ON5 MASS TIMBER BUILDING

OFF-SITE CONSTRUCTION EXPERIENCE

oN5 is a four-storey office building located near the intersection of Ontario and E. 5th Avenue in Vancouver. Built on a narrow difficult-to-access mid-block site with only 7.54-metre wide wide street frontage, the commercial project overcomes significant constructability challenges by using a prefabricated all-timber structure. Cross-laminated timber (CLT) panels form the floors, walls and roof. The prefabricated loadbearing CLT walls are built to achieve Passive House envelope performance. The CLT floor panels use an innovative adhesive system to perform as a contiguous two-way slab and so forego the need for beams.

A prefabricated CLT exterior wall panels ready to be flown into place. The crane hooks were electronically controlled for remote release. (Image: Scius)

A prefabricated kit-of-parts design

The oN5 commercial (office/retail) project is a demonstration of off-site construction with mass timber. The timber elements were prefabricated to be installed directly off the truck. This included the fully finished mass timber exterior envelope, the CLT floor panels and elevator core as well as the light-wood frame partitions and wood stairs.

The prefabricated timber elements were assembled in a North Vancouver yard, then transported to site in East Vancouver. As offloading had to happen from the street, efficient just-in-time (JIT) delivery was important to minimize the cost and inconvenience of road closures, and exposure to weather. Transportation sequencing was developed using building information modelling (BIM) and refined through a series of virtual builds, to ensure that the right elements would be delivered to site at the right time.

The prefabrication approach meant the primary structure and envelope was completed in 15 days. It also provided the quality control necessary for the envelope to achieve energy efficiency and airtightness goals.

PROJECT TEAM

owner
1155776 BC Ltd

architect
Hemsworth Architecture Inc.

structural engineer
Equilibrium Engineering Inc.

timber specialty engineer
Timber Engineering Inc.

mechanical engineer
Rocky Point Engineering Ltd.

construction manager
Naikoon Contracting Ltd.

electrical engineer
MCL Engineering Ltd.

exterior envelope
Dubas Engineering Ltd.

fire suppression
TC Engineering Ltd.

code
Evolution Building Science Ltd.

geotechnical
GVH Consulting Ltd.

CLT fabricator
Katerra

seismic dampers
Tectonus

structural adhesive
Timbertec

BUILDING STATS

site area
280.375m²

site dimensions
32.185m long x 7.540m wide

gross floor area
840m²

height
17.3m

fsr
3

major occupancies
"D" Business and Personal Services; "F2" Industrial

applicable code
Vancouver Building Bylaw Article 3.2.2.59 (Group D); 3.2.2.77 (Group F)

IMPORTANCE OF OFF-SITE CONSTRUCTION

Combining the low-carbon characteristics of wood with off-site construction techniques offers a simple and scalable solution to addressing building demand and climate change simultaneously.

Off-site construction describes the practice of assembling a building off-site—which includes prefabrication and modular construction. The adoption of digital design and construction tools, notably BIM and the increasing use of manufacturing technology such as robotics, has generated growing interest in off-site construction. Highly engineered and accurate construction systems, such as mass timber, lend themselves to off-site construction and Design for Manufacturing and Assembly (DfMA).

In construction, DfMA uses BIM as the foundation for digital prefabrication and computer numerical control (CNC) processing. DfMA can happen in a range of locations including purpose-built factories to temporary manufacturing or mobile assembly sites. It can yield predictable high-quality components where factors such as moisture content can be controlled.

oN5 demonstrates innovative CLT technology that delivers superior seismic performance, an energy-efficient building envelope, natural fire protection and biophilic benefits.

ADVANTAGES

- **Mass timber is an ideal material for off-site construction:** CLT panels are available in large sizes and can be easily milled and fastened to (e.g., screws, nails, etc.). Panels can typically be attached together with simple connections.
- **Ease of off-site construction:** Assembling the CLT panel's envelope off-site, 30 centimetres off the ground and horizontal, was safer, quicker, and less labour-intensive to construct quality, air-tight wall details.
- **CLT is light and durable:** CLT panels are relatively light and durable, with rigidity well-suited to being moved and lifted.

CHALLENGES

- **CLT needs to be protected from moisture:** From off-site assembly and storage to on-site delivery and erection, CLT panels need to be protected from moisture exposure at all times.
- **Wood details need to be thoughtfully designed for rapid on-site assembly:** Connection details need to be developed to safely, easily, and quickly connect both structural and envelope together.
- **Construction planning with the full project team needs to start early:** CLT is delivered as solid panels that need to be cut to size accurately with service penetrations included in advance of on-site assembly. It is difficult to make adjustments on site.

DIGITAL DESIGN & CONSTRUCTION

The oN5 team used a BIM-based project delivery workflow. BIM allowed the team to virtually build the project first, helping plan out and address challenges before actual construction.

The architect and structural engineer developed the building's form, program and structure with input from the construction manager, Naikoon, on constructability given the site constraints—notably the long narrow site with power lines obstructing access from the rear. The site could only be accessed from the narrow street front drove, so the decision was made to assemble the building from back to front using one moveable crane.

Katerra (CLT fabricator/supplier) provided early advice on panel sizes and configuration. Schindler (elevator supplier) was also an important stakeholder in early design discussions given that the core was to be built from 3-storey vertical CLT panels that would also provide the lateral support for the building. The construction manager's design-assist services also included feedback on off-site wall assembly and rapid on-site assembly, as well as for building envelope design and construction (wall, roof and curtain wall). For example, key structural and envelope decisions were made at the early design development phase by the integrated team, to ensure the details would be both buildable and meet Passive House performance.

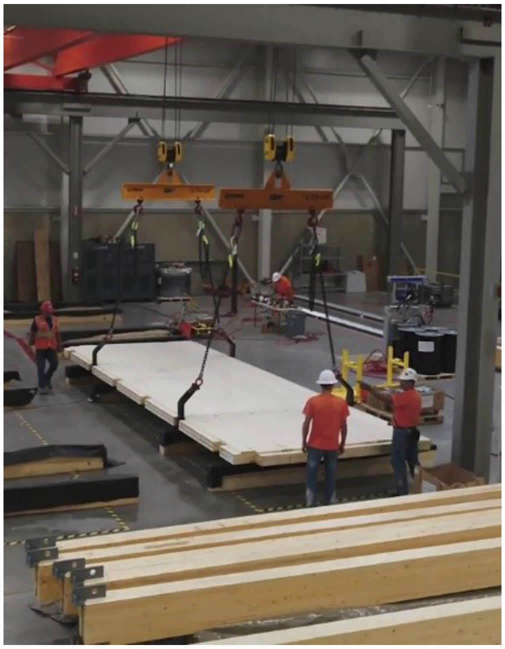
The architect's virtual design model (using Vectorworks) was used to prepare oN5's CLT package. The workflow transition to Katerra's Solidworks model included coordination with Tectonus for the seismic dampers as well as the proposed steel and plywood connections. Input on "downstream" constructability from the construction manager, and "upstream" program and performance from the architect and structural engineer resulted in coordination across oN5's supply chain. As the fabricator was integrated into the project team to inform design, the CLT panel design was optimized for lifting, assembly and safety, and not just fabrication efficiency.

Katerra's model fed directly into CNC fabrication. This locked the structural and structural-dependent elements: elevator, envelope, curtain wall. Katerra's Solidworks-based CNC fabrication workflow minimized instructional errors. Katerra's model also provided a digital twin of the structure and was the foundation for Naikoon's VDC Revit model from which off-site construction and on-site assembly was planned. For example, shop drawings for structural steel, curtain wall, envelope details, etc. were started much earlier pre-construction, based on Katerra's model. This early start was needed for the seismic dampers, as they were designed and fabricated offshore with a long lead time.

The BIM digital workflow was complementary, not a substitute, for the collaboration and coordination necessary to leverage mass timber off-site construction advantages. For example, the complex, combined structural-envelope CLT details were designed collaboratively, amalgamating shop drawings and mock-ups into the design phase, streamlining the construction.

KEY FEATURES OF BIM

- **Allows close collaboration with the CLT fabricator, with BIM being used for CNC fabrication of the CLT panels in the factory.**
- **Allows virtual design and construction VDC) to intricately plan and execute site assembly.**



CLT Panel fabrication. (Image: Katerra)

ON5 MASS TIMBER BUILDING

BIM VDC MODEL

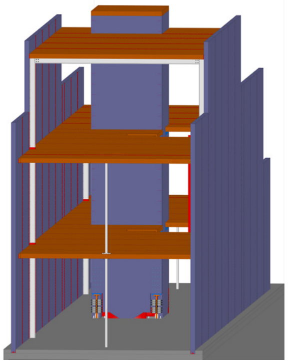
Design model
Hemsworth Architecture provided the Vectorworks and Sketchup architectural design model, which communicated the overall, coordinated design of the completed building.

Structural model
Timberworks and Katerra provided the Solidworks model of the structural CLT system, for CNC fabrication, based on the wall, floor and roof elements of the architectural model.

VDC model
Naikook Contracting provided the Revit, VDC model based on the Solidworks model, virtually building out structural connections and temporary works for site assembly such as lifting points and shoring.

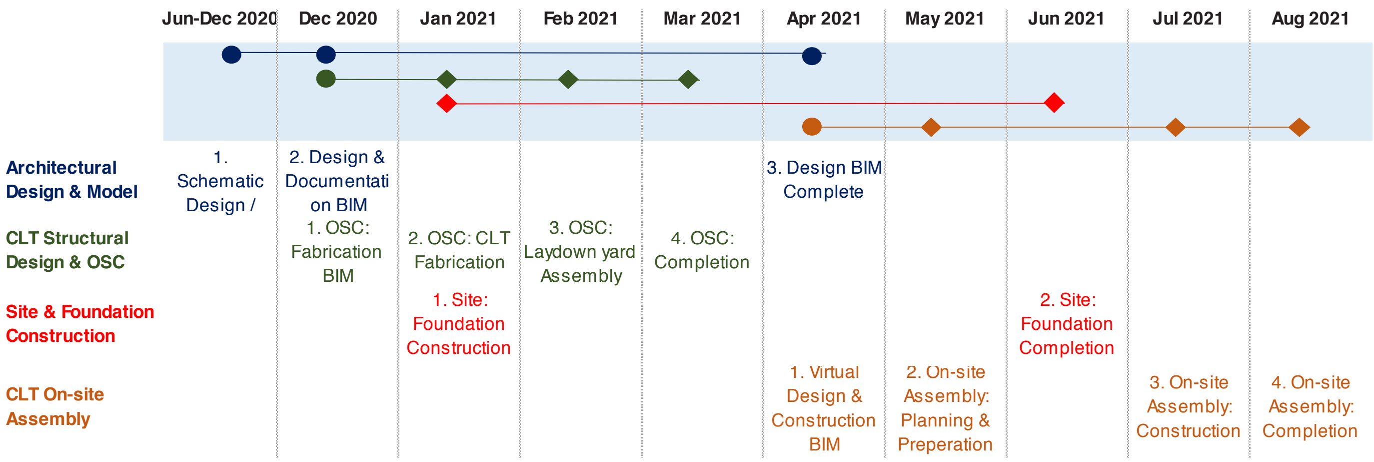
VDC model deployment
Digital VDC project delivery achieved a level of coordination that supported the development of practical, efficient structural and envelope design, which facilitated accurate and rapid off and on-site construction.

(Image: Hemsworth Architecture)



(Image: Timber Engineering)

(Image: Naikoon Revit Model)



DESIGNING FOR OFF-SITE CONSTRUCTION

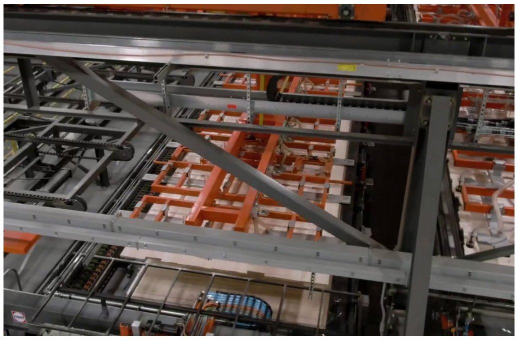
The success of oN5 was set at project start-up, integrating mass timber off-site construction into the project's DNA: informing project setup, contracts and team agreements.

The timber elements of oN5 used a kit-of-parts design that could be fabricated while the ground floor concrete work was proceeding on site, accelerating the overall project schedule.

The primary structure and envelope comprised CLT panels for the exterior walls, floors, roof and elevator shaft that were milled and cut in the fabricators plant and delivered to the North Vancouver yard for inspection, organizing and finishing. For the envelope, 200 millimetres of air-barrier paper wrapped mineral wool insulation, with fibreglass spacers and C-channel rainscreen was installed on the panels, complete with prefinished exterior metal cladding. This work was completed with the panels on the ground, improving safety and efficiency.

The structural-envelope panels consisted of 5-ply CLT panels 3-metres wide and oriented vertically, with the largest being more than 11-metres tall, spanning over 3 storeys. Careful attention was paid to the CLT wall panel connections, flashings and structural steel elements, especially between different materials and at roof to wall to floor transitions, to ensure airtight connections required for energy performance. For the envelope panels to be installed quickly, the connections between the CLT walls and floor plates were standardized where possible using steel angles and various types of Simpson Strong-tie timber fasteners. Given that the largest envelope panels weighed 3,175 kilograms, test lifts were conducted at the yard to ensure that they could be lifted, handled and installed without damage.

OFF-SITE PROCESS



Katerra – factory fabrication. (Image: Katerra)

Laydown – Off-site assembly. (Photo: Scius)

Site assembly. (Photo: Naikoon)

DESIGNING FOR OFF-SITE CONSTRUCTION

Inventing structural tools

The structural engineer and the timber specialty engineer had the experience, relationships (with other leading engineers) and technical know how to create the tools and design the CLT structure with Tectonus dampers and TS3-enhanced panels. The success of oN5 was the integration of a range innovations at the same time, in the context of a typical project in the City of Vancouver: permitting, zoning, budget and schedule, etc. and actually being successful: at $475/square feet, CLT assembly on time and achieving an airtightness rating of 0.6ACH.

Structural construction coordination

The primary structure with was only possible through co-design between the engineer and the construction manager. The engineer and tradespeople "hard coded" tolerances, adjustability, constructability and construction logistics into the structural design. This optimized the structure for rapid site, including the envelope connections at assembly joints.

Key structural complexity savings

oN5 team's performance revealed that simplifying labour (install, handling, etc.) and optimizing assembly had greater cost and time savings than from material substitutions or deletions. The team also proved a unified design process which minimized over design, and complex details and confusion over contract documents. This lean approach ensured the team's efforts were focused on construction method and means, and not legal risk, assumptions or information/communication errors.

Integrated delivery

The oN5 team functioning like a single organization, with tremendous trust and an easy-going relationship ensured the project was an overall success, and not just focused on the innovative structure. For example, the required TS3 design tolerance of 0.005mm was achieved through co-development into the CLT and off-site fabrication, still allowing for rapid on-site assembly.

KEY RESULTS

- **rapid assembly of CLT on time**
- **~$475/ft^2**
- **0.6ACH airtightness rating**

"Creating the tools to design oN5, with Tectonus and TS3 was fun: but where the project really became enjoyable was working with the team of talented builders to create practical, successful structural design."

– Hercend Mpidi Bita P.Eng
Timber Engineering Inc.

OFF-SITE CONSTRUCTION: MANUFACTURING FACILITY

Katerra, the CLT fabricator, was integral in the design and off-site delivery of oN5's CLT panels and steel angles. Panels were delivered precisely processed and ready for envelope assembly installation.

CLT fabrication

Using the BIM design model and project data, Katerra collaborated closely with the team to set the following for CLT fabrication.

Panel sizing, dimensions and tolerances: Considering structural, crane constraints necessary for safe, rapid on-site assembly.

Structural connections: Providing the steel angles at wall and floor panels, milling panels for a flush fit, and cutting the CLT elevator core panels to accept seismic dampers.

Major openings and penetrations: Including duct runs, pass-throughs and elevator openings.

Panel processing

Katerra's coordinated model feed into CNC cutting and milling, with the same model used as a reference for Naikoon's Revit-based VDC model, minimizing errors. CNC fabrication of the CLT panels included cutting, precision milling for flush steel connections and TS3 joint application (down to the nearest millimetre), and centres of gravity marked for safe moving of panels. This included carefully thought-out panel dimensions for adjustment on-site to facilitate rapid site assembly and minimize assembly creep.

Finishing

The interior side of CLT is exposed. The panels were surfaced in the factory, optimizing quality, and saving time later during finishing.

TS3 primer application

The TS3 primer was applied at the factory where conditions were ideal to meet manufacturer's specifications.

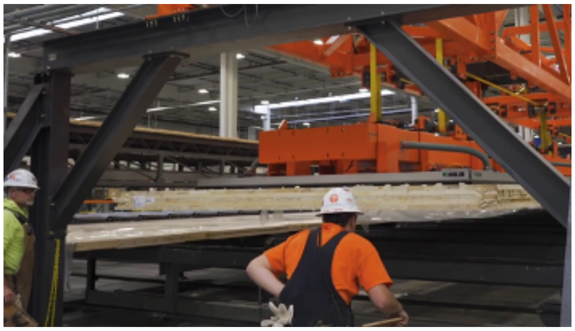
Packaging for delivery

Completed CLT panels were then wrapped in air-barrier paper, labelled per the coordinated fabrication model and loaded in a logical order for delivery to Canada.

Inspection and delivery of panels

Important to the fabrication of CLT panels off-site, across an international border was ensuring there was an agreeable procedure for inspecting and accepting panels. With the possibility of transportation damage and other issues, the two parties agreed to a specified period of review at Naikoon's yard for full acceptance of panels, and included terms for Katerra to replace unacceptable panels, up to and including crediting and return delivery.

Design for off-site construction required a highly detailed, mature design much earlier than typical construction methods, which allowed for prefabrication of the CLT and light-wood frame elements, and the detailed virtual planning of site assembly.



(Image: Katerra Promotion Video)

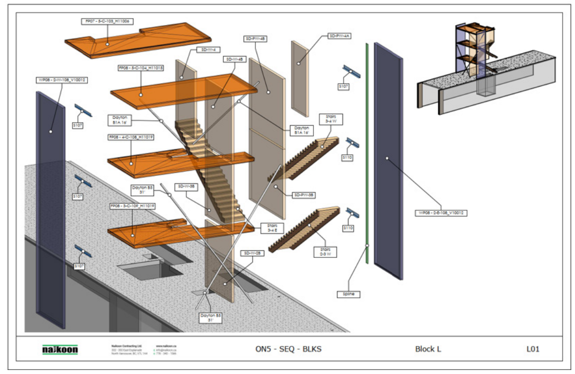
TS3 primer application. (Image: Naikoon)

Lay-down truck loading. (Image: Naikoon)

OFF-SITE CONSTRUCTION: VIRTUAL PRE-CONSTRUCTION

The VDC process coordinated the prefabrication processes with the on-site phases of construction. The oN5 team's "project success approach" to collaboration was essential to achieving this. With a detailed assembly plan and VDC sessions, the oN5 team was able to accelerate progress each day.

The iterative, collaborative development of the VDC model meant the team could strategize, innovate and refine solutions for rapid site assembly before the first panel was delivered on-site. For example, the engineer simplified the number of plywood fasteners and their spacing (connecting butt-jointed CLT panels), while the architect and envelope consultants simplified envelope connection details as VDC-based rehearsals uncovered challenges or issues to rapid site assembly. The team noted minimizing or eliminating typical project's communication, legal and information barriers through a commitment to collaboration allowed the team to explore and solve the intertwined structural-envelope-construction challenges.



Structural digital twin. (Image: Naikoon)

VDC planning and preparation

VDC site assembly plan

The sequencing of CLT panels, prefabricated interior walls and stairs, were all detailed and planned as part of VDC, breaking down the task into 15-minute intervals.

JIT delivery

Transporting the panels from North Vancouver to the site in Vancouver considered a wide variety of factors:

Panel sequencing: The order of panels was coordinated between the laydown yard and site, for easy delivery.

Trucks and delivery: Scheduled to keep site assembly moving forward. 5th Ave was closed for oN5's construction, but only allowed enough room for one truck and the crane at a time for panel delivery.

Productivity: Ensuring the pace of work maximized trades, crane and truck productivity but still allow for breaks and extra time in-case things slow down.

Optimizing crane and equipment use: Balancing budget, safety and logistics, ensuring the right crane, equipment and shoring was deployed daily.

Optimal crew size

Ensuring the team has sufficient personnel for the assembly plan and for unexpected issues. oN5 had nine mass timber installers on-site.

Contingency planning

The VDC session also allowed the oN5 team to talk through a walk-thru, creating contingencies for unexpected issues, such as for rain or if assembly was abruptly stopped for any reason.

VDC discussion. (Image: Naikoon)

LAYDOWN YARD ASSEMBLY

Key to oN5's success was off-site assembly at Naikoon's laydown yard in North Vancouver. This included field reviews at the laydown yard by the architect and envelope engineer, a panel test lift and layout of panels for just-in-time delivery later during site assembly.

The pre-assembly process in North Vancouver meant that the CLT panels were finalized quickly—(with all structural-envelope connections attached)—and the additional prefabricated elements could also be completed and coordinated. The off-site assembly resulted in high quality envelope details which allowed for quick, safe and more convenient assembly than traditional on-site construction.

Delivery

The panels were unloaded in a logical order based on the coordinated fabrication model, where a panel inspection was completed for any damage from transportation or loading.

Envelope assembly

Panels were laid out deliberately to facilitate quick and accurate production by aligning panels for easy layout and assembly materials.

Assembly preparedness

The production plan had included important ancillary requirements:

Rain protection: Movable shelters were prepared to protect against rain during assembly.

Equipment, tools, and material layout: The crew logically laid out everything needed, making off-site assembly much quicker than on-site installation.

Quality control

Production on the ground was quicker, safer and required far less effort and equipment, than traditional on-site installation and resulted in a quality envelope.

Mock-ups and reviews

Mock-ups were completed at the laydown yard, eliminating the need for it on-site, and streamlining reviews to facilitate rapid on-site assembly.

Testing for assembly

The team utilized this phase to test important aspects of site assembly, including a physical test lift to confirm computer simulations of deflection and ensure the panels and envelope assembly would not be damaged during crane flying.

Partition and stair prefabrication

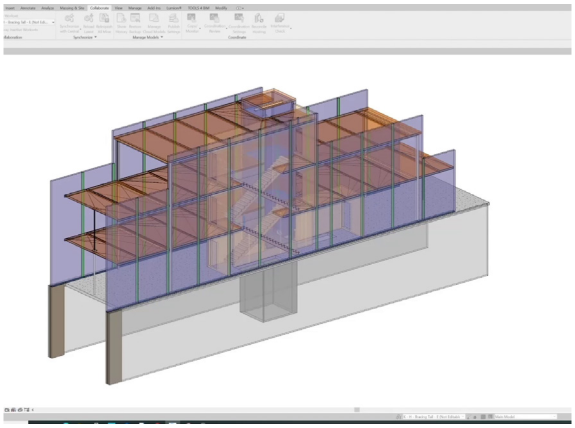
In addition to the CLT panel assemblies, non-load bearing wood-frame walls and wood stairs were prefabricated and integrated in to the VDC and assembly plan.

From top to bottom: (a) Laydown Yard movable rain shelters allow for continuous productivity; (b) Envelope assembly is completed on the ground, where works is safer, quicker, and higher quality; (c) Test life: for maximum deflection during crane flying. (Photos: Scius)

ELEMENTS OF SUCCESS...

Team approach to design

For the VDC process to be successful, oN5 required unified coordination, alignment and prioritisation of design with means and methods, integrated into project early on. This was largely successful because of attention provided by the owner/structural engineer and architect. The team's collaborative approach meant information and technical requirements were always discussed, coordinated, prioritised and set as a group, focusing the team's effort on exactly what needs to be done, minimizing effort and errors.



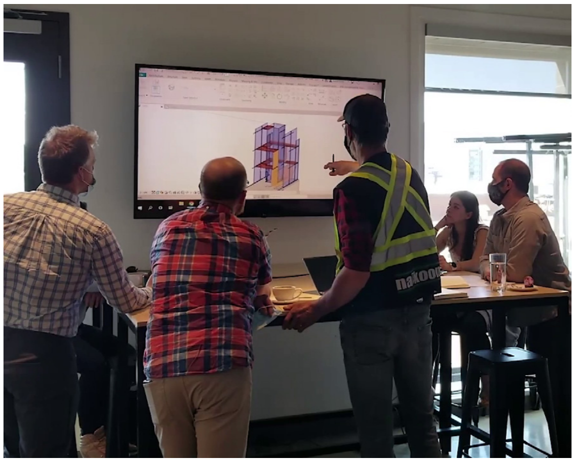
VDC model annotation. (Image: Naikoon)

Streamline design workflow

VDC's key advantage from integrating construction design was the focus of effort on value-add activities downstream that directly contributed to oN5's technical success. The development of a "live" digital twin of the oN5 building as design matured was integral to identifying, solving and innovating solutions before they became problems on-site. The model was also useful day-to-day: from pointing out key envelope details for the architect, to daily briefings in the site trailer, to more accurate pricing during design.

Weekly BIM coordination

Through weekly meetings, the construction manager at-risk focused on creating and leveraging the VDC model to plan the efficient, cost-effective and safe construction of oN5. While this required the architectural and structural design to be set early, this workflow better assigned risk to those the most suited to manage it—and yield the best outcomes. For example, the workflow allowed for a series of VDC planning and rehearsals, that were the cornerstone of the precise step-by-step site assembly plan.



Team meeting. (Image: Naikoon)

Trust-based contract administration

Complementing BIM VDC was oN5's streamlined contract administrative practices, agreed upon in principle in the team charter. The team's trust-based approach to contract administration focused on outcomes "at the speed of the project"—and not paperwork processing. For example, the structural engineer and construction manager worked extensively during forming to simplify the reinforcing steel for cast concrete foundations, suspended slab, and CMU. This process reduced the types of bars and simplified the bending and splicing requirements, leading to significant labour cost savings. This would be repeated with the fastener types leading up to rapid CLT site assembly. The level of trust and direct lines of communication ensured the team's limited time and energy was focused on project needs, and not on liability or administrative barriers, which can be handled after time-sensitive or pressing issues are solved.

… AND OPPORTUNITIES FOR IMPROVEMENT

Do more at the factory

The oN5 team noted a lot of the tasks on-site could have also been shifted off-site. For example, with BIM, the pre-cut plywood connection panel could have also included pre-drilling pilot holes for fasteners, speeding up on-site connections.

Considering factory finishing: For the next project, the oN5 team will push finishing into the factory, where reveals, fit or surface treatments could be applied quickly and precisely.

Coordinate CLT tagging with supplier: While the supplier worked closely with the team during design, the tagging of CLT panels could have been much better organized, from fabrication through to on-site sequencing, eliminating some of the tedious checking and reorganization.

Off-site storage considerations

Storage of CLT panels at the laydown yard could have been improved. For example, the under-side of CLT panels needed to be protected from sun bleaching, and with very long large panels, dunnage would have been better deployed parallel to panel length, to minimize bowing.

Plan for adjustability

The oN5 team carefully planned out adjustability in dimensions for CLT panels and steel hardware, which made assembly much easier when aligning and securing panels.

Field ad-hoc solutions

Field solutions are still required at times. For example, the order of assembling non-load bearing walls and prefabricated stairs was modified during assembly. However, prior VDC planning was a significant factor in why ad-hoc solutions were successful in the field.

Panels were tarped to protect from the elements. (Image: Scius)

ON5 MASS TIMBER BUILDING
DIGITAL PREFABRICATION OUTCOMES

oN5's successful rapid site assembly was the result of preparation: off-site construction being a significant part.

The integrated design process including the fabricator meant they were engaged towards project success, and not just to deliver the CLT package. While the upfront effort may appear significant, the downstream benefits: quicker assembly, less errors and better assembled quality, justified the effort. The oN5 team stresses the integrated, collaboration was the first critical element to success.

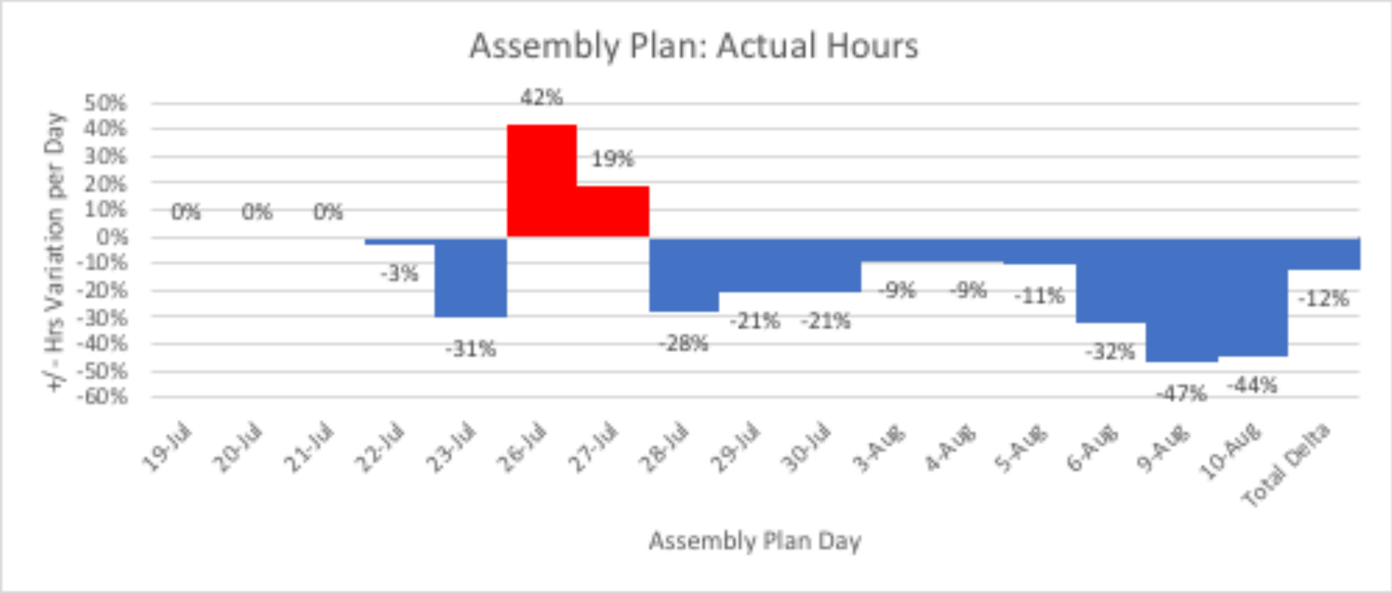
KEY RESULTS

Pace: Panels at lay-down yard
2 days / CLT panel

Pace: Panels at site assembly
0.58 days / CLT panel

Estimated effort
1-2 hours of VDC coordination / 1 day of assembly

Estimated project cost savings
$80,000



Percent of actual hours over/under the planned hours for each day of site assembly. (Chart: adapted from Naikoon data)

This is the third in a series of bulletins regarding oN5. Other bulletins include: introduction; high performance low carbon construction; on-site construction & project delivery; and regulatory perspectives. All bulletins can be found at www.naturallywood.com/project/on5-building.

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