The Living Pā: Kaitiakitanga; Whanaungatanga; Akoranga

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ABSTRACT

The Living Pā is a 3-storey mass timber building currently being constructed for Te Herenga Waka Marae at Victoria University of Wellington's Kelburn Campus. The International Living Futures® 'full' Living Building Challenge® certification is a central goal for the project. This is generally considered the most rigorous sustainability standard a building can achieve. Compliance with this standard significantly dictates materials selection for the project. For structure this means widespread use of timber, including a mass timber structure and timber piles. The geometry of the site means the structure has a narrow aspect ratio. Further to this, the site itself is challenging. It sits on the headwaters of the Kumutoto Stream, which has contributed to a variable rock profile. Varying thicknesses of weak fill overlay the rock and are unsuitable for founding. The ambitious client brief presents significant design and construction challenges. This paper demonstrates how collaboration between disciplines has helped to overcome these challenges in a high seismic zone.

1 SUSTAINABILITY

The Climate Crisis describes the impacts of global warming and climate change and has been described by the United Nations as the "defining crisis of our time". It is the result of greenhouse gas emissions being produced at record levels by human activity that has accelerated global warming, with 2023 being recorded as the hottest year on record. Almost all human activity either directly or indirectly contributes to the climate crisis and it has been estimated that the Building and Construction Sector account for around 20% of New Zealand's carbon emissions[1], through the energy and materials used in buildings (MBIE, 2020). These

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[1] Ministry of Business, Innovation & Employment (2020). Whole-of-Life Embodied Carbon Emissions Reduction Framework.

emissions come from all stages of a buildings lifecycle as outlined in the life cycle stages diagram shown in Figure 1 (LETI, 2020) below.

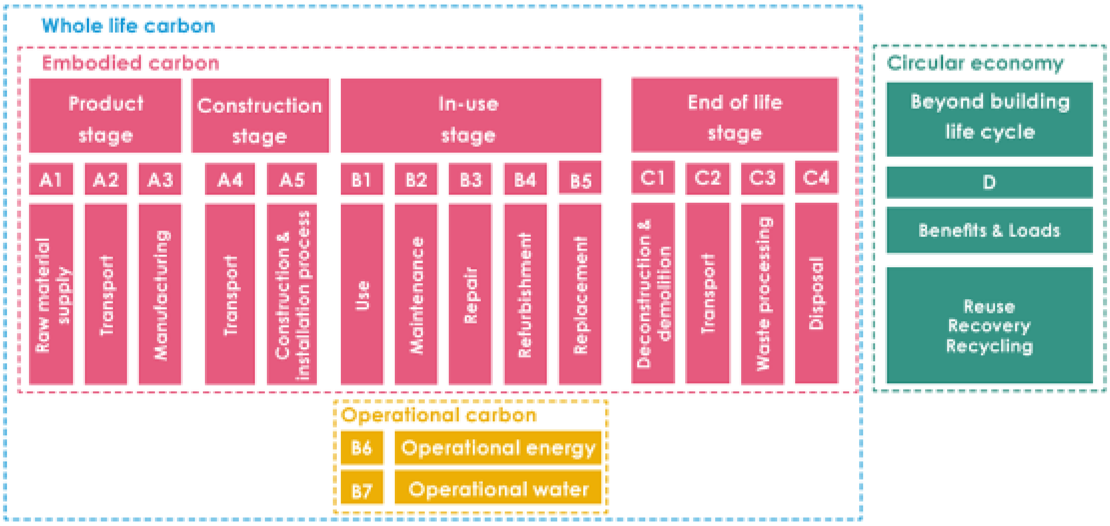

Figure 1: Module framework for life cycle assessment of buildings

As is widely accepted now, the “business as usual” (BAU) approach to the design of buildings needs to change to address the crisis. This is done by addressing both embodied and operational carbon through the specification of low carbon materials, minimising waste reduction and using more energy efficient and renewable building systems. Designs however need to extend past carbon and reflect the changing climate by ensuring buildings are resilient and inclusive to the surrounding community that may need to lean on a new building as their surroundings and way of life change in response to a changing climate.

1.1 Living Building Challenge

To reduce the climate impacts of buildings there are several building certification programmes that projects can commit to that will take the client, the design team, the contractor and the end users on a journey to creating a lower impact building. One of these certification programmes is the International Living Future Institute’s® Living Building Challenge® (LBC) and it is recognised internationally as the world’s most rigorous green building standard. The Living Building Challenge is broken down into seven performance area (called petals) that address different impacts of the building. The seven petals include:

- Place - Restoring a healthy interrelationship with nature.
- Water - Creating developments that operate within the water balance of a given place and climate.
- Energy - Relying only on current solar income.
- Health + Happiness - Creating environments that optimise physical and psychological health and wellbeing.
- Materials - Endorsing products that are safe for all species through time.
- Equity - Supporting a just and equitable world.
- Beauty - Celebrating design that uplifts the human spirit.

The driving theme behind LBC is regenerative design which is where a whole living system approach is taken that works to mimic, and work with, the surround ecosystem. In the case of the Living Pā this has been approached in several ways. From embodied and operation carbon perspectives, it has been designed to have very low embodied carbon using a mass timber superstructure and completely self-sufficient in both water and energy consumption through the use of water retention, on site wastewater treatment and solar power generation. Various Embodied Carbon Emissions Reports have been completed. The building is upfront carbon negative (i.e. the net figure to Modules A1-A5). Negatively assuming all the timber is burnt or buried when the building is deconstructed in the future, there is still a 43% reduction on the BAU case, though it is the authors' opinion that given the immediacy of the climate crisis, the upfront carbon is the important number, and alternative disposal mechanisms should be considered for timber buildings in the future.

To address the wider impacts of construction and the materials that the building uses, 90% of waste needs to be diverted from landfill and all products need to be verified against the Living Building Challenge Red List®. The Red List® is an ever-growing list of chemicals found to have short and long term negative environmental impacts. Finally, LBC looks to better the project's impact from cultural and economic perspectives, by focusing on the end user experience through biophilic design, air quality and ensuring the building is equitable to all that use and live around the building.

2 THE DESIGN BRIEF

Spanning 3000m3 over 3- storeys, the Living Pā significantly extends Te Herenga Waka Marae's capacity to bring people together to learn, live and share a regenerative future. In adopting the Living Building Challenge this Māori-led project declared its intentions to test those involved (from design and construction, to occupancy and maintenance) in their true concern for the things that we are most connected to – the land and each other. This project's primary objectives centre around the marae's core values and principles:

- Rangatiratanga – Leadership and tackling complex issues by considering then in the context of their system so that our overall success is seen as a whole and not the success of one sub -system, -area or -hierarchy.
- Kaitiakitanga – Taking responsibility and centering a relational approach to nature.
- Whai mātauranga – Fostering innovation and excellence, and actively pushing the boundaries of knowledge and benchmark practices.
- Whanaungatanga – Working together, and relating to each other based on collective, rather than individual, needs.
- Akoranga – Prioritising learning and teaching opportunities and processes.
- Manaakitanga – Fostering a culture of care and community.

The brief, fundamentally, is for a building which is very forward thinking, innovative, and ambitious. From materiality, to functionality, to building and structural form, it pushes the boundaries in almost every sense. To realise such a brief requires a lot of motivation from everyone involved, and a high degree of collaboration and teamwork.

Architecturally, LBC is a primary focus, understood through a te ao Māori lens. It is difficult to overestimate the work and intellectual property associated with this process. In terms of architectural form, the building fills the site, wrapping right up to the Glasgow St retaining wall. Timber as a structural material is embraced, rather than fought. Mass timber is inherently large, and this is celebrated with much exposed timber in finished building. Openness to promote engagement in learning is a key principle, and this is carried through into the interplay between structure and architecture.

Figure 2: Architectural Render of the Living Pā

The building integrates with the existing marae, itself a focus of the project and triumph of pan-iwism and multiculturalism since its inception. Open and interconnected spaces throughout the Living Pā promote engagement in teaching and learning.

Functionally, the building is very ambitious. It is largely passively ventilated, collects its own water, generates all its own power and processes its own waste. Large water storage tanks sit to the west of the building, the roof (and beyond) is covered in solar panels, and a 5-tank wastewater treatment plant sits to the north of the building. The work and collaboration of the Client, consultant team, and contractor to realise this vision is very significant.

3 GROUND AND FOUNDING CONDITIONS

The site is underlain by alternating sandstone and mudstone of the Rakaia Terrane. Based on a review of a 1902 historic photograph, the site before development was likely a densely vegetated, steeply sloping, upslope end of a gully dipping towards the northeast. Earthworks in the early 1900’s has filled the main gully along Kelburn Parade and possibly two side gullies within site (see Figure 3). The “Red lines” indicate approximate locations of spurs. The “Blue arrows” show the approximate location and dipping direction of gullies. The sites building platform appears to have been formed by excavation in the south and west and filling in the east. The southern end of the site is also likely to have been the headwaters of the Kumutoto Stream prior to filling in Kelburn Parade.

Figure 3 (Right) shows a typical inferred ground profile across the site. The bedrock generally dips in the east and northeast direction- refer site plan in Figure 4. The depth to rock across the proposed building footprint is highly variable ranging from 2m to 13m below existing ground level. The variability of the rock level is further complicated by the two in-filled side gullies noted in Figure 3 and the Kumutoto Stream.

The Fill and Colluvium are generally weak and highly variable in nature. Additionally, there is a risk of lenses/pockets of liquefaction within the Colluvium and Fill below groundwater level. Accordingly, the Fill and Colluvium are not considered suitable for founding. Greywacke Rock is the only suitable stratum for founding at this site. The rock level variability at this site coupled with the preferred foundation option (driven timber pile) presents significant challenges to both the design and construction described in subsequent sections.

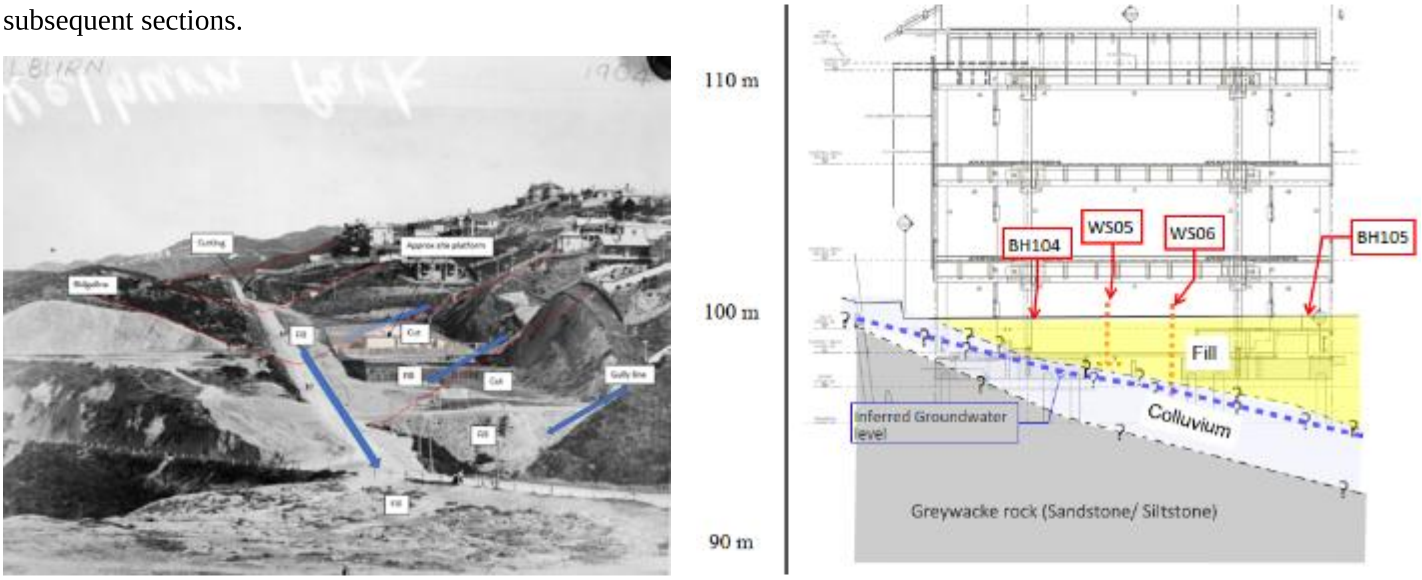

Figure 3 Annotated 1902 historic photograph looking south showing earthworks filled the gullies at Kelburn Parade. Right: Inferred Ground Profile

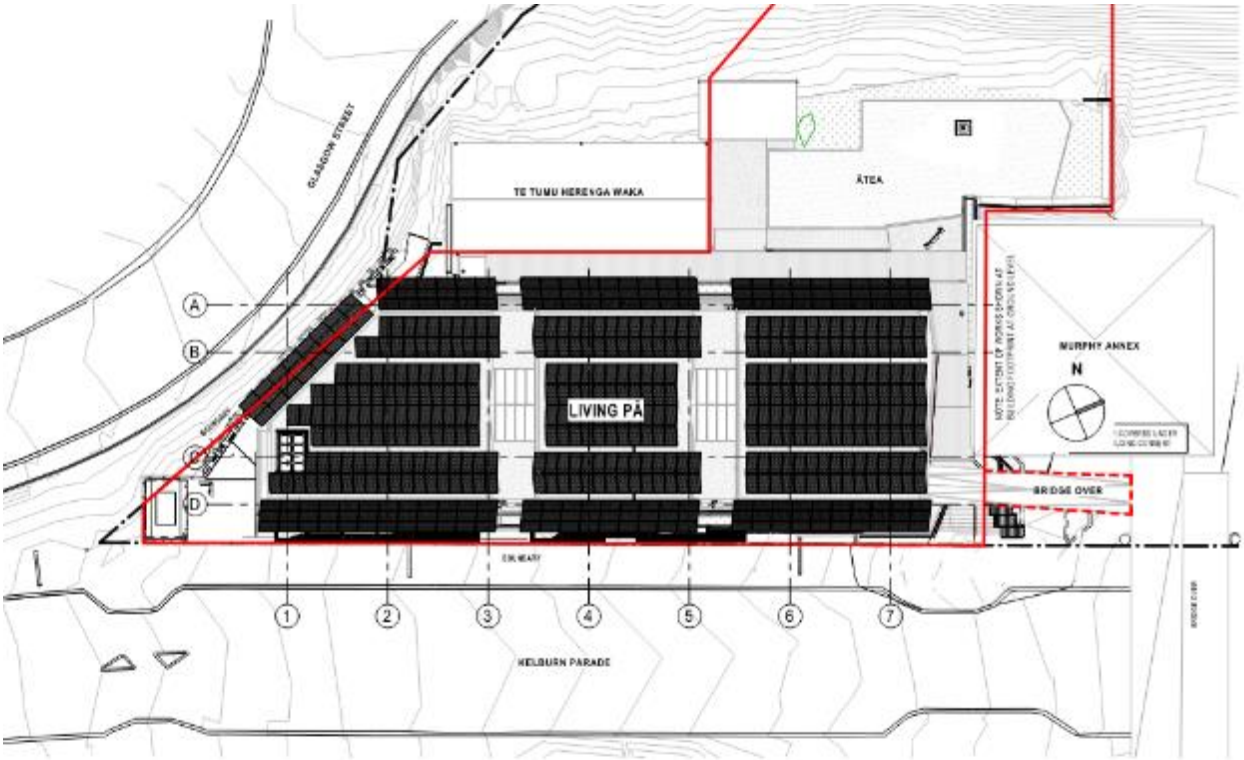

Figure 4: Site Plan

4 THE FOUNDATION SOLUTION

As noted above, it is evident that the ground is challenging with a very steeply sloping and variable rock head and infilled gullies. The timber structure further adds to the challenge. The structural form is sensitive to differential lateral stiffness because timber does not have the same natural rigidity as traditional reinforced concrete or steel. Significant differences in lateral pile-cap deformation could damage the timber superstructure.

Given the challenges described above, a traditional reinforced concrete substructure coupled with other piling solutions may appear to be the preferred solution for this site. However, this is not a "business as usual" project. This project has great ambitions beyond the norm, and the project brief is to use timber wherever possible. Therefore, the design and construction team were tasked to develop the preferred foundation solution comprising driven timber piles over the majority of the building footprint. Where rock head is known to be shallow, reinforced concrete bored piles were implemented to maintain lateral stiffness compatibility and to provide the required base shear resistance.

5 THE STRUCTURE

The design brief, the sustainability imperative, and the architecture are major drivers of the building structure. Mass timber is used extensively throughout the building, with relatively small amounts of concrete used in the foundations, and steel for connections and heavy structural elements.

5.1 Gravity Structure

Mass timber can have many advantages over reinforced concrete. Because it is light, it is easily transportable, and as it can be easily machined, it can be easily prefabricated. This makes offsite manufacture attractive, and therefore speeds up site installation. The CLT 'double tees' are a good example of this – a CLT floor with CLT beam webs. They have been prefixed together in the Red Stag factory in around 7.2 x 3.0m panels. They can be easily dropped into place to provide an instantly trafficable floor.

The CLT TTs then typically span onto CLT/ glulam box beams. To give the desirable open spaces through the building, these span nearly 9m, which is high for timber and these beams have significant load. To save time and cost of developing the full shear flow with screws, these have been glued together with epoxy. A half box beam was manufactured and tested to verify the creep properties of the beam. This performed very close to the expected behaviour, with 8.0mm initial and 14mm final deflection predicted, and 7.0mm and 13.5mm observed.

Figure 4: Test Beam Setup

The box beams then span onto large prefabricated LVL T columns. These also form part of the seismic system, as discussed below.

Connections between gravity elements generally rely on either bearing, diagonal screws, or both. Corbels and bearing notches have been commonly seen in carpentry and timber construction for a very long time. Diagonal screws are a modern invention- they use large, fully threaded engineered screws, commonly up to 13mm in diameter and 1.0m long. Providing they are correctly orientated on an angle to the shear plane, they will be primarily in tension, and capacities of around three times the direct shear capacity are possible.

To connect with nature, particularly the vegetation to the west side of the building, large glulam planters are suspended at the building second floor. These are outside the building footprint, so are hung from large steel tubes at roof level and CLT spandrels at the façade. They laterally brace themselves as a horizontal moment frame.

5.2 Seismic Structure

The main lateral bracing structure is a two-way timber moment frame, with bespoke buckling restrained steel dampers as yielding elements. Transversely, there are 2 half portal frames, with a damper providing a moment connection into the LVL T columns, and a pin at the outer column. Dampers run vertically, which essentially makes the beam simply supported with a point load, and a large ‘beam column’ joint shear at the column. It effectively applies a point moment to the column through a bearing block at one end and a large steel dowel at the other. Longitudinally, dampers run horizontally, with corbels and angled screws into the column.

The superstructure periods calculated by DTC in the transverse and longitudinal directions are 0.9s and 1.1s respectively. The yield drifts are 55mm and 75mm, and design strengths 0.21 and 0.22g. The building is designed as Importance Level 3, as a client requirement rather than necessarily a code requirement. Calculated with displacement based design, the centre of mass displacements are 135mm (1.5%) and 160mm (1.75%), equivalent to ductilities of 2.0 and 2.6. The building has slight offset between the centre of mass and stiffness of just under 5%, but is heavily penalised by the 10% accidental eccentricity in NZS1170.5 due to the aspect ratio. Static pushover analysis for this building is not an accurate representation of reality, therefore principles from Priestly (M. J. N. Priestley, 2007) were used to analyse torsional displacement by hand – including the accidental eccentricity this was about 205mm (2.3% drift) at the extreme edge. These were checked with non linear time history analysis. Results of NLTHA give 133mm centre of mass and 190mm edge displacements.

Timber is strong longitudinally; around 30-40MPa in tension for LVL. Perpendicular to the grain, it is brittle, and much weaker, with around 0.5-1.0MPa in tension – the direction you split timber with an axe. Where seismic forces are present, particularly with moment resisting beam column joints, forces tend to be significant and in non-ideal directions. The steel dampers are necked to control forces entering the timber, which is capacity designed. To ensure reliable strength and deformation capacity, as well as controlling the damper overstrength, these were extensively tested. To stop any cracks forming in the timber, each column has 1088 screws, generally running perpendicular to grain. These are up to 20mm in diameter and 1.1m long

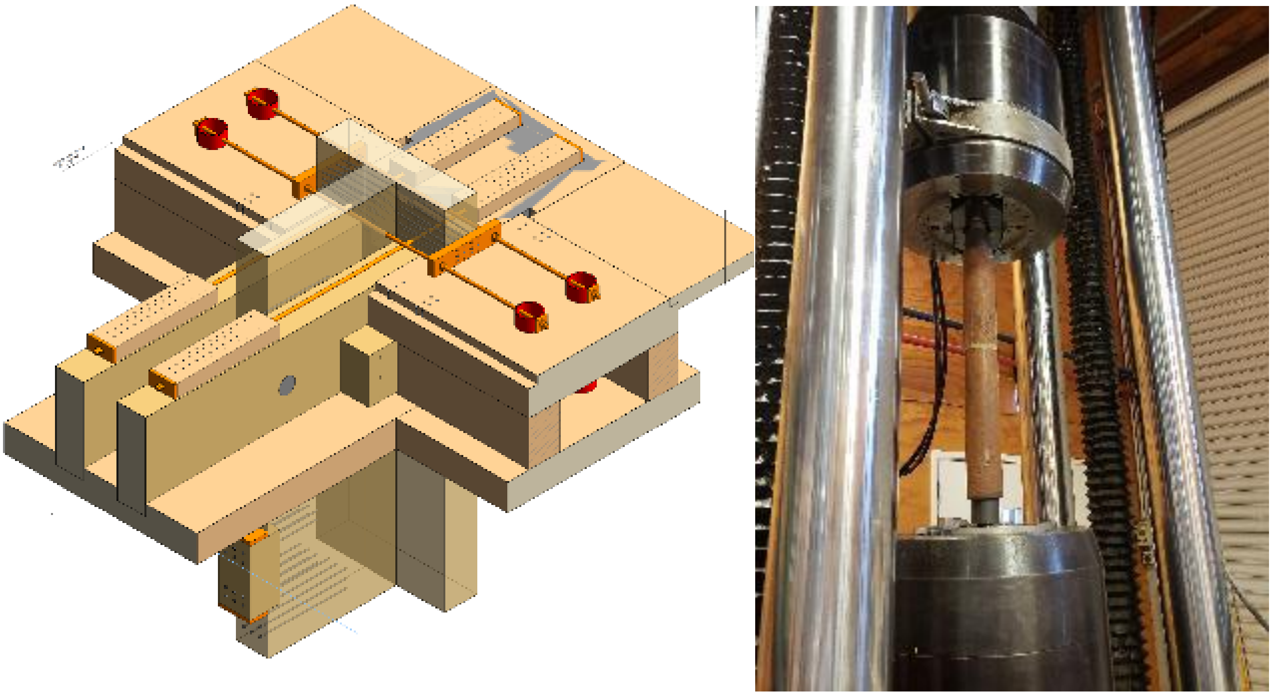

Figure 5: Left: The typical 2-way beam column joint; Right: Testing of the steel dampers

6 THE CONSTRUCTION PROCESS – CHALLENGES AND SOLUTIONS

6.1 Piling

As mentioned, the proposed founding solution was large timber piles, with bored concrete in some locations. The timber piles were driven to a tight set tantamount to practical refusal, and to a depth based on inferred rock head from ground investigations. Several challenges occurred during construction. These are summarised below along with mitigation implemented to overcome the challenges to minimise construction delays and yet satisfy the design:

- *Driven timber piles did not meet minimum founding level to satisfy the lateral design* – The final founding level of these piles was communicated immediately to the design team who quickly undertook design checks and recommended compensating (additional) piles. The contractor would provide live updates of the piling progress via WhatsApp ensuring that the design team were quickly made aware of the issue and it could be resolved. This process allowed the review of the piling records and available ground information to occur promptly and the acceptance (or remedials) of the pile communicated to the contractor. Important information was catalogued and recorded through official channels – i.e. emails and Site Reports.

- *Smaller 225SED floor piles 'glancing' (off vertical) or breaking when rock is shallow, hard and likely dipping at a steep angle* – The contractor would monitor the driving and penetration of the pile carefully in areas where 'glancing' could be a problem and would stop driving when hard ground was reached.
- *Collapse of a bored pile during drilling where rock is at the surface* – In one case a bored pile had likely hit a fissure connected to water source and the inflow coupled with highly fractured nature of the rock caused the collapse. A 5m casing was sunk a metre below the ground surface. This had to be removed as the hole around had collapsed, causing construction delays from trying to extract the sunken casing (see Figure 7 below). The remedial was to implement a longer casing coupled with drilling fluid (polymer). It is important to note here that significant issues during construction are possible even when they appear unlikely – refer lessons learnt.

Figure 6: Case pile in collapsed hole

- *Mobilisation of plant to site to complete both timber driven and concrete bored piles* – given the tight constraints of the site and the size of plant required, both the bored and driven piles could not be constructed at the same time. Therefore, the piling had to be staged more than initially anticipated, which unfortunately added to mobilisation costs but gained programme benefits. To reduce the impact of this, good communications and timely receipt of solutions and recommendations were key to the piling works. This is because due to the site constraints, the piling contractor may not be able to return to the problematic pile if other piles were installed.

6.2 Timber Superstructure

The Living Pā is the first mass timber building that L.T. McGuinness has constructed and as such the construction planning focused heavily on minimising and managing the existing documented risks associated with such a structure. Some of the key challenges and advantages experienced during the superstructure erection phase are outlined below

- *Model coordination and tolerance management* – Tennent Brown Architects, Dunning Thornton and L.T. McGuinness worked with the mass timber and structural steel suppliers Nelson Pine, Red Stag and MJH Engineering to coordinate the superstructure through the shop drawing stage in Revit and through intensive shop drawing checks, testing tolerances and constructability considerations before the timber went in to fabrication. Physical models of the building were also made to test erection methodologies. An example of this process working well was the successful install of the 1.8m long, 150mm diameter solid steel pins that were hydraulically pumped through five layers of ~300mm thick LVL with only 2mm of tolerance in the hole. All pins were installed successfully and with no onsite remediation required to get the pins through.

Figure 7: 150 diameter steel pin installation

- *Speed of erection* – when Wellington wasn’t blowing a gale and the tower crane could operate for a full week, a complete grid of the building could be erected and in the case of the lift shaft, a full lift shaft could be installed in a day. The prefabrication of the timber and repeatability of the general structure allowed for quick install times that could also be refined throughout the project. It was made apparent early however that “just in time delivery” was not a realistic methodology and instead the timber was stored offsite locally and brought to site on an “as required” basis.

Figure 8: Installation of prefabricated 'double T' floor panel

- *Moisture management* – one of the biggest lessons learnt on the project, with the methodology being regularly adjusted throughout the project. Dunning Thornton and L.T. McGuinness have worked closely together to refine the process and to ensure regular monitoring of the timber is carried out so that any significant moisture issues could be addressed quickly and before there are any long-term negative effects. The project has used wireless 24/7 moisture meters, handheld moisture probes, fans and vacuums as the primary tools to both monitor and manage moisture build up. LVL is susceptible to moisture ingress, so critical structural elements are capped as in Figure 9 for weather protection. The structural specification allows for the timber to exceed 15%MC, but at closing in, the timber needs to be at 15%MC or below. At the time of writing the timber is typically at 15%MC or below which is critical for the intumescent coating on the timber to be applied and therefore all following on fit out stages of the project.
- *Southern structure* – the southern end of the building was the last section to be erected and differs greatly from the rest of the building requiring a completely revised erection methodology. The advantages of prefabrication were not totally lost, but the speed advantages gained with the

repeatability of the structure north were lost, significantly reducing erection speeds and requiring temporary propping not previously required.

7 COLLABORATION AND LESSONS LEARNT

7.1 Collaboration

The success of this LBC project is largely attributed to the collaboration between various parties of the project team. The different organisation that each party work for is put aside and the project operates as a big coherent whanau with a common goal. A summary of the collaboration in this project is presented below:

- Workshops prior to each phase of works (eg piling, primary superstructure) between consultants and contractor to collaboratively identify risks and possible mitigation. The preferred mitigations for each risk undergo robust scrutiny that considers cost, constructability, performance, sustainability and resilience.
- The whole project team have consistently prioritised open communication and responsiveness between all parties. It is almost impossible to design and build a building of this level of innovation and complexity without constant open communication, and a commitment to teamwork. The team has used a variety of tools to make this as easy as possible from WhatsApp group chats, Procore mark ups and the prioritisation of team meetings, either in person or online to solve issues.
- Great team morale and dynamics. This project uses the same teams who have a long-standing history of working together and have developed excellent relationships. In addition to this there is a key focus on meeting away from the design table to have social events that have helped the team get to know each other better outside of work, the value of which cannot be underestimated.

7.2 Lessons Learnt

This project has pushed many boundaries for building design and construction. As a result, we have compiled a large amount of knowledge about what can be done, particularly within the sustainability space. A summary of the lessons learnt on this project is presented below:

- Consider a more intensive site investigation particularly when highly variable ground conditions exist (e.g. on a hillside) with a history of significant earthworks. A balanced cost-benefit site investigation scheme could potentially reduce costs during construction. Trial piles will allow construction issues to be identified early and mitigations developed and hence minimise construction programme and costs risk.
- Never underestimate the challenges presented by Wellington’s highly fractured rock when constructing bored piles in this material. Have adequate contingency on site (e.g. longer casings, polymer set up) so that these may be implemented as dictated by the ground conditions.
- Innovative solutions are high risk by their very nature. To build the sustainable buildings of the future efficiently and economically, balances need to be struck. For example, geotechnical uncertainty is usually a key aspect on a project. Where this is greater than normal, traditional, higher carbon alternatives may be the best all round solution. On a site with poor ground and variable rock, and if a timber superstructure is used, reliable piling methods such as bottom driven steel tubes, and a concrete ground floor diaphragm would derisk the process and save standing time. Carrying out a life cycle analysis can be a powerful tool in assisting with making this decision.
- Some of the major project successes are the result of offsite manufacture, with the key to this being repeatability. Even difficult work can be done well if planning is done once and repeated, and offsite

manufacture can greatly speed up onsite construction – this is particularly true of timber. Unusual building shapes use up design and construction planning time and tend to be expensive to build.

- In tall, mass timber buildings, timber seismic resisting structures become marginal. For the two-way moment resisting frame used in this project, a lot of force is concentrated in the joints. For buildings of greater height, hybrid steel/ timber structures become more suitable.
- Mass timber is still a fledgling industry in New Zealand. As such, and because there are multiple subcontractors involved, coordination between shop drawings is less mature than for structural steel. Despite good team efforts, more site work was required than would be ideal.
- Moisture management of the timber is challenging, but can be kept under control with regular communications between the contractor, architect and engineer particularly with regards to erection methodology and proposed storage solutions. Pushing of water off the timber is also not recommended and instead the use of fans and vacuums has proven to work best.

8 ACKNOWLEDGEMENTS

The authors would like to thank Te Herenga Waka – Victoria University of Wellington for providing us with the opportunity to work on this exciting project and permission to publish this paper which itself is part of the purpose of the LBC – opportunity to share the experience and lessons learnt to help inspire and inform future sustainable buildings and projects.

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