Research on Design Methods for Green Retrofits of Existing Buildings in the Context of Building Stock Renewal

Shilei Bai

Design and Research Institute of China Railway No.4 Engineering Group Co., Ltd., Hefei, Anhui, 230000, China

Keywords: Building stock renewal; Existing buildings; Green retrofitting; Design methodologies; Sustainable development

Abstract: With China gradually entering the stage of building stock updates, green renovation of existing buildings has become an important way to promote sustainable urban development and achieve dual-carbon goals. However, many of the existing buildings have issues such as high energy consumption, lack of comfort and degraded function that urgently need to be updated renovated and re-enlivened by scientific design methods. In the context of approaching stock replacement this paper systematically reviews the benefits and value from green retrofitting existing buildings. It nuances design methodologies among spatial and functional optimization, energy-saving and environmental technologies, and smart systems and operational management. By way of case studies, it sets out applicable green retrofitting pathways and strategies for each building type. Results suggest that not only does green retrofitting greatly reduce building energy consumption and improve user experience, but it also lengthens the life of a building while providing urban regeneration and low-carbon transformation for its synergistic development. The green retrofitting of existing buildings should be aligned with strategic policy approaches, technological developments and operational management to ensure that urban renewal and ecological civilization development are carried out in an integrated manner in the future.

1. Introduction

With China's socio-economic transformation and deepening urbanization, the construction industry has gradually transformed from a large-scale new-intensive development model entering a nationwide period of existing building renewal [1]. The high energy consumption, functional degradation, and poor environmental quality of a large number of existing buildings built in different periods are also unable to meet people's demand for a high-quality life and the needs of green low-carbon development [2]. Under the guidance of the “dual carbon goals” and sustainable development strategies, the green retrofitting for existing buildings has been becoming more and more an important aspect in urban renovation and ecological civilization construction [3]. The reasons for going green in terms of retrofitting are not limited to enhancing the physical performance of buildings [4]; they also include rearranging areas, etc., optimizing energy habitat, and alternative operation management models. This is of great significance for improving the quality of urban ecological environment and promoting energy conservation and emission reduction [5]. However, this has proved difficult in recent years with limited systematic approaches and uneven coverage of technical pathways as well as poor generalisability of the experiences gained through case studies [6]. This paper explores design strategies for greening existing buildings in the framework of stock building renewal. This includes spatial and functional optimization planning, energy-saving and environmental protection technology applications, smart system construction, operational management. This study conducts multiple case studies to synthesize practical insights, aiming to provide theoretical reference and methodological support for systematically promoting green retrofitting of existing buildings in China.

2. The Relationship Between Existing Building Renewal and Green Retrofits

With China's urban development entering a new period of "supply-side adjustment", that is, "cutting

DOI: 10.25236/icacel.2025.001

less on the front end and attaching more importance to the stock"--from an emphasis on adding new buildings to one faced with retrofitting the existing building [7]. Most of the existing buildings were constructed decades ago in accordance with obsolete design criteria and technologies, causing to high energy consumption as well as inability to meet current human needs for comfort, safety, and functional diversity [8]. Renewal of existing buildings has become an irresistible choice for urban development, and green retrofitting is a key avenue to promote energy conservation, emission reduction and quality improvement [9].

Green retrofitting of existing buildings—at scale—is the most effective way to extend a building's lifecycle from a value perspective [10]. It allows for the recycling of existing resources by optimizing spatial layouts, structural systems and energy systems. Not only can this mode of action minimize resource wastage and environmental pollution caused by blocking reconstruction, but also the performance of buildings as a whole can be improved through the application of low-carbon and energy-efficient technologies, thereby responding to society's demand for a green lifestyle. Gentle renovation, therefore bridges the gap between the reclamation of existing buildings and sustainable development. Building Energy Consumption Intensity

$$E_{intensity}=\frac{E_{total}}{A_{floor}} \quad (1)$$

As one part of comprehensive urban renewal, green retrofitting plays a significant role in providing new development momentum to existing buildings. Urban renewal is not just infrastructure, it is all three types of coordination. Green retrofitting of existing buildings can improve the living environment for residents, enhance urban operational efficiency, and achieve energy conservation and emissions reduction to promote the attainment of "dual carbon goals". It also promotes the formation of green industrial chains, drives technology innovation and applications, and accelerates the low-carbon and smart development of cities.

It shows high complementarity and consistency between the renewal of existing buildings and green retrofitting. The former also supplies the operational basis and demand contexts for the latter, while the latter feeds sustainable development ideas and practices to the former. Instead, their organic integration not only deeply responds to the real dilemma existing in traditional urban structure but also cultivates general improvement of urban spatial quality, thus reconstructing a pattern of green renewal and ecologically symbiotic urban development. This establishes a theoretical basis for the interpretation and implementation of design methodologies.

3. Design Methods for Green Retrofits of Existing Buildings

The process of retrofitting existing buildings is a systematic process for green building. It needs rational optimization of the whole space and function to seize modern usage demand, as well as minimize resource and environment during building running by using energy-saving and environmental protection technology. It should also be equipped with digitized intelligent technology and operation management models to realize the green management in full life-cycle of building. The three are mutually supportive and synergistic, together serving as the core design methodology system of green retrofitting for existing buildings.

3.1 Spatial and Functional Optimization Methods

The first step towards greening existing buildings is spatial and functional optimization. Its primary goal is to ensure the building's longevity while meeting present social needs—scientifically based design can facilitate both. And with the changing population structures and lifestyles, many existing buildings cannot meet the expected functional requirements. Hence, space optimization and function reconfiguration are integral parts of green retrofitting. This approach not only optimizes the spatial utilization but also contributes to better environmental and operational quality of the building. Heat Transfer through Building Envelope (steady-state)

$$Q=U \cdot A \cdot (T_{in}-T_{out}) \quad (2)$$

A major method of spatial optimization is functional conversion. This can be achieved through green retrofits that would repurpose existing buildings that suffer functional vacancy or underutilization resulting from industrial upgrades, future urban development pathways, and changes in the local community. Turn idle industrial plants into cultural and creative zones, old office complexes into shared work or apartment life studios. Functional conversion avoids unnecessary waste of resources and can also regenerate building stock, adding a new vitality to urban development.

Spatial reuse focuses on design innovation that increases flexibility and adaptability while maintaining the existing building envelope. This includes internal space reconfiguration and circulation optimization, facade renewal as well as public space reimagination to enhance the building's relationship with its urban context. By introducing publicly accessible spaces, green courtyards, or rooftop gardens as items while renovating spatial quality will improve and interactions between users will be encouraged which in turn can help in formation of conditions for sustainable living. Overall Heat Transfer Coefficient (U-value)

$$U=\frac{1}{R_{si}+\sum\frac{d_i}{\lambda_i}+R_{se}} \quad (3)$$

The spatial and functional optimization is a field where human-centered design plays an inevitability role. Green retrofitting must be broadened to go beyond energy-saving and environmental technologies within buildings, addressing occupant experience and health needs as well. The basic functional requirements can be met while further improving the comfort and health of users of existing buildings using natural lighting, ventilation, good acoustic and visual environment, and barrier-free design as well. This human-centered approach to spatial optimization enables addressing dual goals: maximizing building performance and ameliorating the living environment, as thus fully realize its social value in green retrofitting.

3.2 Application Methods for Energy-Saving and Environmental Protection Technologies

The energy-saving and environmental protection technologies are the core of green retrofitting for existing buildings. They aim to minimize the operation energy consumption of buildings and their environmental impact through scientific technical means, thus realizing carbon reduction and promoting sustainable development goals. Whereas new constructions tend to be light on energy efficiency standards and modern facilities, existing buildings are often far worse. Thus, when retrofitting, focus on installing energy-saving equipment and environmental protection measures whilst improving performance without sacrificing its ecological benefits.

As a practical implementation, energy-saving retrofits of the building envelopes are considered in first place. Thermal insulation performance is directly affected by the envelope systems—walls, roofs and windows. By improving external wall insulation, upgrading roof insulation and replacing with high-performance windows, heating and cooling energy consumption can be reduced by a significant percentage. Incorporating green materials is simply adding to the energy efficiency and aesthetics while also being safe. These measures feature reasonable investment and significant energy savings, making them the most widely applied technical approach in green retrofits, showed in Figure 1 :

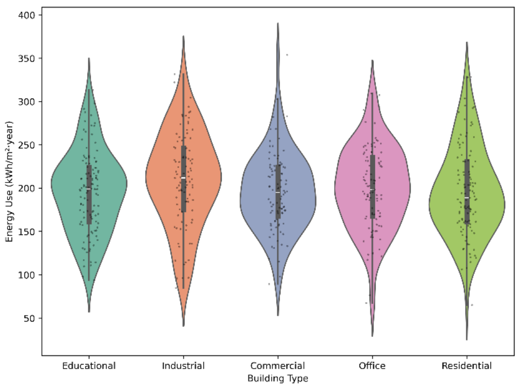

Figure 1 Energy consumption distribution by building type

Renewable energy sources allow for green retrofitting of existing buildings. To address this, technologies such as photovoltaic power generation, ground-source heat pumps and air-source heat pumps may be powerful tools for achieving energy independence from fossil fuels and carbon emissions reduction. Building-integrated photovoltaics (BIPV) can be integrated into building facades and roofs, where possible, to achieve energy efficiency, functional aesthetics, ecological harmony and visual harmony. Energy Savings Rate after Retrofit

$$\eta_{save}=\frac{E_{before}-E_{after}}{E_{before}}\times 100\backslash\% \quad (4)$$

Environmental technologies also comprise a very important field from the perspective of water resource and material recycling. Installation of rainwater harvesting and reuse systems concurrent with water-efficient plumbing and fixture installation minimizes overall building water use during retrofits. Using recyclable and low-pollution green building materials, as well as maximizing the overuse and reuse of existing construction materials will not only reduce the waste of resources and pollution to the environment in the process of construction, but is also in line with circular economy principles. Altogether, these levers are strong ones that can sustain the push to 'green' existing buildings through retrofitting.

3.3 Smart Technologies and Operational Management Methods

The adoption of smart technologies in green retrofits is indeed an inevitable trend and a significant driver for improving building sustainability. As the IoT, big data and artificial intelligence proliferate, building operations are being transformed from manual control to automated intelligence. Smart systems allow for dynamical monitoring and adjustment of energy consumption and environmental parameters, further decreasing the operational energy use and increasing occupant comfort.

Intelligent retrofits rely on smart monitoring and energy control. With the implementation of smart sensors and monitoring platforms capable of real-time capture of data such as indoor/outdoor temperature, humidity, air quality and light intensity. Third, these systems connect with HVAC and lighting systems to plan for demand-based energy supply and make real-time adjustments. The system also lowers the brightness of lights or volume of air when occupancy levels are low to avoid wastage. The result is a more responsive and adaptable way of saving energy than previous systems that simply turned down power at certain times or relied on manual management. Life Cycle Cost (LCC) of Retrofit

$$LCC=C_{initial}+\sum_{t=1}^{n}\frac{C_{operation}(t)+C_{maintenance}(t)}{(1+r)^{t}} \quad (5)$$

Smart retrofits focus on detailed management during the life cycle of operations and maintenance. Smart management platforms have already added these capabilities to existing facilities by leveraging remote monitoring and proactive alerts for equipment status, enabling early detection and repairs. This avoids energy waste or safety risk from operating sunder equipment. Big data analytics provide operators with energy consumption trend forecasts and optimization recommendations, helping formulate more scientific operational strategies and enhancing overall building management efficiency, showed in Figure 2 :

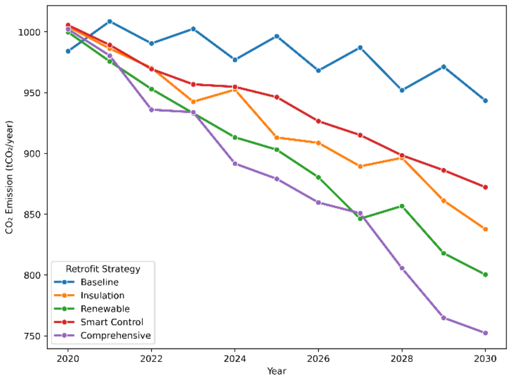

Figure 2 Carbon emission reduction trend with retrofit strategies

These smart solutions are not limited to an energy saving goal, but enable full green management from cradle to grave of a building. Such a building achieves end-to-end tracking and optimization of energy consumption and carbon emissions, promoting continuous low-carbon performance tied to intelligent technologies across the design, construction, operation, and maintenance phases. In addition, smart platforms provide interactive interfaces for users to promote public engagement and acceptance of green lifestyles while forming a virtuous cycle between technology-management-society.

4. Case Study Analysis and Methodology Summary

In cases of green retrofitting, such typical practices are often significant intuitions and evidence for the design methods study. The analysis of successful international and national best practices in green retrofits demonstrates that due to differences in contextual conditions, functional needs, and renovation goals across building types various strategies are applied. Many historic building renovations in Europe and America, for example, focus on incorporating energy-saving technology as much as possible whilst maintaining the original appearance. In contrast, in China innovation concentrates on raising the efficiency of energy use and ensuring better spatial quality of residential as well as public buildings.

Take, for instance, an industrial factory that is reborn as a cultural and creative park. By keeping and repurposing the original spatial structure, this project was successful at functional reprogramming and spatial regeneration. The design team took care to incorporate green technologies, such as external wall insulation and strengthening, photovoltaic systems on the roof and rainwater recycling systems. These actions were not only able to extensively lower the operational energy need of the building however also develop enough support for sustainable energy to provide yearly power needs for the complex. In addition, the public gathering areas and landscaped courtyards improved the environmental quality as a whole for the building to satisfy modern functionality while providing ecological viability.

Some of these aging neighborhoods went to envelope energy efficiency and equipment modernization in residential building retrofits. Installing high-performance windows and doors, adding exterior insulation systems, and incorporating intelligent HVAC control systems resulted in dramatic reductions in residents' energy costs and operational loads. Improving public space and employing barrier-free design can enhance residents' quality of life and reinforce the community's capacity for sustainable development. These cases show that green retrofits need to be materially designed across three dimensions: energy savings technologies, human-centered needs and social benefits. Carbon Emission Calculation

$$C_{emission} = \sum_{i=1}^{n} E_i \cdot f_i \quad (6)$$

From the analysis of the case, several design principles that apply universally were derived: place functional substitution and spatial reuse in a prominent position to prevent wasting resources; pay attention to energy-saving and ecological technology at first, to improve building performance; fully tap intelligent solutions, comprehensively control green operation throughout the life cycle. Place human centered philosophy on an important position for ecological benefits and social value balance. These strategies provide flexibility and practicality applicable to a variety of different types of buildings, with action-oriented pathways for resolving barriers to scaling green retrofits in the existing building stock.

5. Conclusion

Faced with the need for new stock renewal, greening existing buildings has become an instrumental way forward to promote urban sustainability and help achieve carbon neutrality targets. Through this study, the link between building stock renewal and green retrofitting is addressed to explain that green retrofitting is crucial in reducing energy consumption, improving spatial quality, extending building life and carrying out urban renewal. It classifies generic design strategies with respect to three axes: optimization of space and functions, use of energy-saving environmentally friendly technologies, smart solutions and process management. Lastly, it examines and summarizes our typical case studies to extract universally appetizing practical paths. The research shows that green retrofits of existing buildings can not only effectively improve building operationalperformance, but also even improve urban environmental quality, which provides strong support for the construction of ecological civilization.

At this stage in the technical research process, issues like expensive renovation fees, uneven technology implementation among different stakeholders and non-perfect management operation systems of public buildings prevent the extensive application or intensive development of green retrofitting of existing buildings. Future development needs to be a concerted effort between policy guidance, technological innovation and social participation. Institutional and policy incentives should be strengthened to create the building blocks of a green retrofit market. Development of green building materials, new energy technologies, and intelligent management systems must be conducted to mitigate retrofit barriers. Engagement with the general public and users should be improved to support sustainable lifestyles.

The synthesis of design, technology, management and society to accomplish green retrofitting in existing buildings is a systematic approach. In the context of deepening urban renewal, green retrofitting will remain as an important part with effective support for low-carbon development and livable city construction objectives.

References

[1] Aste N, Pero C D .Energy retrofit of commercial buildings: case study and applied methodology[J]. Energy Efficiency, 2013, 6(2):407-423.DOI:10.1007/s12053-012-9168-4.

[2] Gong Y, Li X, Meng F,et al.Toward Green RF Chain Design for Integrated Sensing and Communications: Technologies and Future Directions[J].IEEE Communications Magazine(M-COMM), 2024, 62(9):7.DOI:10.1109/MCOM.001.2300698.

[3] Yang W, Wang M, Ji X,et al.Dynamic characteristic analysis on seismic strengthening of existing rural masonry-timber buildings in Beijing[J].Tumu Gongcheng Xuebao/china Civil Engineering Journal, 2014, 47(3):26-32.DOI:10.1097/00005768-200405001-00806.

[4] Asce M J E A M, Negar Mohammadgholibeyki A M A, Asce A B L F,et al.Achieving Functional Recovery through Seismic Retrofit of Existing Buildings: Barriers and Opportunities[J].Journal of Performance of Constructed Facilities, 2023, 37(4):13.DOI:10.1061/JPCFEV.CFENG-4395.

[5] Borkowski E, Rovas D, Raslan R .Adaptive building envelope simulation in current design practice: findings from interviews with practitioners about their understanding of methods, tools and workarounds and implications for future tool developments[J].Intelligent Buildings International, 2022, 14(2):19.DOI:10.1080/17508975.2021.1902257.

[6] Gupta R, Gregg M, Cherian R .Developing a new framework to bring consistency and flexibility in evaluating actual building performance[J].Structural Survey, 2020, 38(1):228-255.

[7] Fedorczak-Cisak M, Radziszewska-Zielina E,Boena Orlik-Kodoń,et al.Analysis of the Thermal Retrofitting Potential of the External Walls of Podhale's Historical Timber Buildings in the Aspect of the Non-Deterioration of Their Technical Condition[J].Energies, 2020, 13(18):4610. DOI:10.3390/en13184610.

[8] Mantha B R K, Menassa C C, Kamat V R .A taxonomy of data types and data collection methods for building energy monitoring and performance simulation[J].Advances in Building Energy Research, 2015, 10(2):1-31.DOI:10.1080/17512549.2015.1103665.

[9] Hassan A, Alomayri T, Noaman M F,et al.3D Printed Concrete for Sustainable Construction: A Review of Mechanical Properties and Environmental Impact[J].Archives of Computational Methods in Engineering, 2025, 32(5):2713-2743.DOI:10.1007/s11831-024-10220-5.

[10] Caterino N, Nuzzo I, Ianniello A,et al.A BIM-based decision-making framework for optimal seismic retrofit of existing buildings[J].Engineering Structures, 2021, 242(3):112544. DOI:10.1016/j.engstruct.2021.112544.