Critical Mass: Scaling Passive House at Bunker Hill

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ABSTRACT

Recent regulatory changes have fundamentally shifted the conventional building design and delivery paradigm in Massachusetts. Implementation of the 2023 Stretch Energy Code and the Specialized Opt-In Code prioritizes reductions in operational carbon emissions, necessitating a comprehensive restructuring of architectural design, project delivery, and construction strategies. This paper examines the Bunker Hill Housing redevelopment, a 2,699-unit master plan project leveraging an integrated, kit-of-parts prefabrication methodology to deliver Phius-certified buildings at scale. The study analyzes a design methodology incorporating cross-laminated timber (CLT) and fully clad, panelized exterior wall assemblies alongside the collaborative fabrication workflow required to achieve Phius certification, including a whole-building airtightness threshold of 0.06 cfm/sf at 50 Pa.

Findings demonstrate that integrating early-phase design coordination with a prefabricated kit-of-parts workflow yields a 32% to 41% reduction in construction duration compared to regional benchmarks, alongside a 20% reduction in construction costs compared to conventional Type I construction. Achieving these schedule and cost efficiencies relies on maintaining team continuity across multi-building phases, executing physical performance mock-up testing to resolve component interfaces prior to construction, and optimizing Passive House design levers to minimize wall assembly thickness. As contemporary multifamily developments face compounding economic pressure to mitigate construction financing exposure, the reduction of construction duration and the establishment of schedule predictability must be elevated to critical design constraints on par with energy performance metrics. This paper employs a practitioner-led research methodology, in which the iterative design process, performance mock-up testing, field observations, whole-building diagnostic testing, and empirical lessons learned across multiple buildings constitute the foundation of the investigation.

Introduction

Project Team

For the initial phase of the development, Building M, RDH Building Science provided building enclosure consulting, Phius consulting, and Phius verification services, collaborating with Stantec as the architect and Suffolk Construction as the general contractor. This comprehensive scope carried over to the second phase, Building F. Efficiencies were gained through this integrated consulting approach, which leveraged close alignment between the CPHC, Verifier, and building enclosure consulting roles. This continuity allowed for ongoing design continuity and capitalized on lessons learned from one project to the next. The resulting collaboration enabled tightly coordinated studies balancing whole-building energy modeling, thermal finite element analysis of alternative facade designs, and the long-term durability central to established building enclosure practices.

Industry Context

The United States faces a significant housing production shortfall, with the national housing stock undersupplied by approximately 3.7 million units (Freddie Mac 2024). Concurrently, decarbonization mandates are expanding, with 24 states and the District of Columbia adopting specific greenhouse gas emissions reduction targets (C2ES 2026). While many jurisdictions have not yet implemented regulatory frameworks to alter the built environment, the trajectory of the Massachusetts building energy codes serves as a transferable model for balancing housing production with 2050 decarbonization commitments.

An optimal technical pathway toward operational decarbonization couples building electrification with Passive House standards. Attempting to electrify multifamily building stock without concurrently reducing peak heating and cooling loads introduces critical capacity risks to the electrical grid. Comparative load models demonstrate that a standard multifamily podium building designed to 2021 International Energy Conservation Code (IECC) baselines utilizing electric resistance or conventional heat pump space heating imposes a winter peak grid demand approximately four times greater than an identical building envelope optimized to Passive House standards, specifically 3.3 Btu/hr-sf compared to 0.8 Btu/hr-sf (Ormond 2026).

At a systemic scale, simultaneous interconnection of unoptimized, 2021 IECC-compliant electric buildings would require extensive grid infrastructure expansions, creating utility delays that could defer occupancy timelines. Conversely, suppressed peak demands achieved through Passive House compliance mitigate the necessity for immediate grid upgrades, thereby streamlining utility interconnection and reducing potential delays in bringing housing online. Minimizing aggregate electrical demand preserves regional grid affordability while executing mandatory decarbonization mandates.

Regulatory Context

In 2021, the Massachusetts Climate Act committed the Commonwealth to achieving net-zero emissions by 2050. In response, the Department of Energy Resources (DOER) developed the updated Stretch Code and Specialized Opt-In Code, effective since July 2023 (DOER 2022). These codes encourage electrification in combination with Passive House, or alternative compliance pathways replicating specific Passive House criteria. This compliance framework relies on four core technical pillars:

- Low air infiltration verified by mandatory field testing.
- Thermal bridge mitigation accounting for clear field, linear, and point thermal bridges.
- Strict envelope U-value requirements, including vertical envelope UA backstops and high-performance fenestration.
- Ventilation energy recovery requiring high-efficiency heat and energy recovery systems.

As of 2026, 59 municipalities covering approximately 60% of the state's population have adopted the Stretch Code, and 49 municipalities covering approximately 33% of the population have adopted the Specialized Opt-In Code (Ormond 2026). Under the Stretch Code, multifamily residential buildings can achieve compliance through HERS certification with specific target scores (45 for all-electric, 42 for mixed-fuel), Passive House certification, or the Massachusetts TEDI path. The Specialized Opt-In Code mandates Passive House certification, through either

PHI or Phius, for all new multifamily residential buildings exceeding 12,000 square feet (DOER 2022).

Consequently, the early-phase, building-science-based design approach fundamental to passive building principles is becoming an established baseline among the architecture, engineering, and construction community, as well as building owners. Utilizing Passive House certification as a mechanism for operational decarbonization within the building code establishes the building enclosure as a primary system for achieving state emissions targets. Throughout this paper, 'Passive House' refers to the code compliance pathway inclusive of both PHI and Phius, as referenced in the Stretch and Specialized Opt-In Code under C407.3. 'Phius' refers to the specific certification standard followed by this project.

Conventional Construction Process

Within the Greater Boston metropolitan area, prevailing market-rate multifamily housing developments frequently utilize Type III '5-over-1' podium construction, consisting of a single-story structural steel and composite metal deck podium beneath five stories of conventional, stick-built wood framing. While these wood-framed assemblies are predominantly constructed on site, their project schedules could experience significant optimization through the integration of panelized systems. Mid-rise and high-rise developments exceeding the heights permitted for Type III structures require Type I or Type II non-combustible construction, utilizing structural steel frames with composite concrete floor plates. Although these construction types incur higher capital costs, high-rise Type I structures frequently leverage prefabricated envelope systems, including unitized curtainwalls, precast concrete panels, or cold-formed metal framed (CFMF) mega-panels suspended from the primary structural steel frame.

However, conventional prefabricated enclosures present distinct building enclosure performance vulnerabilities. Precast concrete panels introduce significant clear-field R-value challenges, particularly with thermal bridging caused by structural connections penetrating continuous interior insulation. Unitized curtainwall systems also exhibit derated thermal performance due to multi-planar, three-dimensional heat transfer occurring through repetitive aluminum mullion and spandrel profiles.

The development of custom, fully integrated panelized enclosures introduces complex engineering challenges, particularly regarding the continuity of building enclosure control layers. When a panel is fully prefabricated with interior sheathing, a weather-resistive barrier/air barrier (WRB/AB), continuous exterior insulation, and finished cladding, maintaining watertightness and airtightness at the inter-panel joints becomes a critical failure point. Furthermore, panel joints and fenestration penetrations can cause localized thermal bridging if they are not carefully detailed. While legacy building codes omitted the quantification of geometric and structural thermal bridges, the Phius standard requires accounting for heat loss through thermal bridging. Designing a comprehensive, load-bearing wall panel that integrates everything from interior stud framing to exterior cladding is a significant engineering task. This complexity intensifies when detailing panels to meet the airtightness and thermal performance criteria mandated by Phius certification, all while maintaining bulk water management strategies fundamental to long-term durability.

A distinct market gap exists for mid-scale buildings positioned between traditional Type III podium structures and high-rise Type I or II high-rises. At this intermediate scale, panelization has historically been excluded from the design and delivery process. Commercial fabricators specializing in panelized enclosures rarely operate within the mid-rise multifamily sector, as the premium cost of these high-performance systems is financially non-viable for mid-scale project budgets. Concurrently, to date, regional fabricators who traditionally serve the mid-scale housing market often lack the manufacturing infrastructure, technological capacity, and technical expertise required to produce the fully integrated, high-performance panel assemblies optimized for Phius compliance.

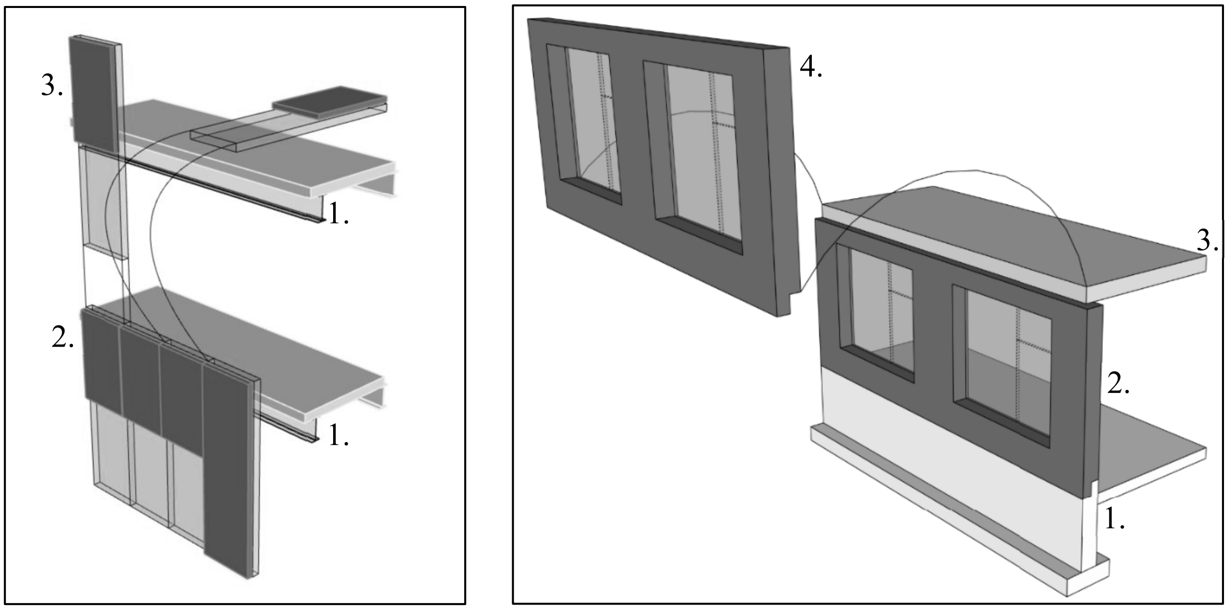


Figure 1. Left: Example sequencing of conventional non-load bearing hung wall panel systems common to Type I and II construction: unitized curtainwall. Right: Sequential CLT floor and load-bearing wall panel construction.

Project Context

The Bunker Hill Housing redevelopment is located in Charlestown, a neighborhood of Boston, which is a Specialized Opt-In Code community. From the outset of the project, prior to Passive House certification becoming a local code requirement, Leggat McCall Properties committed to Phius certification for all 15 buildings in the development, responding directly to the regional housing shortage and the need for climate change mitigation. This mixed-rate development comprises 2,699 dwelling units, replacing lower-density public housing. Because Passive House design requires early, whole-building coordination of enclosure performance, structure, and mechanical, electrical, and plumbing (MEP) systems, the project leveraged this early design integration to support a prefabricated enclosure strategy that could be refined and replicated across multiple buildings.

The development team faced the challenge of delivering high-performance buildings in a systematic way, at scale. In parallel with increasingly rigorous energy codes, multifamily housing projects face mounting pressure to reduce time-to-delivery and financing exposure, elevating minimized construction duration and schedule certainty to design constraints on par with energy performance. This emphasis on productivity is driven by extended entitlement timelines and financing constraints typical of large urban housing projects, which can amplify the cost impacts of prolonged construction durations.

The first building, a six-story structure containing 102 units, was completed in 16 months and assembled by a crew of five carpenters and one crane operator. This outcome was achieved during the first execution of an entirely new construction system. Minimizing the duration of the construction schedule yields a significant financial impact due to the corresponding reduction in construction-period financing costs (Nigro 2026).

Figure 2. Completed view of the Phius-certified multifamily building M at the Bunker Hill Housing Redevelopment, Charlestown, Massachusetts.

Hypothesis

This paper employs a practitioner-led research method, in which the design process itself, performance mock-up testing, field observation, whole-building testing, and lessons learned across multiple buildings constitute the basis of the investigation. It is hypothesized that a panelized, prefabricated kit-of-parts approach designed for on-site assembly reduces construction duration and construction financing costs, thereby producing housing faster than the standard timeline (Freddie Mac 2024) while successfully achieving Phius certification.

Design, Delivery, and Validation

Developing the Kit of Parts

This study employs an iterative design and validation process, in which the building project serves as a full-scale test platform to evaluate and refine a prefabricated kit-of-parts approach. The developer sought to establish an economy of scale across the master plan by producing a kit of parts that could be adapted for all 15 buildings, which range from 4 to 10 stories, to increase housing production. The design team utilized the first building in the development, Building M, as an initial test case to refine design and construction sequencing for subsequent buildings.

The goal was to drive timelines through an intelligent set of components that can be put together in an infinite array of configurations, sizes, and buildings (Nigro and Grady 2025). The approach targets timeline compression and efficiency to lower or stabilize construction costs without reducing quality or harming labor, simplifying on-site work to produce more housing (Nigro and Grady 2025).

To meet the project's timeline and performance criteria, the design team evaluated multiple component iterations for the kit of parts. The finalized system utilizes cross-laminated timber

(CLT) for the floor assemblies, a precast concrete core, and a panelized exterior wall system. Each component was selected to reduce downstream labor, eliminate redundant structural systems, and simplify construction sequencing, minimizing on-site duration and trade coordination complexity.

In Building M, the 7-ply CLT structural floor panels span 64 feet from exterior wall to exterior wall, bearing only on the interior corridor wall without additional vertical structural support. The floor panels bear directly upon a panelized, Passive House exterior wall system fabricated with pre-installed windows. The multiple technical requirements of the exterior walls provided constraints and design challenges that had to be considered simultaneously.

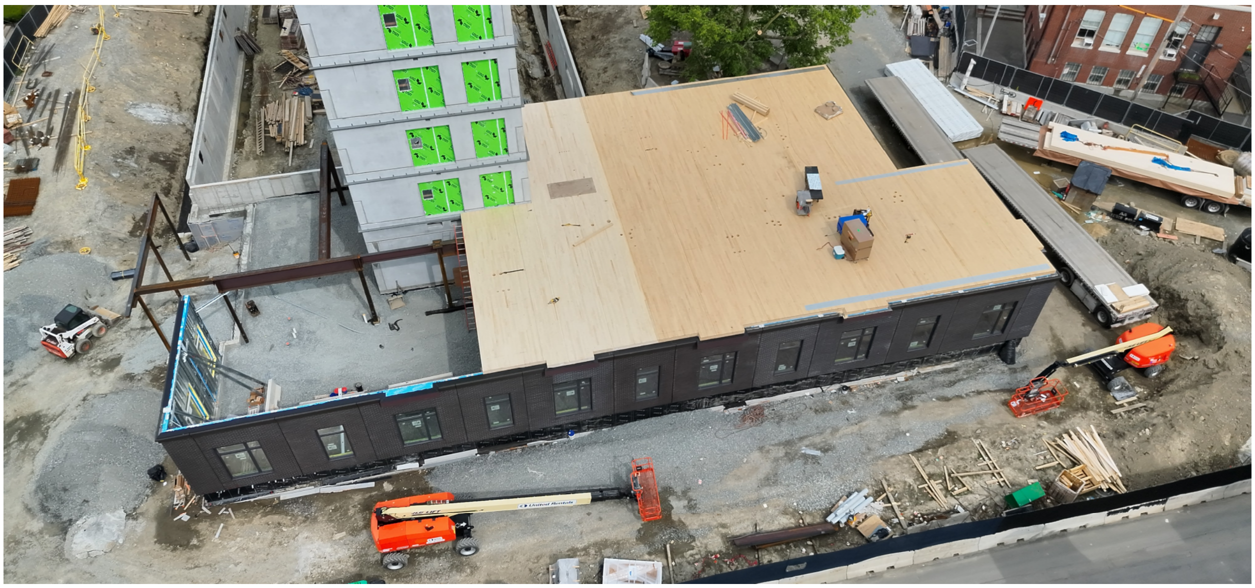


Figure 3. Construction photo of Building F, showing installation of the kit of parts: precast concrete cores, 64'-0" long 7-ply cross laminated timber floors, and fully clad load bearing wall panels.

A Non-Proprietary Panelized Enclosure System

The wall panel design utilizes cold-formed metal framing (CFMF), which is common as exterior wall framing in Type I and II construction but is not typically deployed as a load-bearing wall system. In conventional steel-framed buildings, CFMF spans floor to floor as an infill assembly, remaining secondary to the primary structural steel frame.

While established mega-panel systems using CFMF are available from specific manufacturers, they frequently rely on proprietary components, particularly for panel joints. Interlocking joint extrusion profiles introduce significant cost premiums to a wall panel. Additionally, conventional inter-panel connections are engineered for non-load-bearing assemblies and are unsuitable for the structural demands of this kit-of-parts system. To avoid being confined to a single proprietary system, the owner required a non-proprietary design to competitively bid the project among multiple potential fabricators, maintaining flexibility for repeatability across the master plan.

Traditional panelized systems used on larger-scale commercial buildings are rarely financially viable for mid-scale buildings. To achieve the kit of parts requested by the client, the design team designed a load-bearing CFMF wall panel system, with the CLT floor planks bearing directly on each successive story. This approach eliminated both the costly Type I or Type II primary structural steel frames and traditional hung-panel delivery methods. The team collaborated with a regional fabricator who modified their manufacturing facility and embraced this panelization methodology.

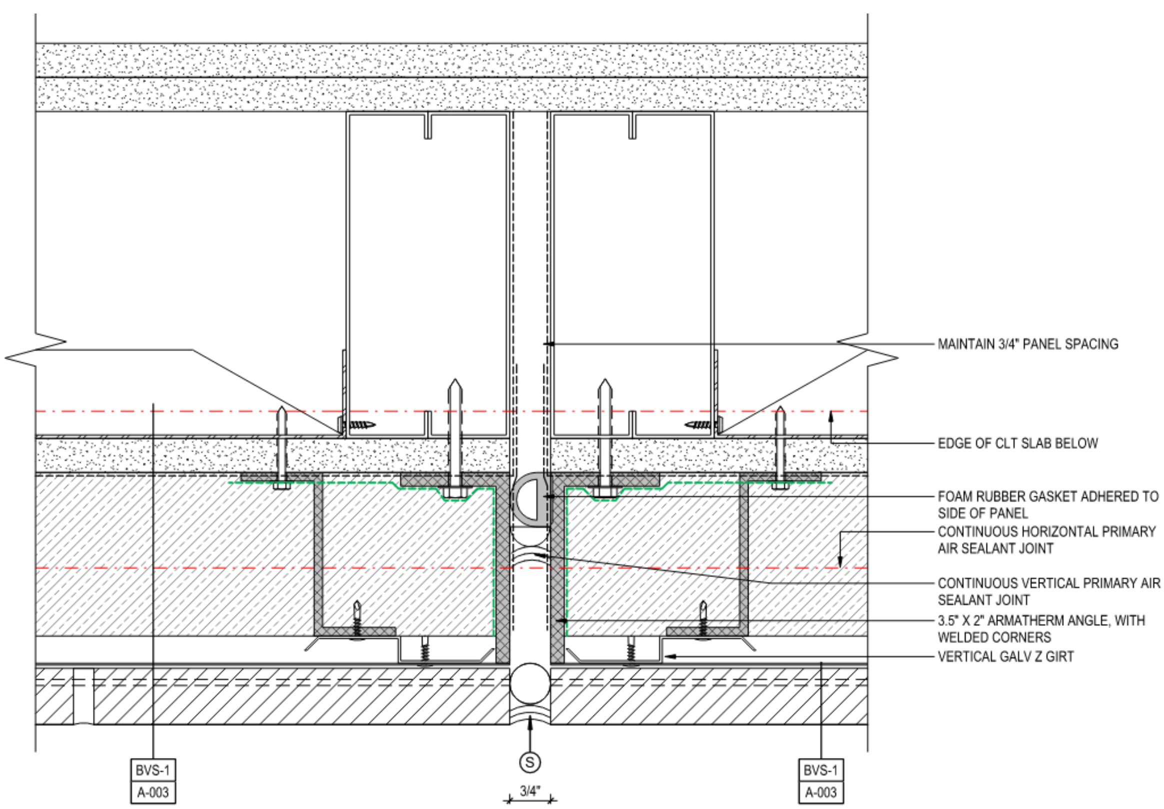
To address performance and structural constraints, the team designed a rainscreen wall assembly built on a CFMF backup wall, configured with 3 inches of continuous exterior mineral wool and a thermally broken clip-and-rail system supporting the cladding. Various cladding types, including thin brick, metal panels, and fiber cement board, were integrated into this standardized backup wall assembly.

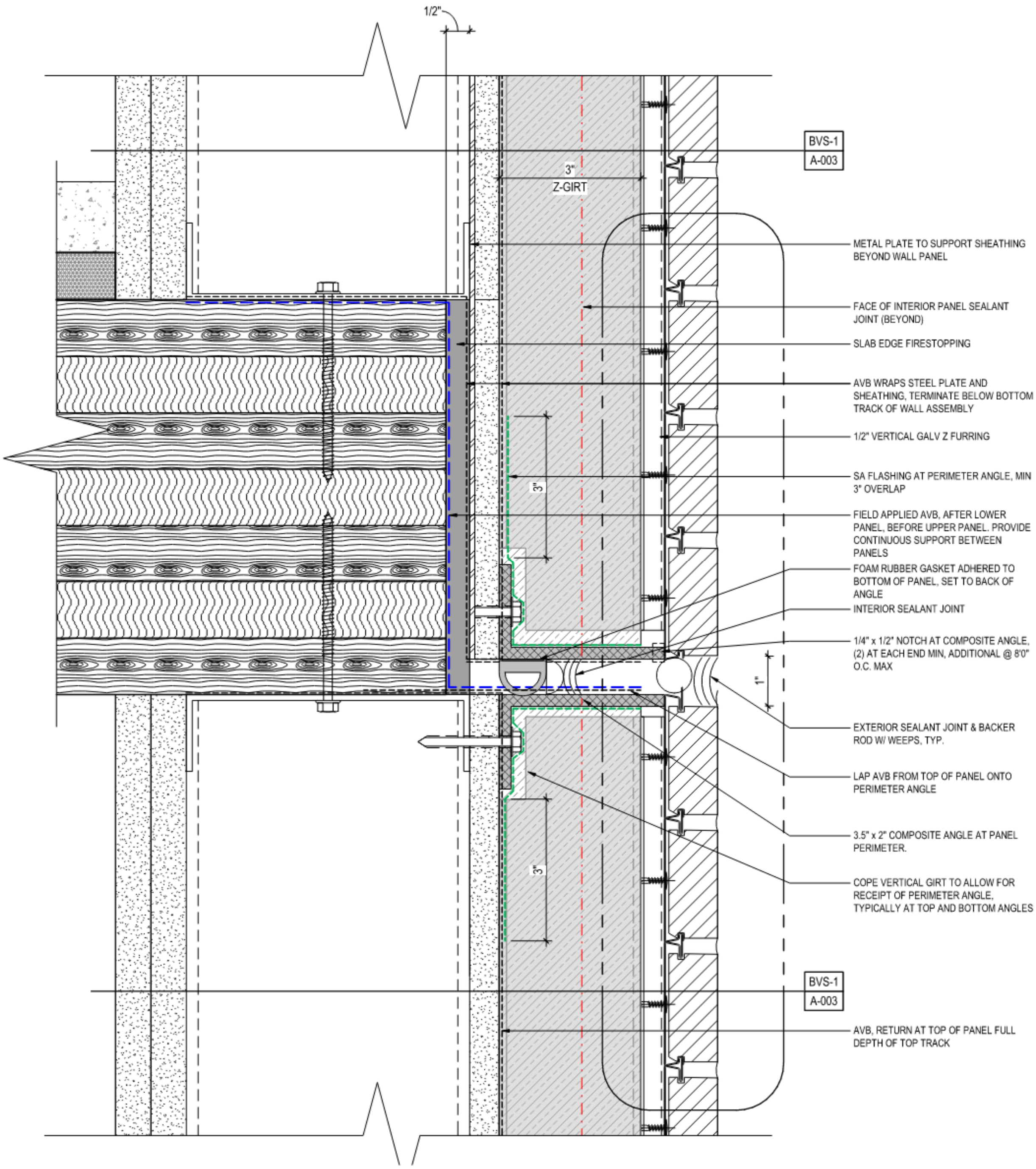
Enclosure Design Challenges

The component installation sequence presented a distinct challenge in ensuring air- and water-tightness. In a typical concrete- or steel-framed building, the primary structural frame is erected prior to the installation of exterior wall panels that are hung off the structure. These conventional panels are non-load-bearing and allow for field adjustability, where a typical panelized system with gasketed mating joints can accommodate up to 3/4 inches of movement.

At Building M, the exterior wall panels and CLT floor assemblies were installed successively story by story. This fabrication and installation sequence offered virtually no margin for error, as the panels could not be adjusted once the CLT floors were loaded onto the wall framing.

To establish continuity in the air and water control layers, the panelized joints were wet-sealed with two continuous lines of silicone sealant. Maintaining consistent sealant joint dimensions between the panels was critical to performance. The pre-installed cladding introduced significant challenges, as it restricted access to the joints during installation when field conditions were found to be out of tolerance. Furthermore, because these sealant joints were set back approximately 7 inches from the exterior face, visually inspecting them within the deep panel profile proved difficult.





Figures 4 & 5. Plan and Section details of Bunker Hill Building M vertical and horizontal joints

Collaborative Fabrication Process

The initial panel design was intended to be partially site-clad, specifically at the inter-panel joints using 'leave-outs' where insulation and cladding would be field-applied to allow for installation and inspection of sealant joints. The developer ultimately decided to utilize factory-installed cladding across the entire panel to reduce on-site labor costs. Under ideal circumstances, a project of this nature would involve an early design-assist contract with the fabricator. On larger commercial buildings, curtainwall fabricators routinely build detailed 3D digital twin models to facilitate coordination. However, this process and skillset are not typically possessed in-house by fabricators operating at the mid-rise residential scale.

Given the project goals, an evolving panel design, and a fixed project timeline, Leggat McCall deployed a separate team from RDH, designated as 'RDH 2' and led by professionals with prefabrication experience, to work directly with the fabrication shop. This team collaborated closely with the fabricator to provide design-assist guidance, support performance mock-up (PMU) testing, and oversee fabrication, QA/QC, and installation protocols to help a manufacturer producing this type of high-performance panel for the first time establish quality control practices and achieve efficiencies.

Performance Mock-Up Testing

Building enclosure durability depends heavily on the execution of panel joints, particularly four-way intersections where air and water control layers meet. Performance mock-up (PMU) testing evaluated this unconventional assembly before full-scale production commenced. Three rounds of PMU testing were performed on the Building M panel system:

- Round 1: Diagnostic testing revealed discontinuities in the sealant joints prior to pressure loading. The test chamber could not maintain the required pressure criteria of 1.57 psf (75 Pa) per ASTM E783. Smoke testing identified air leakage pathways caused by sealant joints being installed in different planes, deviating from approved PMU drawings.
- Round 2: The assembly achieved air leakage compliance but failed static water penetration testing per ASTM E331. Inspection revealed voids in the primary seal at the four-way joint, and diagnostic smoke testing indicated leakage along the horizontal panel-to-panel joint.
- Round 3: Incorporating modifications derived from initial failures, the assembly successfully passed both static and dynamic water testing per AAMA 501.1. The RDH 2 team worked with the fabricator to refine the detailing approach to ensure field installation could replicate the passing performance.

This pre-construction testing reduced uncertainty during installation and mitigated the risk of field remediation. Data from PMU tracking allowed the RDH 2 team to develop a graphic shop manual to guide the fabrication and installation sequence, establishing a baseline for quality control among the fabricator, contractor, owner, and design teams.

Results

Construction Execution and On-Site Coordination

On February 2, 2024, the first exterior wall panel was erected on site. To maintain the fabrication and delivery schedule during early mobilization, initial panels were shipped without exterior cladding. Over the subsequent ten months, wall panels and CLT floor assemblies were fabricated and installed, completing the prefabricated kit-of-parts assembly. Collaborative problem-solving occurred through frequent field observations, documentation, and regular coordination meetings. Ongoing coordination among the design team and trades responsible for control layers proved essential for achieving Passive House performance, given the limited tolerance for adjustment inherent in a load-bearing panelized enclosure system.

Despite the first-generation nature of the system, Building M achieved a construction duration of approximately 16 months for the six-story, 102-unit building. This timeframe represents a 33% to 41% reduction in construction duration compared to the typical 24 to 27 month timelines observed by the author on comparable local projects, and a 32% reduction compared to the Northeast regional average of 23.4 months reported by the National Association of Home Builders, validating the ability of the prefabricated kit-of-parts approach to deliver measurable schedule compression.

These schedule efficiencies directly support the project's financial objectives. According to data provided by the owner, utilizing this prefabricated mass timber panel system yielded a 20% reduction in construction costs compared to baseline pricing developed for a conventional Type I steel and concrete structure. This cost differential validates the financial viability of the kit-of-parts methodology as an alternative to traditional high-rise construction types for mid-rise residential delivery.

Design Iteration: Building M to Building F

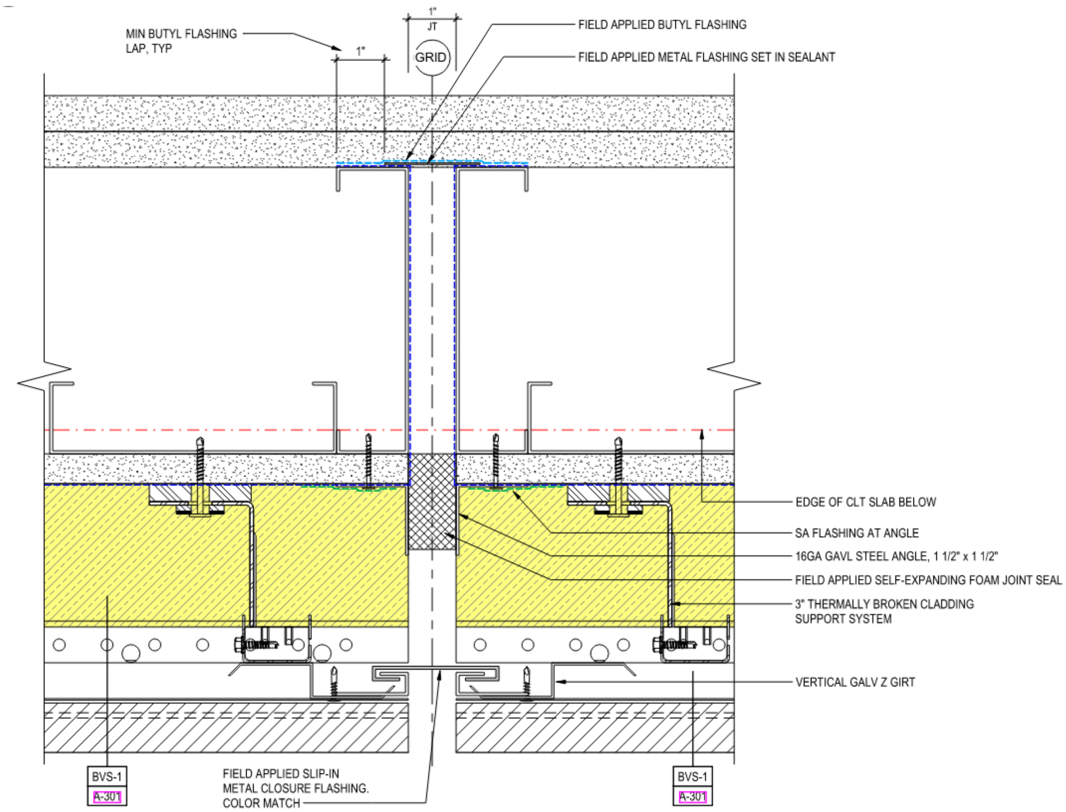
Lessons learned from Building M directly informed refinements to enclosure detailing and installation sequences implemented for Building F. The exterior double sealant joints used in Building M, which required extensive on-site labor from exterior lifts, were determined to be unscalable for three primary reasons:

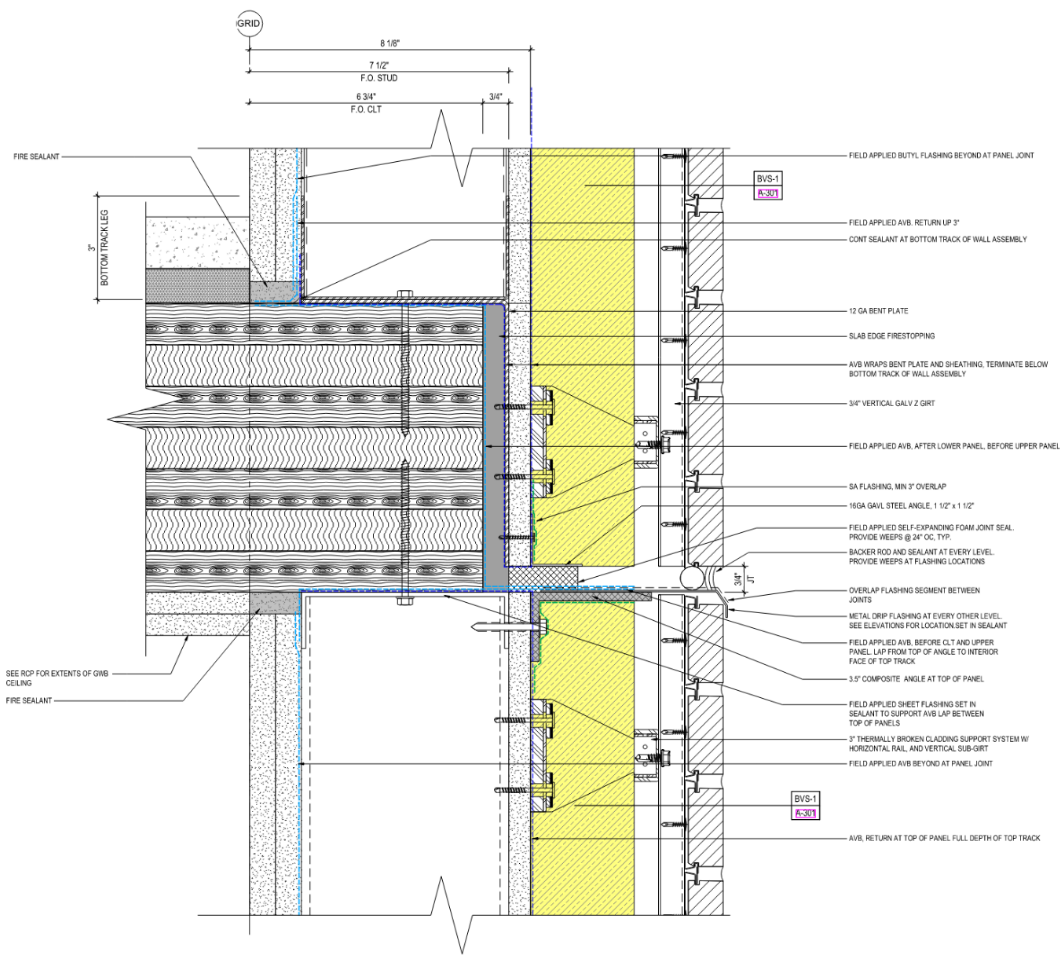
1. On-Site Labor Constraints**.** The approach required field crews to work from exterior lifts to seal joints after panel installation, conflicting with the project objective of minimizing field labor.

2. Height Limitations. Relying on boom lifts for exterior joint deployment is infeasible for taller buildings planned in later phases, as those structures exceed typical lift reach.

3. Quality Control Impracticality. Ensuring quality control for a field-installed double sealant joint was difficult. The exterior joint, which serves as the primary air and water seal, was set back approximately 7 inches within the panel profile, making it challenging to access and visually inspect.

To address these limitations on Building F, the primary air seal was relocated to the interior side of the wall panel. This adjustment allows installation to occur entirely from inside the building, with crews standing on the floor deck rather than working from exterior boom lifts. Bulk water management at panel joints was revised to utilize a self-expanding foam joint seal, wept at horizontal joints, installed from the interior as panels are set. Additionally, a field-applied, slip-in metal closure flashing was introduced at vertical joints to serve as the outermost layer of bulk water management.





Figures 4 & 5. Plan and Section details of Bunker Hill Building F vertical and horizontal joints

Moisture Management

A panelized wall system complements mass timber construction by enabling rapid building enclosure, a full story at a time, limiting potential moisture exposure duration during construction. Moisture management planning is a critical component of mass timber construction (Finch et al. 2025).

In conjunction with the specific building enclosure design, the project team developed a moisture management plan for Building M intended for application across subsequent buildings. Rapid vertical deployment of walls shifted bulk water management to exposed upper floors, requiring active water management following weather events alongside continuous moisture monitoring of CLT elements throughout construction.

The contractor on Building M implemented an alternative approach to recommendations in the RDH moisture management plan, limiting moisture protection to panel splines rather than installing continuous coverage over CLT decks. As documented in Moisture Risk Management Strategies for Mass Timber Buildings (Finch et al. 2025), protection strategy robustness must correlate directly with moisture exposure levels. Implementing a lower level of continuous protection requires immediate active water management after weather events. During construction, standing water was observed on site.

Experience from Building M informed a revised sequencing strategy adopted for Building F, prioritizing accelerated permanent enclosure. The building is erected in four sequential vertical sections utilizing temporary wall enclosures at open ends. This strategy aims to reduce reliance on temporary moisture protection measures over CLT floors by placing the permanent roof over the CLT below more quickly.

Whole-Building Airtightness Testing

Performance of the kit-of-parts assembly was quantified through whole-building airtightness testing. The Phius Verifier engaged during the design phase and coordinated with the contractor to establish the testing protocol.

By August 20, 2024, installation of air barrier components was completed for Building M, allowing the first mid-construction airtightness test to be performed. This interim test occurred during active construction, requiring multiple temporary enclosure measures, including temporary exterior walls at uninstalled storefront openings used for material access, and several uninstalled windows. This initial test yielded a leakage rate of 0.068 cfm/ft^2 at 50 Pa, slightly exceeding the Phius maximum allowance of 0.060 cfm/ft^2 at 50 Pa. Given the extent of temporary openings, the project team determined the performance indicated an acceptable trajectory but scheduled subsequent interim testing prior to final verification.

The second interim test achieved an air leakage rate of 0.051 cfm/ft^2 at 50 Pa. High-wind conditions during this test period limited the procedure to negative pressure only, rather than combined positive and negative pressure cycles required for full ASTM E779 compliance reporting. However, data provided confidence that the finalized enclosure would achieve compliance under standard testing conditions.

The final verification test recorded a passing air leakage rate of 0.055 cfm/ft^2 at 50 Pa, meeting the Phius threshold of 0.060 cfm/ft^2 at 50 Pa. While the target threshold was not met during the first unadjusted interim test, the sequential testing process identified leakage paths early, mitigating the risk of late-stage enclosure remediation and supporting schedule certainty.

Discussion and Conclusions

The Kit-of-Parts Approach Delivered Measurable Schedule Reduction

Building M achieved a construction duration of approximately 16 months for a six-story, 102-unit building as a first-generation system. Building F, containing approximately 345 units, is tracking a 17.5-month construction duration, representing an increase of only 1.5 months despite a threefold increase in unit count. In comparison, conventional multifamily residential buildings of similar or smaller scale within the Boston area typically exhibit construction durations of 24 to 27 months. Shortened construction schedules reduce interest accumulation on construction loans, optimizing project financing and accelerating the timeline to generate occupancy revenue.

Process Efficiency Improves Through Repetition and Team Continuity

The panel fabricator optimized shop logistics between the two phases, transitioning from horizontal fabrication at individual workstations for Building M to a vertically oriented rolling assembly line for Building F. Reflecting this increased fabricator autonomy, RDH 2's direct oversight role decreased significantly during the second phase. Furthermore, the Building F PMU passed compliance testing on the first attempt, compared to the three rounds required for Building M. Maintaining continuity across the project team, including the same architect, contractor, consultants, and panel fabricator, remains central to realizing these compounding efficiencies. Introducing a new fabricator would necessitate repeating upfront technical coordination and the learning curve.

The Building M Exterior Double Sealant Joint Was Not Scalable

The initial double sealant joint design required field crews to execute primary seals from exterior lifts post-installation, conflicting with the goal of minimizing site labor. This approach is unfeasible for taller structures exceeding standard boom lift reach. Additionally, verifying quality control for the interior joint was impractical due to its 7-inch setback within the panel profile, which restricted sealant gun access and visual inspection. The redesigned assembly for Building F relocated the primary air seal to the interior face of the wall panel, enabling installation from the floor deck inside the structure. This modification aligns with initial project objectives and demonstrates the utility of a practitioner-led research method: design, test, observe, and refine.

Moisture Management Requires Matching Protection Robustness to Exposure Level

The contractor on Building M implemented an alternative approach to the RDH moisture management plan by limiting moisture protection to panel splines rather than installing continuous coverage over CLT decks. As documented by Finch et al. (2025), a reduction in passive protection robustness necessitates immediate, active water management following weather events to prevent standing water. To mitigate exposure duration without relying solely on temporary protection membranes, the owner adopted an altered sequencing strategy for Building F. This method erects the structure in four sequential vertical zones to achieve rapid permanent enclosure under a finished roof, though its efficacy remains to be fully evaluated.

PMU Testing Is an Essential Upfront Investment

The three rounds of PMU testing required for Building M, as well as interim whole building airtightness testing, established a technical baseline that allowed Building F to pass the final whole building airtightness test on its first attempt. This initial testing represents a centralized upfront investment for the entire multi-building development. Testing scopes can be compressed on subsequent phases if the established design is carried forward with minor modifications. However, future structural adjustments, such as substituting CLT for wall panel framing, will require new physical testing to validate altered detailing interfaces.

Balanced Passive House Design Levers Enabled a Thinner Wall Profile

The clear field wall R-value achieved resulted from balancing multiple Passive House design variables within the WUFI Passive model. Specifically, the building's compact surface-to-volume ratio, low window-to-wall ratio, and high internal heat gains collectively reduced the thermal resistance required from the opaque wall assembly. Larger structures with favorable geometries can achieve Phius targets with thinner insulation profiles. Architectural decisions neglecting these design levers can inflate required R-values, increasing assembly thickness and potentially compromising the viability of a prefabricated panel system. These findings are geometry-specific and require project-by-project analysis against Phius annual heating/cooling demand, peak heating/cooling loads, and source energy limits.

Replicability Requires Specific Procurement Conditions

Developing a novel building kit-of-parts system requires specific alignment across ownership, design, and construction teams:

- **Ownership Commitment:** The developer must commit to unconventional methodologies on the initial phase, understanding that efficiency gains are realized iteratively over subsequent buildings.
- **Contractor Integration:** The general contractor must actively participate in resolving fabrication, assembly, and transport logistics for an unproven system.
- **Architectural Coordination:** The architect must design within parameters of an optimized Passive House model and technical constraints of panelized manufacturing, coordinating interfaces across structural, enclosure, and MEP disciplines.
- **Enclosure Expertise:** The consulting team must possess cross-functional expertise spanning traditional panelized facades, stick-built framing, building enclosure design, facade engineering, and Phius consulting and verification. Consolidating these roles within a single entity facilitates reconciliation of constructability, cost, and schedule requirements.

For developers managing multi-building parcels, there is opportunity to achieve economy of scale when a system is deployed across multiple buildings. Determining the viability of upfront design investments requires financial analysis weighing initial planning hours against benefits of compressed construction schedules, reduced financing costs, and accelerated revenue generation. Maximizing these efficiencies requires assembling design, construction, and fabrication teams early in the design phases to establish consensus on primary basis of design items before manufacturing commences.

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