumption, and utilizing renewable energy such as solar energy to supply power to temporary facilities.

2.2 Environmental protection materials and resource recycling technology

After being crushed and screened, the waste concrete, bricks and tiles produced by demolition will partially or completely replace natural aggregate to produce road base/subbase materials or recycled aggregate concrete [4]. This technology realizes the resource utilization of solid waste and reduces the ecological damage and raw material cost caused by quarrying. Use industrial by-products such as fly ash and slag as admixture; Promote the application of long-life building materials, and reduce the material consumption and maintenance frequency in the whole life cycle from the source.

2.3 Water saving and environmental protection technology

The rainwater collection system, sedimentation tank and wastewater treatment and reuse facilities at the construction site are established, and the treated water is used for dust suppression, vehicle washing and maintenance, which greatly reduces the consumption of municipal clean water [5]. Intelligent spraying dust suppression system (automatically started and stopped according to dust monitoring data), full coverage of bare soil during construction, real-time monitoring and control of construction noise, in-situ treatment or safe disposal technology for contaminated soil, and minimize the interference to the surrounding ecological environment and residents' lives.

2.4 Intelligent and digital management technology

BIM (Building Information Model), GIS (Geographic Information System) and Internet of Things (IoT) technologies are applied to the whole process of municipal road engineering. Realize the optimization of earthwork excavation and filling balance, pipeline collision inspection to avoid construction damage, real-time monitoring and dynamic optimization of construction progress and resource consumption, thus improving efficiency and reducing waste from the management level [6]. The UAV is used for earthwork calculation and progress inspection, and the intelligent compaction system is used to ensure uniform compaction quality and avoid over-voltage or under-voltage, saving energy and materials.

3. Economic benefit analysis method of green construction technology

In view of the controversy about "high initial investment and unclear long-term benefits" of green construction technology, this study abandons the traditional static analysis method that only focuses on the construction period cost, and adopts LCC analysis method to construct an evaluation model that can quantify its long-term comprehensive economic benefits.

Systematically calculate the LCC and benefit of the project, and the cost part covers the initial investment cost, operation and maintenance cost, external environmental cost and residual value or demolition and disposal cost (as shown in Table 1); Benefits include direct economic savings such as electricity, water and materials saving and indirect environmental benefits reflected by reducing environmental costs; Finally, the economic and environmental advantages of the green construction scheme compared with the traditional scheme are comprehensively evaluated by calculating key indicators such as net present value (NPV), benefit-cost ratio (B/C Ratio) and dynamic payback period of investment.

Table 1 LCC classification of green projects

Cost category	Describe
Initial investment cost (C0)	Including the incremental cost of green technology itself and the investment of related intelligent monitoring equipment.
Operation and maintenance cost (C1)	The focus is on the maintenance and repair costs after the road is put into use. The key source of benefits is the cost savings caused by the extension of maintenance interval and the reduction of maintenance workload brought by green technology.
Environmental external cost (C2)	In order to reflect the "green" value, the cost of environmental pollution control is internalized. Including carbon emission cost (which can be calculated according to the market price of carbon trading), waste disposal cost, water resource consumption cost and so on. The reduction of environmental cost brought by the application of green technology constitutes one of its core benefits.
Residual value/demolition disposal cost (C3)	Consider the residual value of recyclable materials or the cost of demolition and disposal at the end of the project.

Admit that there are uncertainties in the evaluation, such as fluctuations in energy prices, carbon trading prices and material prices [7]. Through sensitivity analysis, the key variables that have the greatest influence on the evaluation results, such as electricity price, price difference between recycled aggregate and natural aggregate, carbon emission cost, etc., are identified, and the fluctuation range of these variables is analyzed, so as to provide risk reference and strategic suggestions for decision makers.

4. Case analysis

Taking the newly-built "Ecological Avenue" project in a city (with a total length of 5.2km, two-way six lanes and a design speed of 60km/h) as the object, this paper makes an empirical study.

4.1 Project overview and scheme design

The project passes through the urban fringe area, surrounded by residential areas and ecological protection areas, and is sensitive to noise, dust and long-term environmental impact during construction. The project duration is 18 months. The study set two comparison schemes:

(1) Traditional solution (TS): using hot mix asphalt (HMA), natural aggregates, conventional watering to reduce dust, and traditional project management mode.

(2) Green Scheme (GS): A number of green technologies such as WMA, recycled aggregate (30% replacement rate is used at the grass-roots level), intelligent site management system (including BIM platform, intelligent compaction, on-line monitoring of dust noise) and rainwater collection and reuse system are integrated.

4.2 LCC and benefit analysis

The evaluation period is set as 30 years (construction period is 1.5 years+operation period is 28.5 years), and the social discount rate is 8%. By identifying and estimating the LCC of the two schemes, the following results are obtained (Table 2).

Table 2 LCC benefit comparative analysis table (Unit: RMB 10,000)

Cost/benefit category	Traditional scheme (TS)	Green scheme (GS)	Difference (GS-TS)
Initial investment cost (C0)	28,500	30,200	+1,700
Incremental cost of green technology	-	+1,700	-
Operation and maintenance cost (C1)	9,200	7,500	-1,700
(Discounted to Present Value) Environmental external cost (C2) (including carbon emission, waste disposal, etc.)	1,850	1,200	-650
Demolition disposal cost (C3) (The residual value is negative and the demolition cost is positive)	-800	-500	+300
Total cost (LCC)	38,750	38,400	-350

The cost of the green scheme is about 6% (+17 million yuan) higher than that of the traditional scheme due to the use of WMA additives, recycled aggregate processing and intelligent site system. In the green scheme, due to the better performance of WMA pavement and the stable structure of recycled base, it is estimated that the maintenance frequency and material consumption can be reduced by 20%, and the maintenance cost can be significantly reduced. Based on the local carbon transaction price (50 yuan/ton CO_2) and the unit price of waste disposal, the carbon emission and solid waste emission costs in the construction and operation stages are quantified. The green scheme reduces the environmental cost by 35% through energy saving, emission reduction and resource utilization. The residual value of natural materials used in the traditional scheme is higher, while the recycling value of recycled aggregate in the green scheme is lower, so the residual value income is slightly lower.

Based on the data in Table 1, calculate the main economic evaluation indicators:

Incremental Net Present Value (ΔNPV): ΔNPV = (LCC_TS - LCC_GS) = 38,750 - 38,400 = 3.5 million yuan.

From the whole life cycle, the green scheme saves 3.5 million yuan in total cost compared with the traditional scheme, which has economic advantages.

Benefit-cost ratio (B/C Ratio): Operation and maintenance savings and environmental cost savings are regarded as benefits (B = 1700+650 = 23.5 million yuan), and green incremental investment is regarded as costs (C= 17 million yuan).

B/C Ratio = 2350 / 1700 ≈ 1.38 > 1.

The benefit of green incremental investment is higher than its cost, and the project is economically feasible.

Dynamic payback period (Pt): Calculate the years of green incremental investment (17 million yuan) recovered through operational savings and environmental cost savings.

After calculation, the dynamic payback period of the green technology of the project is about 9.2 years (less than 1/3 of the 30-year evaluation period).

4.3 Sensitivity analysis

The economy of green scheme is easily affected by the fluctuation of key price parameters. In this study, the sensitivity of electricity price (which affects WMA production and intelligent equipment operation), carbon trading price and the price difference between recycled aggregate and natural aggregate are analyzed (Figure 1).

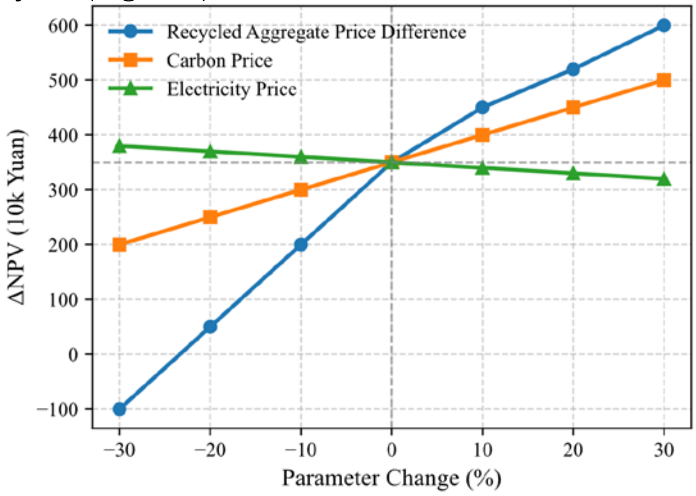

Figure 1 Influence of key parameter fluctuation on incremental net present value (ΔNPV) of green scheme

The price difference of recycled aggregate is the most sensitive factor. When its price advantage is expanded (the price difference is expanded to +30%), the economy (ΔNPV) of the green scheme is significantly improved to about 6 million yuan; If its price advantage weakens or even disappears (the price difference is -30%, that is, recycled aggregate is more expensive than natural aggregate), the economy of green scheme will drop sharply or even be negative. This shows that a stable waste recycling policy and market are very important for the promotion of green technology.

The sensitivity of carbon price is high. With the improvement of China's carbon trading market and the increase of carbon price (+30%), the economic benefits of green scheme due to emission reduction will be more prominent (ΔNPV will be raised to about 5 million yuan). This confirms the long-term value of green technology under the "double carbon" policy. The impact of electricity price fluctuation is relatively small, indicating that the cost-effectiveness of energy-saving technologies (such as WMA) has certain stability.

Although green construction technology needs high initial investment in municipal road engineering, it can produce remarkable economic benefits in the whole life cycle of the project by reducing long-term operation and maintenance costs and environmental external costs. Under the parameters of this case, the green scheme can achieve a net saving of 3.5 million yuan during the project period, and the investment payback period is about 9 years.

5. Conclusion

This study systematically analyzes the technical application and economic benefits of green construction concept in municipal road engineering, and draws the following conclusions:

(1)The application of green construction technology in municipal road engineering has significantly improved the traditional construction mode with high energy consumption and high pollution. WMA technology can save energy and reduce consumption by reducing fuel consumption and harmful gas emissions. The application of recycled aggregate concrete reduces the waste of resources and ecological damage; Intelligent management technology improves the construction efficiency and reduces the waste of resources. These technologies have effectively promoted the transformation of municipal road engineering to green and low carbon.

(2)Although the initial investment of green construction technology is 20%-30% higher than that of traditional mode, its LCC has obvious economic advantages. Taking the "Ecological Avenue" project in a city as an example, the total cost of the green scheme is 3.5 million yuan, the incremental net present value (ΔNPV) is 3.5 million yuan, the benefit-cost ratio (B/C Ratio) is about 1.38, and the dynamic investment payback period is about 9.2 years. This shows that green construction technology has obvious advantages in long-term operation and maintenance and environmental cost saving.

(3)Sensitivity analysis shows that the price difference of recycled aggregate and carbon trading price have great influence on the economy of green scheme. When the spread of recycled aggregate is expanded to +30%, the economy of green scheme is significantly improved; The rising carbon price further enhances the economic benefits of green technology. Therefore, a stable waste recycling policy and market mechanism are very important for the promotion of green technology.

To sum up, the application of green construction concept in municipal road engineering can not only achieve the goals of energy saving and environmental protection, but also produce significant economic benefits in the whole life cycle of the project. In the future, we should further promote the large-scale application of green construction technology, and promote its sustainable development through policy guidance and market mechanism optimization.

References

[1] Cui Xiaoming. Application of Green Construction Concept in Campus Construction Projects[J]. Building Materials World, 2025, 46(04): 109-112.

[2] Cao Wei. Application of Construction Technology under the Concept of Green Environmental Protection in Green Buildings[J]. China Strategic Emerging Industries, 2025, (23): 109-111.

[3] Li Jifan. Application and Benefit Evaluation of Green Construction Concept in Building Construction[J]. New Urban Construction Technology, 2025, 34(07): 51-53.

[4] Zhang Nianshi, Ma Zongcong, Zhang Zhaotang. Research on Selection Strategies and Construction Application of Decoration Materials under the Concept of Low Carbon[J]. China Building Decoration and Renovation, 2025, (13): 100-102.

[5] Lan Fu'an. Optimization and Application of Interchange Bridge Engineering Construction Organization Scheme under the Concept of Green Construction[J]. Transportation Energy Saving and Environmental Protection, 2025, 21(03): 193-197.

[6] Ma Shihai. Research on the Application of Green Residential Building Construction Technology Based on the Concept of Energy Saving and Consumption Reduction[J]. Residential Industry, 2024, (03): 40-42.

[7] Ma Tao, An Dandan. Innovation and Application of Building Construction Technology under the Background of Green and Energy-saving[J]. China Brand and Anti-counterfeiting, 2024, (04): 67-68.