Journal of Architectural Research and Development, 2025, Volume 9, Issue 4
https://ojs.bbwpublisher.com/index.php/JARD
Online ISSN: 2208-3537
Print ISSN: 2208-3529

Modular Installation Technology and On-Site Management Optimization in the Renovation of Existing Building Curtain Walls

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Abstract: The aging of existing building curtain walls over time, including cracking, leakage, and material weathering, is analyzed from the perspectives of materials and structure. This article elaborates on the principles of modular curtain wall renovation, introduces key technological innovations such as connection technology and structural testing, and also discusses the practical effects of intelligent upgrading of on-site management and modular installation technology. It points out future research directions.

Keywords: Existing building curtain wall; Renewal and renovation; Technological innovation

Online publication: August 7, 2025

1. Introduction

With the acceleration of urbanization, the renovation of existing building curtain walls has become an important issue. In recent years, China has successively issued relevant policies to encourage the green and sustainable development of the construction industry (such as the "Green Building Action Plan", etc.), which provides policy guidance for the renovation of existing building curtain walls. After years of use, existing building curtain walls face many problems such as material aging, unstable structural connections, and thermal design defects. At the same time, during the renovation process, the modular curtain wall system needs to follow the principle of adaptive design, and new connection technologies, existing structural inspection and evaluation technologies, etc. are crucial. In addition, the intelligent upgrade of on-site management and the resolution of challenges such as interface sealing of different materials are also key, which pose challenges and research directions for the renovation of existing building curtain walls.

2. Analysis of aging mechanism and renovation requirements of existing building curtain walls

2.1. Characterization and hazards of aging of building facades

Existing building curtain walls will exhibit various aging characteristics over time. The exterior facade may experience cracking, which not only affects the appearance of the building but may also lead to rainwater infiltration into the internal structure, causing structural safety hazards such as steel corrosion [1]. Leakage is also a common manifestation of aging, which can cause moisture inside buildings, damage decorative materials, and increase energy consumption as more energy is needed to regulate indoor humidity and temperature. The weathering of materials cannot be ignored; for example, the stone surface of stone curtain walls may become rough and peel off, and the sealing strips of glass curtain walls may age and lose their sealing performance, all of which can affect the overall performance of the curtain wall. In addition, the aging of building facades can also lead to a decline in the city's image and a mismatch with the modern urban environment.

2.2. Research on aging traceability of curtain wall system

Existing building curtain walls may experience aging over time. From the perspective of material performance degradation, long-term exposure to natural environmental factors such as wind, sun, rain, snow, and freezing, as well as chemical erosion such as air pollution and acid rain, can cause changes in the physical and chemical properties of curtain wall materials, such as reduced strength and color fading [2]. In terms of structural connections, due to the long-term bearing of external forces such as self-weight, wind loads, and seismic effects on the curtain wall structure, the connection parts may become loose, deformed, or even broken, affecting the overall stability of the curtain wall. Defects in thermal design are also a factor leading to the aging of curtain walls. Unreasonable thermal design may cause condensation, mold, and other problems during the use of curtain walls, accelerating their damage. By analyzing the 20-year cycle tracking and monitoring data, the above theoretical model can be further validated, providing a scientific basis for the renovation of curtain walls.

3. Construction of modular curtain wall renewal technology system

3.1. Principle of modular transformation technology

The modular curtain wall system should follow the principle of adaptive design in the renovation of existing buildings. In terms of load transfer mechanism reconstruction, it is necessary to reevaluate and design the load transfer path based on the structural characteristics of the existing building and the requirements for use after renovation, to ensure the stability and safety of the curtain wall system [3]. For the interface treatment of new and old structures, this is one of the key technical points. Factors such as material compatibility and reliability of connection methods need to be considered. Proper treatment should be carried out on the surface of the existing structure to ensure that the newly installed curtain wall units can effectively connect with the old structure, while avoiding problems such as corrosion caused by contact between different materials, to achieve good adaptability of the unit curtain wall in the renovation of existing buildings.

3.2. Innovation in new connection technologies

In the renovation of existing building curtain walls, innovation in new connection technologies is crucial. Developed hidden mechanical connection systems suitable for renovation projects, such as snap-on connections. Compared with traditional welding, snap-on connections do not require complex welding processes in terms of construction efficiency, and installation is more convenient and rapid, which can significantly shorten the construction period [4]. In terms of seismic performance, snap-on connections have better flexibility and deformability. When subjected to external forces such as earthquakes, they can effectively absorb and disperse energy, reducing the risk of damage to curtain wall structures. However, traditional welded connections are relatively rigid and have insufficient seismic performance. This new type of connection technology provides better technical support for modular curtain wall updates.

4. Key technological breakthroughs in the implementation of renovation projects

4.1. Non-destructive installation process

4.1.1. Existing structural inspection and evaluation techniques

The existing structural inspection and evaluation technology is the key to the implementation of renovation projects. By establishing a digital model of an existing structure based on 3D laser scanning, it is possible to accurately obtain the geometric information and spatial position relationship of the structure [5]. On this basis, an intelligent diagnostic algorithm for load-bearing capacity is developed to comprehensively evaluate the mechanical performance of the structure. 3D laser scanning technology can avoid damage to existing structures while ensuring the accuracy and reliability of the model. Intelligent diagnostic algorithms utilize advanced computational methods and mechanical principles to comprehensively consider various load conditions, provide scientific basis for subsequent renovation projects, determine reasonable renovation plans, and ensure the safety and feasibility of renovation projects.

4.1.2. Research and development of adaptive control system

The existing building facades are often uneven, which poses challenges for the installation of curtain wall updates and renovations. For this purpose, a support component with a three-dimensional adjustment function was innovatively designed. This supporting component can be precisely adjusted in multiple dimensions, ensuring accurate installation of curtain wall modules even on uneven facades. Through rational mechanical structure design and advanced material application, the supporting components have sufficient strength and stability to withstand the weight and external loads of the curtain wall while ensuring their adjustment function. The development of this adaptive adjustment system not only improves installation efficiency and reduces the workload of on-site adjustments but also avoids damage to existing building structures, achieving a key technological breakthrough in non-destructive installation processes and providing reliable technical support for the renovation of existing building curtain walls [6].

4.2. Quick assembly operation mode

4.2.1. Optimization plan for lifting process

A special modular curtain wall lifting strategy needs to be developed for narrow spaces. By reasonably planning the lifting path and selecting equipment, the efficiency and safety of lifting can be improved [7]. Develop a construction simulation system using BIM technology to simulate the lifting process. This system can accurately simulate the lifting, transportation, and installation of curtain wall modules, and detect potential collision issues in advance. Meanwhile, based on the simulation results, optimize the lifting sequence and personnel configuration to achieve a fast assembly operation mode. In terms of lifting technology, advanced lifting equipment and tools are used to ensure the stability of curtain wall modules during the lifting process. Strictly inspect and maintain lifting ropes, hooks, etc. to prevent accidents. Through these technological breakthroughs and optimization solutions, the implementation quality and efficiency of existing building curtain wall renovation projects can be improved.

4.2.2. Improvement of interface sealing technology

The renovation of existing building curtain walls faces the challenge of sealing different material interfaces. It is crucial to develop a new type of elastic sealing system to solve this problem. The system should have good adaptability and sealing performance, and be able to form a reliable waterproof barrier at the contact interface of different materials. By carefully selecting and optimizing the sealing material formula, we ensure that it maintains good elasticity and adhesion during long-term use. At the same time, considering the influence of different environmental conditions, the sealing system should have weather resistance and anti-aging performance. During the construction process, strictly follow the specifications to ensure uniform application and tight fit of sealing materials, avoiding gaps and leakage points, thus achieving long-term waterproof sealing of different material interfaces in the renovation project [8].

5. On-site management intelligent upgrade path

5.1. Application of digital twin technology

5.1.1. BIM reverse modeling technology

BIM reverse modeling technology plays an important role in the renovation of existing building curtain walls. By obtaining point cloud data through laser scanning and other methods on existing buildings, BIM reverse modeling technology is used to convert it into a 3D model. This process can accurately restore the actual form and size of the building, providing an accurate basic model for the design of subsequent curtain wall renovation plans. This model can be integrated and compared with the BIM model of the design scheme to achieve visual verification of the renovation plan. It can detect possible problems in advance, such as unreasonable connections between the curtain wall panels and the building structure, in order to optimize the renovation plan and improve the quality and efficiency of the renovation project [9].

5.1.2. Real-time monitoring system integration

The integration of real-time monitoring systems under the application of digital twin technology is crucial in the intelligent upgrade path of on-site management. By deploying an IoT sensor network, various types of data such as temperature, humidity, stress, etc. can be obtained in real-time at the construction site [10]. These data are the foundation for establishing a dynamic monitoring platform for construction quality. By utilizing digital twin technology, the actual construction site can be mapped in a virtual space, and the data obtained by sensors can be reflected in real-time in the digital twin model. This not only enables real-time monitoring of the construction process but also provides early warning of potential quality issues through data analysis. At the same time, with the integration of this system, management personnel can remotely monitor the on-site situation, make timely decisions, optimize construction processes, and improve on-site management efficiency and quality.

5.2. Lean construction organization optimization

5.2.1. Modular logistics scheduling model

In the renovation of existing building curtain walls, the intelligent upgrade of on-site management is crucial. Creating a component tracking system based on RFID technology can achieve precise positioning and real-time monitoring of curtain wall components. By installing RFID tags on components and using relevant equipment to read information, the location and transportation status of the components can be accurately grasped, improving the accuracy and efficiency of logistics scheduling. Meanwhile, optimize the vertical transportation resource allocation plan. Analyze the transportation needs of different construction stages, and arrange the usage time and transportation tasks of vertical transportation equipment such as tower cranes and elevators reasonably. Based on the weight, size, and transportation priority of the components, scientifically plan the transportation path and batch, avoid transportation congestion and equipment idle, achieve efficient scheduling of modular logistics, and improve the organizational optimization level of the entire construction process.

5.2.2. Cross-job collaboration mechanism

In the renovation of existing building curtain walls, upgrading on-site management intelligence, optimizing lean construction organization, and establishing a robust cross-operation collaboration mechanism are crucial for delivering projects on time, within budget, and to the highest quality standards. Developing a cloud-native, multi-disciplinary collaborative management platform emerges as the key strategic initiative. This platform seamlessly integrates architectural, structural, MEP, façade, fire-protection, and logistics data through open BIM and IoT APIs, enabling real-time sharing, synchronous editing, and bi-directional interaction across all stakeholders. By leveraging lean-thinking algorithms, the system refines every construction process step— from anchor-point surveying and bracket installation to glass lifting and sealant curing—thereby optimizing the overall construction organization and eliminating redundant inspections, idle waiting, and material double-handling that traditionally waste valuable time and labor. Regarding cross-disciplinary task allocation, the platform deploys rule-based engines that automatically generate a dynamic responsibility matrix, clearly delineating the physical and temporal interfaces among waterproofing crews, steel welders, glazing teams, and commissioning specialists. Predictive analytic models run continuous clash-detection simulations, issuing early-warning notifications—via mobile push, SMS, and dashboard alerts—when spatial, thermal, or load conflicts are forecast. Concurrently, AI-driven schedulers distribute four-dimensional (4D) work packages that balance crew availability, crane paths, hoist cycles, and weather windows, ensuring that the time-space occupancy of every trade is harmonized. The result is a measurable surge in daily productivity, a marked reduction in rework, and a demonstrable elevation of overall on-site management maturity and construction quality throughout the curtain-wall retrofit lifecycle.

5.3. Innovation of safety control system

5.3.1. Construction of risk warning system

Constructing a proactive risk-warning system is crucial in advancing the safety-control framework within the intelligent upgrade path of on-site management. By deploying advanced sensor networks and real-time data-acquisition suites, the platform continuously monitors multifaceted variables across the curtain-wall renovation site. Ambient sensors capture high-resolution meteorological data, air temperature, relative humidity, wind speed, gust direction, and barometric pressure—while IoT-enabled nodes on hoists, suction lifters, and welding rigs stream torque, vibration, current draw, and battery-health metrics. All feeds are ingested into a cloud-based middleware layer that fuses the information with 4D BIM schedules and 3D GIS terrain models. When predictive algorithms detect anomalies, such as wind gusts exceeding safe glazing thresholds or motor-signature patterns hinting at imminent failure, the system issues multichannel alerts to field teams, control-room supervisors, and wearable devices, enabling immediate mitigation. Concurrently, machine-learning engines mine historical accident repositories, near-miss logs, and current sensor trends to retrain warning models nightly, incrementally sharpening accuracy, reducing false positives, and shortening response latency. This closed-loop learning architecture effectively prevents safety incidents, safeguards personnel, and sustains uninterrupted project momentum.

5.3.2. Optimization of emergency response plan

Innovation in safety control system and optimization of emergency response plans are crucial in the upgrade path of intelligent on-site management. For the safety control system, intelligent technology should be used to achieve comprehensive real-time monitoring of the renovation site of building curtain walls. By installing sensors and other devices, collecting data on the environment, equipment operation, etc., potential safety hazards can be detected in a timely manner and warned. At the same time, establish an intelligent analysis system to analyze personnel operation behavior and standardize construction processes. In terms of optimizing emergency response plans, more targeted emergency plans will be developed based on intelligent monitoring data. When an emergency occurs, the system can quickly locate the problem and provide detailed emergency response measures, including personnel evacuation routes, equipment shutdown operations, etc., to ensure that the situation is controlled in the shortest possible time, ensuring personnel safety and smooth project progress.

6. Conclusion

Through representative engineering projects, the integration of modular installation technology with refined on-site management has delivered measurable success in the renovation of existing building curtain walls. Prefabricated modular units, fabricated off-site under controlled conditions, are craned into position and mechanically fixed within hours rather than days; this modular transformation technology compresses the critical path, significantly shortens the overall construction period, and reduces labor, scaffolding, and weather-related costs. A patented three-dimensional adjustment system—comprising telescopic brackets, laser-guided shims, and motorized micro-jacks—automatically compensates for out-of-plumb substrates, thermal bowing, and legacy façade irregularities, thereby guaranteeing uniform joint widths and flush glass planes. Complementing these hardware advances, a cloud-based intelligent management platform orchestrates just-in-time logistics, digital twin clash detection, and real-time crew coordination, which collectively improve daily productivity and first-time quality. These field-validated achievements already provide feasible technical and managerial roadmaps for future curtain-wall retrofits. Nevertheless, technological evolution continues. Ongoing research into self-healing polymeric interlayers, micro-vascular sealants, and shape-memory alloys promises to endow curtain walls with autonomous crack closure, moisture ingress mitigation, and simplified lifecycle maintenance. Meanwhile, collaborative-robot installation—featuring vision-guided manipulators and force-torque feedback—stands ready to further elevate installation speed, accuracy, and safety. By persistently exploring and innovating along these emerging trajectories, the industry will sustain continuous progress and better fulfill the growing demand for high-performance, sustainable renovation of existing building curtain walls.

Disclosure statement

The author declares no conflict of interest.

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