

A Comparative Study of Carbon Emissions in the Whole Life Cycle of Old Building Rehabilitation and Reconstruction Scenarios

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Abstract. This paper provides a comprehensive comparison of carbon emissions, cost-effectiveness, and disaster risk mitigation between old building rehabilitation and reconstruction scenarios through a full life cycle assessment (LCA) framework, combined with the China Building Carbon Emission Calculation Standard. The results show that the reconstruction scenario has higher carbon emissions and high initial investment but better structural resistance to disasters. In contrast, the retrofit scenario has reduced carbon emissions and initial costs but increases its post-disaster recovery needs. This study highlights the importance of balancing short-term economics with long-term carbon reduction. Future research should extend to different climate zones and building types, incorporate carbon emissions during the demolition phase, and explore carbon trading mechanisms, thus providing policymakers and practitioners with a basis for optimizing building retrofit decisions and contributing to global carbon neutrality goals.

Keywords: Retrofit; retrofit cost-effectiveness; building fabric; carbon emissions; cost; risk.

1. Introduction

Buildings account for 28% of global carbon emissions[1], with China contributing over 20% due to rapid urbanization. Despite the growing emphasis on carbon neutrality, existing studies predominantly focus on either emission reduction[2] or cost optimization[3], neglecting the synergy between environmental, economic, and resilience goals. This study addresses this gap by integrating China's "Carbon Emission Calculation Standard"[4] into a multidimensional LCA framework, aiming to answer: How can retrofit and reconstruction schemes balance immediate affordability with long-term carbon neutrality and disaster resilience?

2. Methodology

2.1. Carbon Emission Calculation Methodology

Carbon emissions are measured in three stages: material production, transportation, and operation. The carbon emission factors for each stage are determined according to the Chinese standard[4].

To achieve the three objectives of "carbon reduction, cost reduction, and disaster resilience" in the renovation of old buildings, green technologies, and disaster prevention strategies need to be integrated through systematic design. The following are specific implementation plans:

a. Low-carbon material recycling

Recycled concrete waste is processed into a recycled aggregate (RAC) for foundation reinforcement[5], which can reduce carbon emissions by 40%; industrial wastes such as fly ash and slag are utilized to replace cement, which reduces carbon emissions from raw material extraction, which can reduce the amount of cement while improving building strength and enhancing the disaster-resistant performance of buildings.

b. Energy-saving renovation and passive design

Firstly establish a vertical greening system[6], set up green plants for shading on the building façade, reduce the air-conditioning load in summer through transpiration; then establish a sloping-roof rainwater diversion system to synchronize the solution to the problem of heat insulation and

flood prevention; and heat-insulating materials such as expanded polystyrene (EPS) are used to reduce the thermal conductivity by using a closed-cell structure while reducing the load on the wall[7].

c. Disaster-resistant performance enhancement design

Enhances the building's disaster-resistant performance by strengthening the node connections and modularizing the structure, and reduces Carbon emissions of the post-earthquake rebuilding[8]; the waterproof performance of the foundation is evaluated, and additional flood protection baffles and seepage diversion layers are installed to avoid uneven settlement.

d. Low-carbon strategy for the construction process

Shorten the transportation distance and prioritize the use of local materials, which reduces the carbon emissions of transportation[9]; optimize the procurement of materials through the BIM model, which reduces the waste of construction; and classify the on-site construction wastes and improve the reuse rate of the materials.

2.2. The costing method

Adopts the “bill of quantities” method, using software to create and import the building model (BIM), automatically extracting the amount of work, selecting the appropriate quota subheadings or list items according to the type of project, and taking into account factors such as labor costs, material costs, machinery costs, management fees, profits, and market price dynamic adjustment, to generate complete project cost documents.

3. Case Study

Based on the above methods, this study takes a training building in Xi'an as an example, with a service life of 50 years, which has been in use for 40 years, with a total floor area of 184.96 square meters, and problems such as wall cracking, insufficient insulation, and risk of flooding and earthquakes, which can no longer be continued to be used as a training site. There are two remedial strategies: reconstruction and construction.

4. Result and Discussion

4.1. Results of the calculation of carbon emissions

In this case, the full life cycle of the project is divided into three phases: production of building materials, transportation of materials, and operation of the building, without considering the demolition of the building. Using the method of calculating carbon emissions in Section 2, the original carbon emissions of the building, the carbon emissions of the reconstructed building, and the carbon emissions generated by the retrofitting building (tCO₂e) can be derived. This is shown in Table 1. Carbon emissions increased by about 51% by reconstructing and 8% by retrofitting. Therefore, based on considering only carbon emissions, construction is the best solution.

Table 1. Comparison of Carbon Emissions from Original Condition, Reconstruction, and Construction of Buildings

	Stage 1	Stage 2	Stage 3	Total	Decrease(+) or increase(-)
original building	16887.07	6836.27	2617.97	26341.31	
Rebuilding	24852.92	9418.14	5464.14	39735.20	+13393.89
Reconstruction	14742.64	4020.78	2370.90	24188.36	-2152.95

4.2. Cost analysis

The cost of the original building can be derived according to the method of calculating the cost in section 2, as shown in Table 2. If you choose to reconstruction, it will increase the construction and labor costs and the project's initial investment. Therefore, if you only choose from the perspective of total cost, construction is the best solution.

Table 2. Project costs

Project Type	Element	Subtotal (in yuan)
Sub-component project	Diffusers, windows and doors, cast-in-place concrete reinforcement, etc.	457776.08
Measures Project	Safety and civilization construction costs, environmental protection, scaffolding, etc.	36903.19
Other Project	Provisional sums, provisional estimates for specialized works, etc.	11078.8
Total		468854.88

If the reconstruction option is chosen, the initial investment will be higher, but its design life will be longer than that of the rehabilitation option, and the full life cycle of reconstruction (including maintenance) may be lower if calculated on the basis of the average annual cost, and the reconstruction option meets the high resilience standard better and reduces the hidden costs of future post-disaster rehabilitation (e.g., insurance claims). This option increases initial investment but avoids long-term risks; the retrofitting option is more economical in the short term, but future deterioration of materials may lead to repeated maintenance, increasing cumulative costs, and hidden carbon emissions. The final plan should be selected based on the actual needs of the project to measure carbon emissions, costs, and disaster risks.

5. Conclusions

This study conducted a comparative analysis of the full life-cycle carbon emissions and costs of rehabilitation and reconstruction options for old buildings, and came to the following conclusions: (1) The retrofitting option performs better in terms of carbon emissions and costs, and the reconstruction option has more potential for disaster resilience; (2) Although the initial investment of disaster protection design is higher, it achieves win-win economic and environmental benefits by reducing the need for post-disaster restoration over the whole life cycle; (3) It is crucial to balance short-term economics with long-term carbon emission reduction, and it is recommended to adopt strategies such as localized material sourcing, biobased substitutes, and smart energy systems. If analyzed from the perspective of carbon emission reduction and cost reduction, the choice of reconstruction is the best option; if analyzed from the perspective of disaster resistance performance, retrofitting is the best option. Future research should expand to different climate zones and building types, incorporate carbon emissions during the demolition phase, and explore carbon trading mechanisms to provide a more comprehensive basis for building reconstruction decisions and contribute to the global carbon neutrality goal.

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