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DIGITAL MODULAR INSTALLATION TECHNOLOGY AND APPLICATION OF LARGE-SCALE CORRUGATED THREE-DIMENSIONAL ARCHITECTURAL GLASS (LIULI) CURTAIN WALLS

XiaoXia Zhao[1, 2*], BaoAn Zhang[1, 2], GuoXiang Zhao[1, 2], Yang Yang[1, 2], RuiDa Zong[1, 2], XueSheng Jin[1, 2]
[1]*China Construction Fourth Engineering Bureau Co., Ltd., Guangzhou 510000, Guangdong, China.*
[2]*China Construction Fourth Bureau Construction Investment Co., Ltd., Shanghai 200000, China.*
[*]*Corresponding Author: XiaoXia Zhao*

Abstract: Large-scale corrugated three-dimensional architectural glass (LIULI) curtain walls represent a high-end façade system that integrates architectural aesthetics, structural safety, and green energy efficiency. This paper innovatively proposes a digital modular installation technology for such systems. By integrating three core methodologies—full-chain digital driving, precision assembly of modular finished products, and a flexible "bottom-supporting and top-hooking" adjustment and locking mechanism—the approach systematically overcomes longstanding challenges including chaotic panel layout, high damage risk during hoisting, and poor alignment accuracy. A safe, efficient, precise, and replicable digital modular installation system is thereby established. For the first time internationally, this technology has been applied at a large scale, covering a total area of 17800 m² with 7240 individual panels. It successfully advances LIULI craftsmanship from interior decoration to architectural curtain wall applications, marking a significant technological leap.
Keywords: Large-scale; Corrugated three-dimensional; Architectural glass (LIULI) curtain wall; Digital modular; Installation technology

1 INTRODUCTION

Colored glaze, as one of the appellations for ancient Chinese glass, was also a variety of artistic glass in modern times. From the discovery of colored glaze precursors in the Western Zhou Dynasty to its peak during the Kangxi and Qianlong periods of the Qing Dynasty, China had a long history of colored glaze manufacturing. At that time, it not only inherited the traditions of ancient colored glaze but also continuously innovated according to modern trends, inheriting from innovation, thus forming the subsequent long-term development [1]. The earliest colored glaze was made by the ancestors using local raw materials, and the formula was somewhat accidental. After accumulating experience and obtaining the mature formula, products with the required performance could be mass produced. With the advancement of science, analytical testing techniques were used to analyze formulas and raw materials, resulting in the formation of experimental components. Up to that era, Boshan-produced colored glaze was the most representative of China, and it was known as the "Hometown of Chinese LIULI (Colored Glaze)". Its series of works gained a high reputation both domestically and internationally (Figure 1) [2]. Its colored glaze firing technique was officially awarded the "National Intangible Cultural Heritage".

Figure 1 Works of Chinese LIULI (Colored Glaze) Craftsmanship [2]
(a) Lotus Pond Moonlight Series of Works; (b) Chicken Fat Yellow Engraved Snuff Bottle; (c) Lotus Breeze and Clear Rhyme Series of Works; (d) Lunar Colored Glaze Lamp

In recent decades, glass had been used by architectural engineers in non-traditional forms. In addition to its traditional uses as a window to make the inside and outside of a building visible and to introduce light, glass was increasingly becoming a medium for artistic expression rather than just an architectural material [3-5]. Terms such as "beyond transparency" had been used to describe architectural visions with a more extensive use of glass. The simplest and most widespread use of glass in architecture was as a curtain wall. Typically, transparent glass panels were suspended on aluminum alloy or stainless steel metal frames to form the building facade enclosure structure, but they did not bear the structural loads of the architecture itself. Glass was also used for internal partition walls and architectural decoration. Architectural glass was usually of the safety type. Tempered glass and laminated glass were commonly used in the curtain wall. From the all-glass architectures in New York, Beijing and Shanghai, to the glass facades of iconic architectures and airport terminals around the world (Figure 2), and then to tourist attractions such as the Zhangjiajie Grand Canyon Glass Bridge, glass had witnessed rapid progress in the field of architecture [6]. In addition, in other buildings, such as Apple Stores, glass was also used as a structural load-bearing material in the form of blocks [7].

Figure 2 Typical Glass Curtain Wall Architectures [6]
(a) Shard, London; (b) Shanghai Central Business District; (c) Shanghai Tower; (d) Jewel Changi Airport, Singapore; (e) Apple Store on Fifth Avenue, New York

In the field of building engineering, LIULI has thus far been used exclusively for roof decoration and interior ornamentation. Representative examples include the glazed tile roofs of the Beijing Cultural Palace of Nationalities and the National Library of China, as well as the Tang tri-color (Sancai) ceramic columns inside the Xi'an Metro Zhonglou Station [8]. For the new Nanjing Porcelain Tower, the outward-cantilevered wing slabs of the tower are encapsulated with ultra-clear (low-iron) glass [9]. The inner glass panels undergo a series of processes—pattern etching, hand glazing, and high-temperature firing—to achieve the tower's distinctive glazed wing appearance, see Figure 3.

(a) Glazed Tile Roof of the Beijing Cultural Palace of Nationalities

(b) Liuli Column Decoration at Xi'an Metro Zhonglou Station

(c) Glazed Tower Wings of the New Nanjing Porcelain Tower
Figure 3 Decorative Applications of Liuli Products in Building Engineering [8-9]

In summary, this paper reviews the origin and evolution of glass materials both domestically and internationally, and conducts a comparative analysis of glass material classifications, casting processes, and mold selection. It is found that glass materials are gradually shifting from traditional decorative crafts to functional products for modern architecture. With the rapid development of contemporary society, glass is achieving an ingenious integration of traditional culture and building functions. However, despite its distinctive cultural and artistic characteristics, Chinese LIULI materials have thus far remained confined to craft artworks, with no involvement in the field of modern building functions. Based on the project background of the China Beijing–Hangzhou Grand Canal Museum, and considering that this LIULI product is applied to a building curtain wall on a large scale for the first time, this paper proposes a digital modular installation technology for large-scale corrugated three-dimensional architectural glass (LIULI) curtain walls, with the aim of establishing a safe, efficient, precise, and replicable digital modular installation system.

2 PROJECT OVERVIEW

The Beijing–Hangzhou Grand Canal Museum of China is one of the cultural protection and inheritance projects during the 14th Five Year Plan period of the National Development and Reform Commission. It has been incorporated into the national construction plan of the Grand Canal National Cultural Park, which is of great significance for promoting the culture of the Grand Canal, improving the heritage protection system, enhancing urban cultural construction and comprehensive supporting service capabilities. This project reflects the important heritage level status of the Grand Canal in China's cultural and natural landscapes, with the design concept being "a museum reflecting the canal". Among them, the innovative concept of the "water reflecting facade" is applied to the exhibition hall of the podium building. For the first time, Chinese LIULI (Colored Glaze) is applied as a curtain wall material to the exterior facade of a architecture. The entire curtain wall is ingeniously pieced together from 7240 blue non-uniform thickness water-wave colored glaze composite panels. The total area reaches 17800m², each piece has a size of 1.0×2.5m, and each piece weighs 350kg. It aims to achieve the visual aesthetic image of "water waves shining and reflecting". In addition, large-sized non-uniform thickness water-wave colored glaze has extremely high requirements for the control of the finish texture and the quality of primary forming during the preparation process. (Figure 4)

Figure 4 Rendering of the Colored Glaze Curtain Wall of the Architecture
(a) Overall Effect; (b) Local Effect; (c) Detailed Effect

Owing to its distinctive material properties and geometric configuration, this system imposes exceptionally stringent requirements on construction:
(1) Difficulty in controlling irregularly shaped panels: The LIULI panels feature a nonlinear gradient distribution, with large individual dimensions and substantial self-weight, resulting in a shifted center of gravity. This makes the panels highly susceptible to stress concentration and damage during hoisting and installation.
(2) Extremely high precision requirements: The corrugated three-dimensional surface renders conventional plane control networks ineffective. Panel joints must simultaneously satisfy spatial 3D coordinate tolerances and continuity of light and shadow, leaving virtually zero fault tolerance.
(3) Inadequacy of conventional techniques: Traditional curtain wall assembly methods fail to address the safe hoisting of heavy modular units or the demand for efficient modular integration of large-scale corrugated 3D components. This leads to elevated construction risks, uncontrollable schedules, and difficulty in guaranteeing finished product quality.

3 TECHNICAL CHARACTERISTICS

3.1 Full-Chain Digital Driving: Resolving Spatial Positioning Challenges of Corrugated 3D Surfaces

Building Information Modeling (BIM) technology is employed to perform 3D parametric modeling and virtual assembly of the corrugated 3D façade. Potential clash conflicts are identified and resolved in advance, and layout data with unique identification codes are accurately exported. Through a multi-source digital construction collaborative management platform, full-lifecycle traceability of each component is achieved. This approach fundamentally resolves the problems of ineffective traditional plane control networks for nonlinear gradient surfaces and the accumulation of fabrication errors from the source.

3.2 Precision Assembly of Modular Finished Products: Substantially Improving High-Altitude Work Efficiency

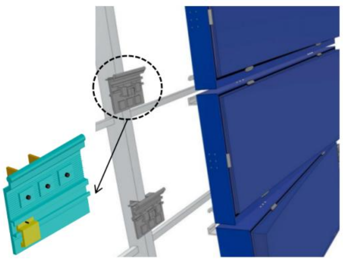
Based on a spatial 3D control network, standardized unit panels embedded with identification codes are positioned using the highest corner point as the key reference. A modular assembly mode of large-area progression coupled with external-corner closure is adopted. This is supported by a dual-machine hoisting configuration using a truck crane and an articulating boom lift, enabling efficient and precise positioning of large-scale corrugated LIULI panels. The approach significantly enhances both safety and work efficiency in high-altitude operations.

3.3 Flexible "Bottom-Supporting and Top-Hooking" Adjustment and Locking: Ensuring Hoisting Safety and Final Quality

A novel flexible jig configuration featuring "bottom-supported positioning followed by top-limited locking" is introduced. Each unit panel is first bottom-supported to eliminate suspension stress, and is then precisely adjusted and locked by adjustable upper clamping fittings. This substantially reduces the hoisting risks and alignment difficulties associated with large-scale, heavy, and brittle LIULI panels, further improving construction safety and as-built quality.

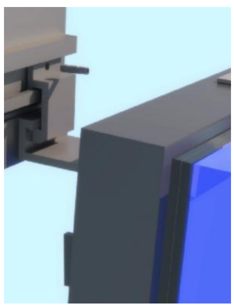
4 TECHNICAL PRINCIPLE

By integrating full-chain digital driving, precision assembly of modular finished products, and flexible "bottom-supporting and top-hooking" adjustment and locking, the complex spatial corrugated 3D LIULI curtain wall system is transformed into a traceable, quantifiable, and assemblable standardized operation. First, BIM technology is used to create 1:1 high-precision 3D parametric models of the irregular corrugated 3D façade. Layout data are accurately exported and unique identification codes are assigned to each component. Through a multi-source digital construction collaborative management platform, full-lifecycle traceability of all components is achieved. Second, based on the digital layout, industrially fabricated LIULI composite units are transported to the site for verification. Using a spatial 3D control network as the foundation, aluminum alloy "bottom-support and top-hook" brackets are installed first. Standard unit panels embedded with identification codes are then positioned using the highest corner point as the key reference. A modular assembly mode of large-area progression coupled with external-corner closure is adopted, supported by a dual-machine hoisting configuration (truck crane + articulating boom lift), enabling efficient and precise positioning of the large-scale corrugated LIULI panels. During installation, each unit panel is inclined outward at 12°–15°. The panel's self-weight is first borne by bearing supports at the top of the brackets (eliminating suspension stress). After the panel's spatial posture is precisely adjusted, C-shaped slider buckles are used to limit the position and secure it with bolt fixation. This substantially reduces the hoisting risks and alignment difficulties associated with large-scale, heavy, and brittle LIULI panels, and further improves both construction safety and as-built quality. (Figure 5)



(a) Relative Position between the Support-Limiting Device and the Unit Panel

(b) Bottom-Support Load Bearing



(c) Top-Hook Position Limiting

Figure 5 Technical Principles

5 KEY OPERATIONAL POINTS

The technological process comprises the following sequence: BIM parametric modeling, virtual assembly, and digital coding → delivery and inspection of finished LIULI composite curtain wall units → establishment of a spatial 3D control network and benchmark positioning → installation of vertical steel mullions → installation of backing functional layers (fireproofing, thermal insulation, waterproofing, etc.) → precise layout of "bottom-support and top-hook" aluminum alloy brackets → hoisting, supporting, alignment, and locking of large-area LIULI composite panel units → hoisting, supporting, alignment, locking, and closure of special-node panel units → sealant application at panel joints → digital acceptance and finished-product protection.

5.1 BIM Parametric Modeling, Virtual Assembly, and Digital Coding

BIM technology is adopted to construct a Level of Development (LOD) 400 corrugated 3D curved surface model at a 1:1 scale. Panel dimensions, non-uniform thickness attributes, and installation coordinates are parametrically associated. A parametric algorithm is used to generate non-repetitive spatial layouts. The LIULI curtain wall is divided into four categories of standard unit panels, each with a specification of 2500mm (L) × 1000mm (W). Every panel is assigned a unique spatial angle, determined by a horizontal intersection angle of 2.44° and a vertical intersection angle of 2.40°. (Figure 6)

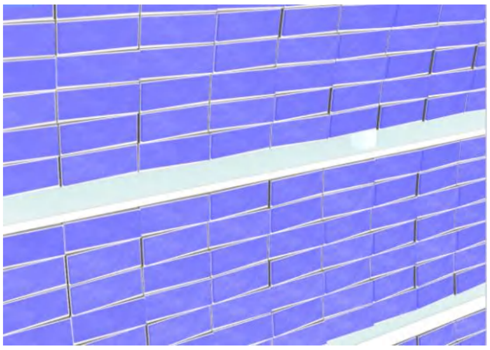


Figure 6 3D Curved Surface Model of the Corrugated Geometry

The thickness of standard LIULI panels gradually transitions from 45mm to 130mm. Each unit panel achieves 3D spatial positioning through differentiated elevations at its four corners: the A-corner serves as the highest reference point, the D-corner as the lowest anchor point, and the B- and C-corners provide gradient connections following a nonlinear algorithm. A full-scale virtual pre-assembly is conducted with 100% clash detection, focusing on resolving structural conflicts at internal/external corners and edge-closure areas. Taking the highest corner point of each unit panel as the positioning datum, panel joints are set at a width of 30mm, forming a non-repetitive spatial layout. Furthermore, sunlight and shadow effects are simulated to ensure a dynamic visual fluidity of the corrugated façade, and 3D visual materials (construction orientation deliverables) are produced. (Figures 7–8)

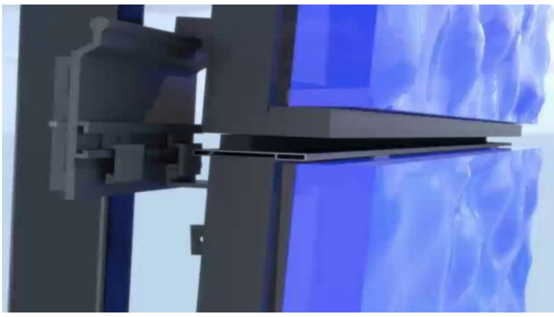


Figure 7 Virtual Pre-Assembly of LIULI Composite Curtain Wall Units

Figure 8 Rendered Visual Effect of LIULI Composite Curtain Wall Layout

3D coordinates of the control points at all four corners of each unit panel are exported in batches, enabling lossless transfer of design data to fabrication and production. Furthermore, based on the determined optimal layout, panels are grouped into batches and assigned a unique digital code following the hierarchy: "Project – Manufacturer – Zone – Row/Column Number – Specification". A QR identity code is generated, and the data is synchronously uploaded to the multi-source digital construction collaborative management platform, enabling scan-to-access traceability and full-chain life-cycle management. (Figure 9)

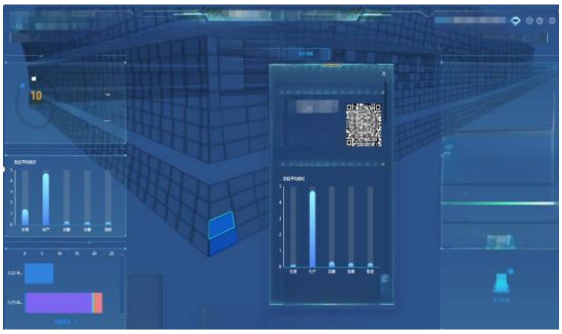


Figure 9 Full-Lifecycle Traceability Management of LIULI Unit Panels

5.2 Delivery and Inspection of Finished LIULI Composite Curtain Wall Units

The LIULI composite panel unit is fabricated by laminating a non-uniform-thickness LIULI slab with the following interlayer configuration: 2.28mm PVE + 10mm heat-strengthened glass + 1.52mm PVE + 10mm heat-strengthened glass. Furthermore, an aluminum alloy auxiliary frame is bonded to the composite panel using sealant, and stainless steel support plates are mechanically fixed around the perimeter of the frame to form the complete LIULI composite curtain wall unit. Upon the batch-by-batch arrival of the units at the site, the QR identity code on each unit is first scanned to verify its specification, row/column number, zone, and other information, ensuring a closed-loop logic of "one code, one item, one designated position." The product markings and accompanying documents are then inspected. Product markings include: trademark, color/pattern variety, batch number, production date, and quality inspection approval seal. Accompanying documents include: product certificate of conformity and quality guarantee document. Every individual panel is subjected to 100% inspection covering appearance, dimensions, thickness, color difference, and performance. Products shall be stored in a well-ventilated, moisture-free, rain-sheltered area on a flat, dry surface. Panels must be stacked by category, placed horizontally in groups of five on dedicated transport racks. Storage shall follow the "first-installed, first-out" principle, with panels arranged according to their assigned sequence numbers. (Figures 10–11)

Figure 10 LIULI Composite Curtain Wall Unit

Figure 11 On-Site Product Stacking

5.3 Establishment of Spatial 3D Control Network and Benchmark Positioning

Prior to the establishment of the control network, the elevation control lines, axis-grid control lines, and first-floor reference control points of the main structure are first verified. Considering the complexity and precision requirements of measurement, a 3D laser scanner and its associated system are employed to perform comprehensive precision measurement of the façade, thereby obtaining accurate benchmark lines, 3D coordinates, and other critical data. The layout and setting-out process follows a hierarchical network deployment with step-by-step control approach. Measurement results are adjusted and corrected through least-squares adjustment to eliminate cumulative deviations. The division lines of the LIULI composite panel units are coordinated with the main structure measurements, allowing installation deviations to be timely adjusted, distributed, and absorbed without accumulation. Once the division lines are determined, control lines shall be established in both the vertical and horizontal directions. In the vertical direction, a control line shall be set at intervals not exceeding 20m. (Figures 12–13)

Figure 12 3D Laser Scanning

(a) External Corner (Acute Angle)

(b) External Corner (Obtuse Angle)

Figure 13 Spatial Benchmark Positioning of LIULI Composite Curtain Wall Units

5.4 Installation of Vertical Steel Mullions

Using the projected axis lines and elevation benchmarks as references, connection brackets (corbels) between the main structure and the vertical steel mullions are installed. The brackets shall be firmly welded, with a weld seam height of ≥6mm, proper anti-corrosion treatment, and a positional deviation of ≤±2mm. A truck crane is used to hoist the vertical steel mullions into position, which are then temporarily fixed to the connection brackets. Based on the control lines, the verticality and spacing of the mullions are initially adjusted: the deviation of mullion verticality from the installation axis shall be ≤±2mm; the elevation deviation between two adjacent mullions shall be ≤3mm; and the maximum elevation deviation within the same tier shall be ≤5mm. Once positioned and adjusted, the mullions shall be fully welded and fixed immediately. After slag removal, two coats of anti-rust paint shall be applied. (Figure 14)

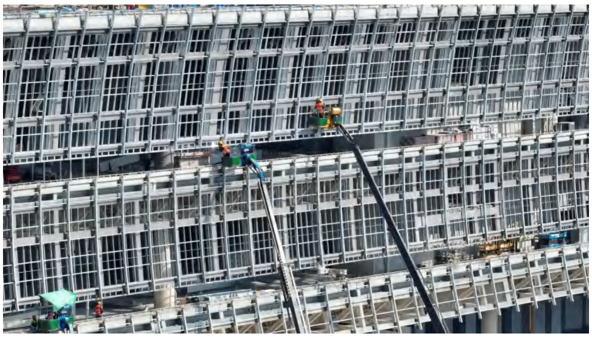


Figure 14 Installation of Vertical Steel Mullions

5.5 Installation of Backing Functional Layers (Fireproofing/Thermal Insulation/Waterproofing, etc.)

Rust and debris on the mullion surfaces are first removed. According to the layout drawings, installation control lines for fireproof rock wool, thermal insulation rock wool, cement fiberboards, and waterproof aluminum panels are marked on the mullions to ensure clear inter-story division boundaries. 100mm fireproof rock wool and 40mm thermal insulation rock wool are laid with staggered joints, maintaining a joint gap of ≤2mm, and are secured with stainless steel insulation pins (@600mm × 600mm). The rock wool shall be tightly packed against the mullions, with interlocking at corners to eliminate thermal bridges and cavities. 8–12mm thick cement fiberboards are then installed, with 3–5mm expansion joints left between boards. The boards are fixed to the mullions using M5 self-tapping screws (@200mm). The surface flatness deviation shall be ≤2mm per 2m, and screw heads shall be countersunk by 0.5–1mm below the board surface, with anti-rust treatment applied to all fastener points. On the exterior side of the fiberboards, 1.5–2mm thick waterproof aluminum panels are installed. The joints between adjacent aluminum panels shall be overlapped, followed by sealant application. Installation screws shall be driven in with sealant, and additional sealant shall be applied over the screw heads after installation. Air tightness is then spot-checked to ensure zero leakage points. (Figures 15–16)

Figure 15 Installation of Fireproof and Thermal Insulation Rock Wool

Figure 16 Installation of Waterproof Aluminum Panels

5.6 Precise Layout of "Bottom-Support and Top-Hook" Aluminum Alloy Brackets

Based on the 3D coordinates of the brackets determined by spatial positioning, the installation centerlines for the "bottom-support and top-hook" aluminum alloy brackets are precisely marked on the vertical steel mullions. Planar and elevation deviations are strictly controlled within ≤±1mm. The bracket back plates are anchored to the mullions using bolts, and after deviation correction, the top and bottom joints are further secured by welding. Stainless steel bolts are used to fasten the aluminum alloy brackets to the back plates. 3D adjustable bolts are employed to precisely control the elevation and set-out position of each bracket. Anti-loosening washers are installed on all contact surfaces, and the tightening torque meets the design requirements. At corner locations subjected to higher loads, shear pins or stiffening ribs are added to eliminate any risk of loosening during service life. (Figure 17)

Figure 17 Precise Layout of "Bottom-Support and Top-Hook" Aluminum Alloy Brackets

5.7 Hoisting, Supporting, Alignment, and Locking of Large-Area LIULI Composite Panel Units

Prior to hoisting, concealed-work inspections are conducted on the inter-story fireproofing, thermal insulation, and waterproofing layers, and all panel units are thoroughly cleaned. Following the non-repetitive spatial layout, standard units embedded with unique identification codes are positioned using the highest corner point as the reference datum. Large-area curtain wall panels are prioritized for hoisting, strictly following a sequence from one side to the other, from bottom to top, and column by column, row by row. A dual-machine hoisting configuration (truck crane + articulating boom lift) is adopted. The crane utilizes lifting hooks and steel wire ropes to secure the unit panels at dedicated lifting points. During hoisting, panels are first lifted to an approximate position, after which workers on the boom lift make fine adjustments, ensuring both safety and accuracy. Once a panel reaches its designated position, a micro-pulley pre-welded to the vertical mullion is used to tilt the panel outward at 12°–15°, which is then slowly lowered onto the bearing support at the top of the bracket to eliminate suspension stress. After the panel's spatial posture is precisely corrected, it is manually and gradually pushed to its intended position. The built-in C-shaped slider buckles within the bracket are then used to limit the position and secure it with bolts. The horizontal and vertical joint widths of the LIULI composite panels are controlled at 30mm. (Figures 18–19)

Figure 18 Dual-Machine Hoisting Using Truck Crane and Articulating Boom Lift

Figure 19 Panel Hoisting, Supporting, Alignment, and Locking

5.8 Hoisting, Supporting, Alignment, Locking, and Closure of Special-Node Panel Units

Upon completion of the adjacent large-area LIULI curtain wall installation, the external-corner unit panels embedded with unique identification codes are positioned using the highest corner point as the reference datum, strictly following a bottom-to-top, row-by-row hoisting sequence. For Side A of the external corner: The LIULI composite panel unit is slowly lowered onto the bearing support at the top of the bracket to eliminate suspension stress. After the panel's spatial posture is precisely corrected, it is manually and gradually pushed to its intended position. The built-in C-shaped slider buckles within the bracket are then used to limit the position and initially tighten the bolts, while the hoisting slings are retained. For Side B of the external corner: The procedure is identical to that for Side A. Both Side A and Side B panels are then further lifted for fine-tuning and correction. The closure angle accuracy is strictly controlled, with a deviation of ≤±0.5°. Forceful hammering or impact correction is strictly prohibited. Once both adjacent panels meet the adjustment criteria, the position-limiting bolts are re-tightened and the closure is locked. (Figures 20–21)

Figure 20 Hoisting of External-Corner Panel Units

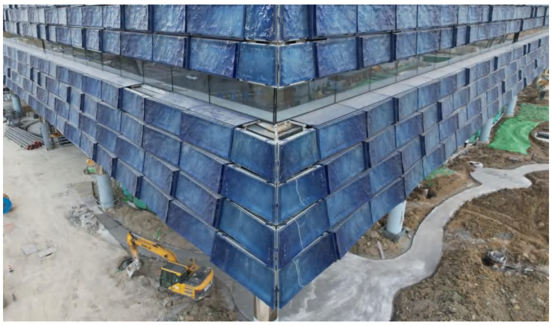


Figure 21 Locking and Closure of Both Sides of the External Corner

5.9 Sealant Application at Panel Joints

After the complete assembly of the LIULI curtain wall, all debris, dust, and protective films along the panel edges are removed from the joints. A dedicated organic solvent (e.g., isopropyl alcohol) is used to wipe the bonding surfaces in a single direction, followed by natural air-drying, ensuring the substrate surface is oil-free, moisture-free, and dust-free, with a qualified contact angle test. Masking tape is applied along both edges of the joint, 1–2mm from the panel edge, requiring straight lines and square corners. The tape must be removed before the sealant skins over to avoid residual adhesive or damage to the bead edges. An EPDM rubber strip is inserted into the joint. Using a dedicated caulking gun with the nozzle tip inserted to half the joint depth, MS sealant is injected at a steady speed in a continuous fill, ensuring the cavity is fully filled with no voids or discontinuities. An arc-shaped finishing tool is then used to smooth the bead into a concave arc or flat profile, with a smooth surface finish, and the number of finishing passes is limited to ≤2. (Figure 22)

Figure 22 Joint Protection and Sealant Application for the LIULI Curtain Wall

5.10 Digital Acceptance and Finished-Product Protection

A 3D laser scanner is used to acquire point cloud data of the completed curtain wall. Fit-comparison with the BIM model is conducted, achieving a 100% acceptance qualification rate. Data including panel identification codes, site inspection records, installation coordinates, and 3D scanning reports are uploaded with one-click to the "LIULI Component Full-Lifecycle Quality Traceability Platform", forming an "one-record-per-panel" electronic identity. This enables traceability of quality accountability and a 100% data archiving completeness rate. Prior to final acceptance, the LIULI curtain wall shall be cleaned from top to bottom using a neutral cleaning agent and soft cloths. The use of strong acids, strong alkalis, or metal tools for scraping is strictly prohibited, ensuring that the surface glossiness is ≥85GU (Gloss Units). It is strictly forbidden to erect scaffolding, hang heavy objects, or use the completed curtain wall as a hoisting load-bearing point, so as to prevent brittle fracture or damage. (Figures 23–24)

Figure 23 As-Built Appearance of the Large-Area LIULI Curtain Wall

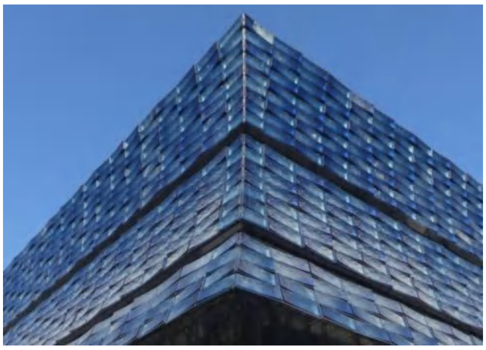


Figure 24 As-Built Appearance of the External-Corner LIULI Curtain Wall

6 BENEFIT ANALYSIS

6.1 Economic Benefit

Table 1 Economic Benefit Comparison

Number	Item	Construction benefit calculation	Total
1	Proposed method (Rapid installation)	Main mullion installation labor: ¥120/m²×17800m²=¥2136000 On-site framing labor: / Machinery cost: 50t truck crane: 4 units×¥2300/shift×123 days =¥1131600; Articulating boom lift: 4 units×¥800/shift×123 days =¥393600 Labor cost: 8 workers×¥320/person×123 days=¥314880 Technical service fee: ¥100000	¥4076080
2	Conventional method (On-site framing)	Main mullion installation labor:¥120/m²×17800m²=¥2136000 On-site framing labor: ¥160/m²×17800m²=¥2848000 Machinery cost: 50t truck crane: 4 units×¥2300/shift×162 days=¥1490400; Articulating boom lift: 4 units×¥800/shift×162 days=¥518400 Labor cost: 16 workers×¥320/person×162 days=¥829440 Technical service fee: /	¥7822240
Comparative analysis: Compared with the conventional on-site framing method, the proposed construction method eliminates the on-site framing process, accelerates the installation efficiency of large-scale corrugated 3D LIULI curtain walls, and yields direct economic benefits of ¥3746160.			

The project's LIULI curtain wall adopted the digital modular installation construction method for large-scale corrugated three-dimensional architectural glass (LIULI) curtain walls. By innovatively integrating core technologies—full-chain digital driving, precision assembly of modular finished products, and flexible "bottom-supporting and top-hooking" adjustment and locking—this method systematically overcomes the challenges of chaotic layout, high hoisting damage risk, and poor alignment accuracy. A safe, efficient, precise, and replicable digital modular installation system is thereby established. An economic comparison between this method and the conventional installation process was conducted from the perspectives of labor, materials, and machinery, as detailed in Table 1. The comprehensive comparison reveals that the proposed method generates direct economic benefits of approximately ¥3746160 compared with the conventional process (on-site framing).

6.2 Social Benefit

The deep integration of BIM, 3D laser scanning, and full-lifecycle traceability technology has enabled a transition of LIULI curtain wall construction from "experience-driven" to "data-driven" practices. This approach overcomes the long-standing industry challenges of "high fragility and difficult positioning" associated with large-scale corrugated 3D panels, and fills the application gap of irregular LIULI as a primary building envelope structure, providing the industry with a replicable digital construction paradigm.

The "factory prefabrication, on-site assembly" model significantly reduces on-site noise and dust pollution, while conserving non-renewable resources. Furthermore, by deeply integrating traditional LIULI firing craftsmanship with modern digital technologies, the method not only preserves the artistic essence of this intangible cultural heritage, but also endows it with the structural safety required of modern buildings, thereby exploring an innovative pathway for the living inheritance of traditional craftsmanship.

The completed corrugated 3D LIULI curtain wall features dynamic light-shadow fluidity and a distinctive texture, greatly enhancing the architectural artistic expression and urban identity. The high-quality as-built outcome improves the urban public space environment, strengthens cultural confidence, and generates a positive social impact and demonstration effect.

7 CONCLUSION

This paper addresses the challenges encountered during the construction of large-scale corrugated 3D architectural glass (LIULI) curtain walls, specifically the difficulty in controlling irregularly shaped panels, extremely high precision requirements, and the inadequacy of conventional techniques. It innovatively proposes a digital modular installation technology for large-scale corrugated three-dimensional architectural glass (LIULI) curtain walls. By integrating three core methodologies—full-chain digital driving, precision assembly of modular finished products, and a flexible "bottom-supporting and top-hooking" adjustment and locking mechanism—the approach systematically overcomes the pain points of chaotic panel layout, high damage risk during hoisting, and poor alignment accuracy. A safe, efficient, precise, and replicable digital modular installation system is thereby established. For the first time internationally, this technology has been applied at a large scale, covering a total area of 17800 m² with 7240 individual panels, successfully advancing LIULI craftsmanship from interior decoration to architectural curtain wall applications, marking a significant technological leap.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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