inside out adverb

1: in such a manner that the inner surface becomes the outer

A sustainable response towards an adaptive reuse of an abandoned warehouse into a residential and mixed-use area by bringing the outdoors in & taking the indoors out. Defining its spaces to foster environmental, economic and social sustainability. It aims to focus on passive design principles, the circular economy, biophilia and constructability in its design and construction.

It aspires to retain the warehouse's original structure and heritage façade to preserve its historical connection while it paves its way for a new build of modular apartments and student accommodation to adapt to its changing need. Nestled in a vast industrial setting of warehouses, the design aims to incorporate an enriching sense of nature to soften its industrial environment at the same time foster a sense of community for its residents. Hence, bringing the outdoors or nature inside and encouraging community interaction by taking the inside outside.

Striving for user comfort and value for money over time, it applies constructability in its modular construction which can function either collectively or separately. Bringing altogether a sense of being one with nature and the community in its form and function.

Introduction

The adaptive re-use and construction of a 3-storey residential building of build to rent apartments and student accommodation demonstrates the use of cross laminated timber (CLT) for its design response. CLT is innovatively growing as a construction material for both residential and commercial buildings, originally in Europe and progressively taking its place in Australia at present (Durlinger, Crossin, & Wong, 2013). This response was taken from its aspiration to instigate its role in the green agenda. By using a life-cycle assessment, the design response aims to investigate the environmental performance of the building, focusing on CLT among other materials from its production, operation, and end-of-life impacts. The design concept envisions to bring the outdoors in and taking the indoors out. This signals the use of natural daylighting and ventilation along with sustainable and environmental material selection and re-use of existing materials from the site. Material selection across the building conforms to its design ethos for its environmental and economic value using a uniform and light-weight structure for ease of construction and minimizing potential waste and error in its construction. This premise corresponds to added client value, the community and environment.

Scope & Limitations:

The report and analysis are based on the Engineer's modelling and representation of its potential structural, operational, cost, and environmental impacts and does not necessarily reflect actual site impacts. The report contains data taken from the preliminary design drawings of the Architect which was based on a combination of SIPs and LVL for its building structure and excludes revisions/changes on the Engineer's report made on the final design which only utilises CLT in replacement to the LVL (glulam) and SIPs panels. The cost and time analysis may not represent the current design response, although its assumptions and projection as outlined on the report will be treated as a reference.

Design Analysis

The selected choice of material investigated were structural insulated panels (SIPS), laminated veneer lumber (LVL) and cross laminated timber (CLT). These were selected for its off-site solutions, can be manufactured in different lengths, and its local proximity and availability.

1. Structural insulated panels (SIPS) are made of two external engineered timber facings with a central polystyrene foam insulation core. The panel is a laminated composite of these materials which can be locally manufactured in Western Australia.
2. Cross laminated timber (CLT) is produced from softwood timber that is cross laminated. It is comprised of three to seven layers, varying in thickness according to its structural requirements. Each layer is sawn and planed and glued altogether under pressure using a polyurethane adhesive. Panels can be fabricated to different sizes, with maximum dimensions of 16.5 m (L) x 2.95 m (W/H) x 0.5 m (D).
3. Laminated veneer lumber (LVL) uses high strength engineered wood and is predominantly used for structural applications. Its strength is comparable to solid timber, concrete and steel and is manufactured by bonding together thin wood veneers under heat and pressure.

The final design response has selected CLT over LVL and SIPS panels for its main material in combination with some structural steel, aluminium, concrete, and selected insulation. The panels are to be sourced locally from CrossLam Australia. Utilising 3 and 5 ply panels which are produced and sourced from Western Australia (WA) or Tasmania.

The selection was based on a comparative analysis between the 3 products: SIPs, CLT and LVL wherein CLT was the most desirable material. Although SIPs have a desirable insulated core, CLT can easily integrate a thermal insulation material in its wall. LVL on the other hand, is superior in rigidity and strength compared to CLT or SIPs. Whilst the 3 products perform similarly and are popularly used in modular construction, CLT was chosen as the material of choice for the design.

The design ethos of maximizing constructability aims to reduce design complexity and foster quick manufacturing and installation whilst meeting temporal and financial targets. It is apparent from using uniform materials and sizing for each module. This uniformity in member sizes and materials results in ease of manufacture and procurement, as the materials utilized are less extensive and potential for material shortages are far less to impact both procurement and manufacturing. Furthermore, potential error and wastage are greatly minimized in the simplicity of its structure.

Fig. 2a-c (L-R) (a) Existing warehouse and heritage façade (b) boat timber frame and salvaged bricks (c) existing corrugated sheets

The reuse of existing materials from the site as well as preserving its heritage component is a key theme in the architectural design. Through the adaptive reuse of the existing warehouse, the design aims to preserve its heritage component (see Fig. 2a), retain the existing structural components of the warehouse and reinforce its existing structural members, and re-use the salvaged parts or materials found on site. This design response not only aspires to preserve the existing cultural heritage component of the site, but also to diminish its environmental impact in construction.

Enlisted below are the list of existing materials that are salvaged and how it will be re-used and adopted to the building design.

Table 1: Re-use of existing site materials

Existing Material	Design treatment
1. timber boat frame	Walkway portal
2. corrugated sheets	Perimeter fencing
3. red bricks	Crushed landscaping toppings

Structural Analysis

The engineer's preliminary structure design using SpaceGass modelling (Figure 3) demonstrates a standard timber and steel construction utilising laminated veneer lumber (LVL) in its structural columns, steel universal beams (UB), timber joists, SIPs wall panels and plasterboard. This was later revised by the Architect replacing the materials to CLT solely for all its structural members for uniformity, ease of construction and simplified joinery using screws and hardware to join the CLT (Refer to Figure 4 for the connection details). An option to use tensile bolts in some areas has been considered to replace screws for added strength in the structure.

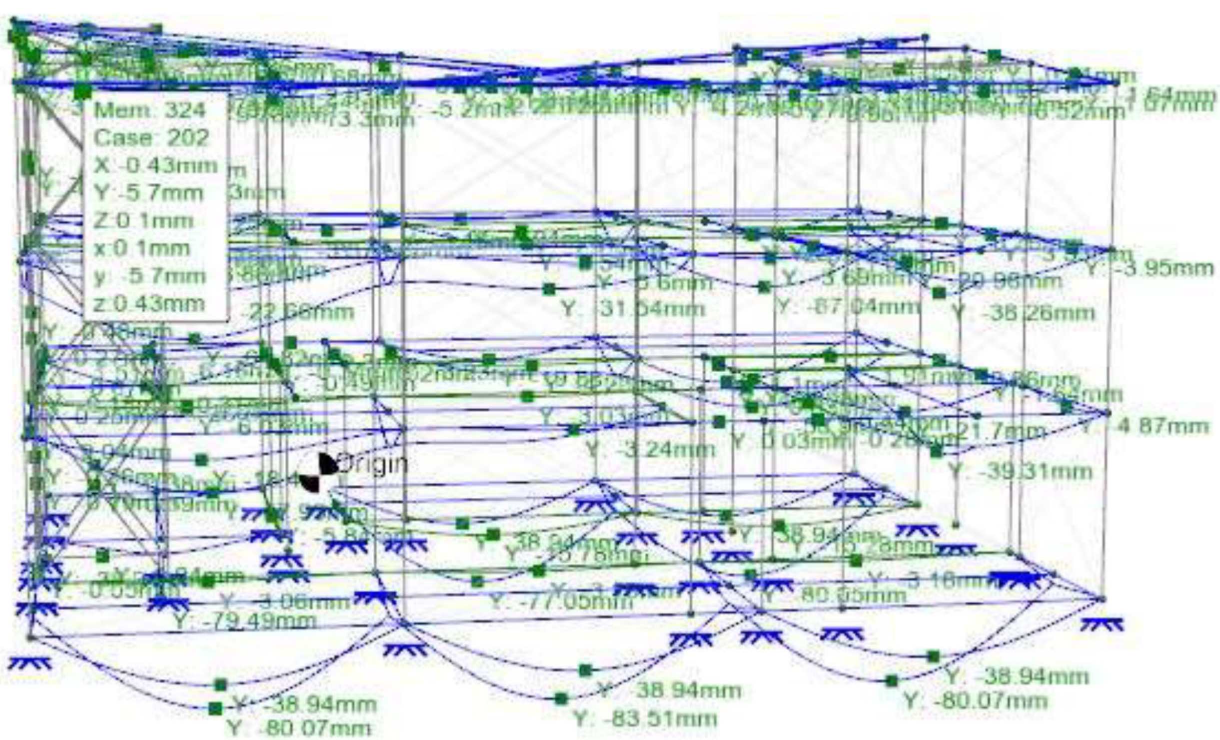

Figure 3: SpaceGass Model with Timber Beams

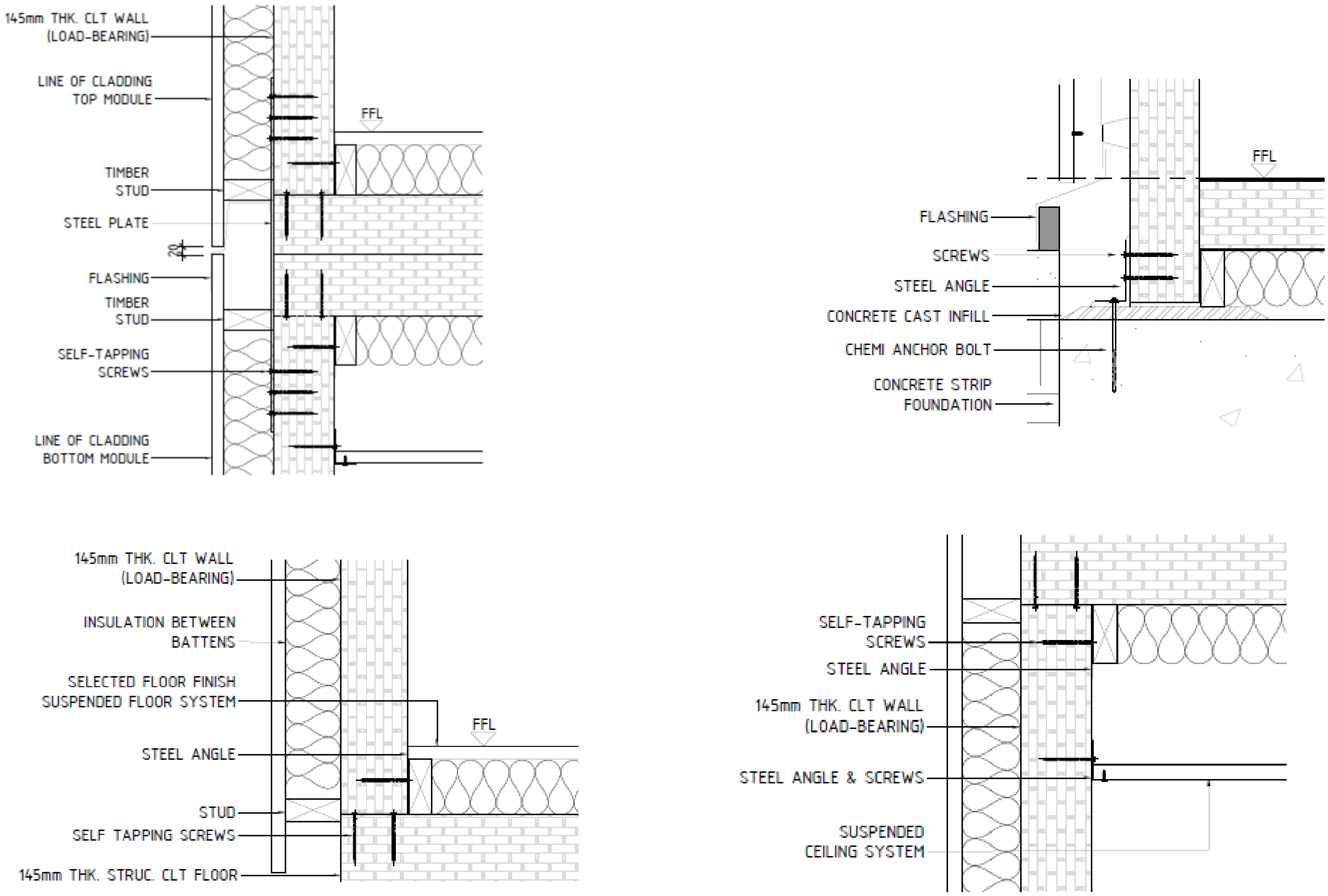

Figure 4: Typical CLT Connection Details (L-R/Top-bottom: Module to module vertical connection, Foundation & wall connection, Floor & wall connection Ceiling & wall connection)
Figure 5: Typical CLT Connection Details (L-R/Top-bottom: Module to module vertical connection, Foundation & wall connection, Floor & wall connection

Schedule/GANTT-chart of site-tasks

The engineer's report was prepared with specific relevance to a low-rise accommodation building within the area. The construction model used in the report follows an off-site manufacturing and on-site assemble system which allows a procurement route for the individual units on an "as-needed" basis. The units are designed to be manufactured and stored off-site and delivered to site for immediate installation into the building. As the units are set in place, fitment of utilities (gas, water, electricity) to each unit can be done in a timely manner, considering the units are already pre-wired and would only need hardwiring and plumbing to the existing mains systems, following certifying by a qualified engineer.

Cost Analysis

The engineering report on its cost projection was produced by adding up materials and labour. The cost considered the plant over the site construction and was broken down into an individual category rather than spreading it amongst multiple activities. This was considered in estimating the costs as majority of the activities are required off-site and the on-site construction activities are simply calculated in days for its duration rather than specific hours to complete each item.

The report calculated a 12-week schedule with allowances for minor slip within non-critical activities. The overall cost for the project, included plant/off-site, labour and materials, amounts to S2,112,468.06 + GST. A profit of 15% which has been identified to be a standard in construction projects over the recent years, as specified by the project team, rounding up a total profit of $275,539.31.

The cost projection from the BOQ, was based on the preliminary design using a combination of LVL, steel, timber, SIPS and plasterboard. An assumption that the forecasted cost may reduce is expected by replacing it solely with CLT and some steel joinery.

S-Curve

The S-curve projected for the construction works in the engineering report, presents 3 obvious increments in the progress of the project according to the construction of the 3 different unit types. The installation, fitment and other sitework costs are noted in smaller increments from the 40th day of construction. It is determined that the schedule follows an aggressive summer schedule, therefore it does not allocate allowances for delay. The traffic flow and road conditions were also assessed by the engineers which does not impact the vicinity of the building. Given that it is in an old industrial site with minimal links to heavily trafficable areas. The on-site construction schedule is also considered to be short enough to fit into the assumed summer months.

S-curve for the construction works

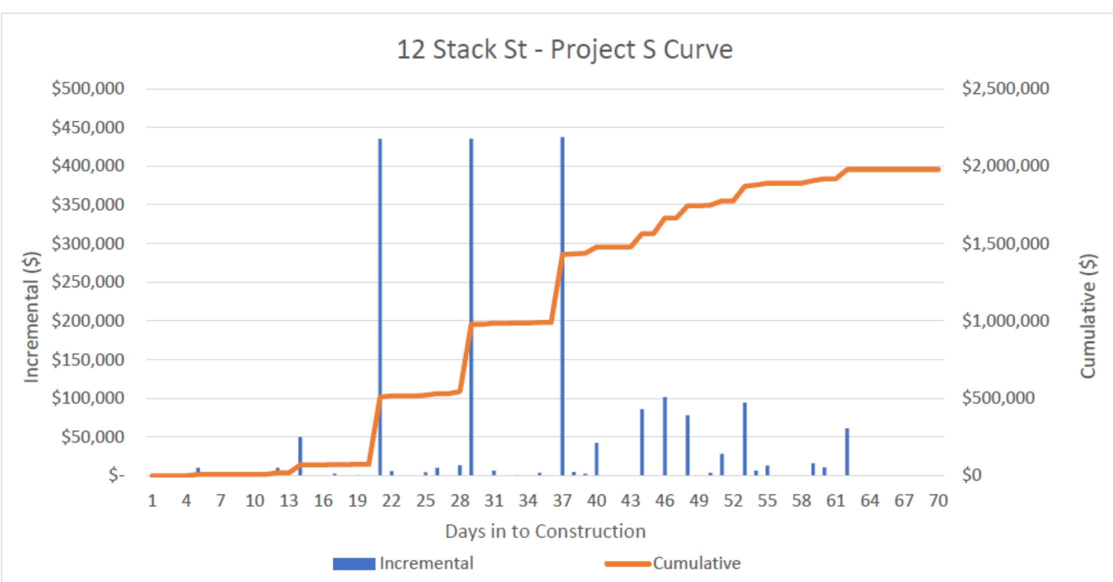

Figure 6: S-Curve of construction works

Environmental Analysis

There were several considerations in the overall design and the premise as a whole to respond according to its sustainability, building performance and life-cycle. Arguably the most significant response was the choice of material, its passive design techniques, and its constructability. Whilst steel is a competitive option both in cost and material life-cycle, notwithstanding its carbon footprint. The appealing factor of CLT is its minimal environmental impact as shown in Table 1 in comparison to the initial proposal using a combination of SIPs, LVL and structural steel shown in Table 2. Compared to steel which is highly reusable, CLT panels are recyclable which can be sent back to the manufacturer for reuse and recycling and items such as sawdust and wood-scraps which are not as easily reused or recycled can be converted to energy through burning.

Below is a comparative assessment of the material's life cycle impact of a single 1-bedroom modular unit excluding cladding and joinery. The data is extracted from a study by Minunno, O'Grady, Morrison, and Gruner (2021). The absence of the following materials: CLT, SIPS and LVL kg CO2 data in the original table are represented using a similar material as an assumption. LVL is represented as timber and SIPS is represented as gypsum board. Some of the CO2 data are taken from a study by Hertz and Halding (2020).

Table 1. Life Cycle Impact: CLT of 1-bedroom module

Materials	***kg CO_2 eq/kg***	***kg of materials***	***Impact materials***
Concrete	0.19	0	0
Reinforcing bars	1.63	0	0
Structural steel	2.21	0	0
Timber	0.45	0	0
Clay bricks	0.24	0	0
Tiles	0.76	0	0
Insulation (EPS)	3.24	0	0
Plaster	0.23	0	0
CLT	0.51	3417.8	1743.078
Mineral Wool	1.60	0	0
Gypsum plasterboard	0.23	0	0
		Total impact of materials =	1743.078

Table 2. Life Cycle Impact: LVL, SIPS & Structural Steel (1-bedroom module)

Materials	***kg CO_2 eq/kg***	***kg of materials***	***Impact materials***
Concrete	0.19	0	0
Reinforcing bars	1.63	0	0
Structural steel	2.21	96139	212467.19
Timber (LVL)	0.45	108.16	49.20961508
Clay bricks	0.24	0	0
Tiles	0.76	0	0
Insulation (EPS)	3.24	0	0
Plaster	0.23	0	0
CLT	0.51	0	0
Mineral Wool	1.60	0	0
Gypsum plasterboard (SIPS)	0.23	90.9185	20.911255
		Total impact of materials =	212537.3109

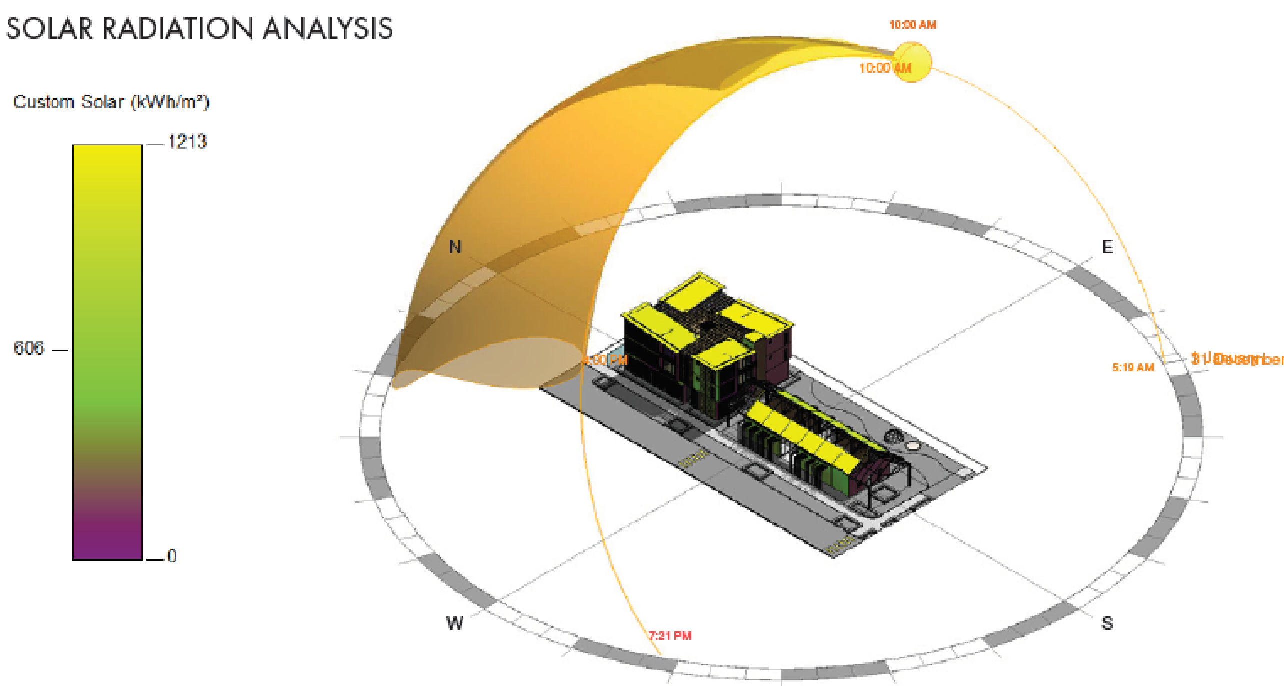

Figure 7: Solar Radiation Analysis

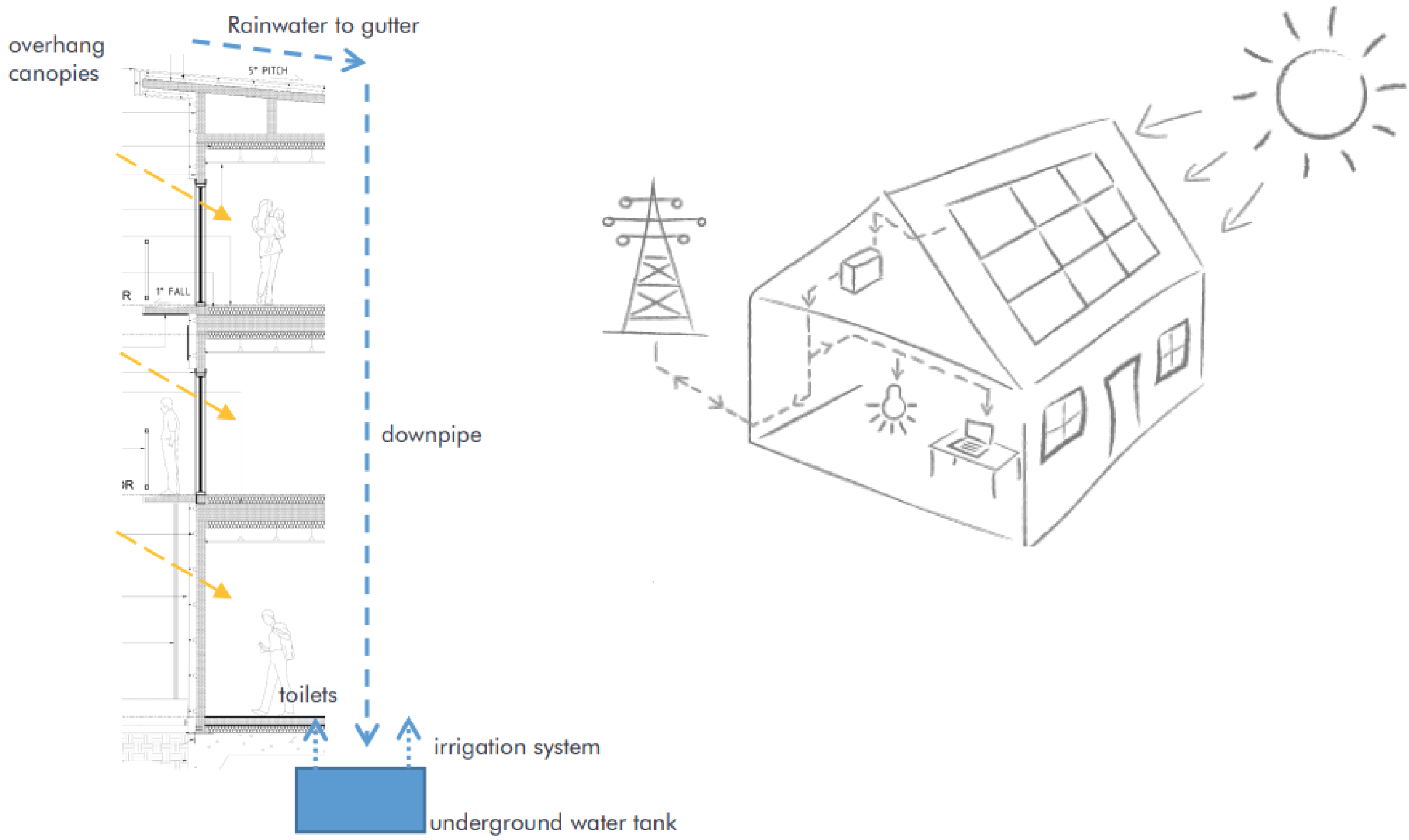

Figure 8: (L) Rainwater Collection Diagram (R) Solar Panel System Diagram

Passive & Active Design Systems

Thermal comfort, acoustic and HVAC performance were considered in the design of each module to improve air quality and reduce electrical consumption. The design response maximises its potential solar access to allow natural ventilation and considered shading elements to reduce unwanted solar heat gain from the harsh western sun. It also deliberates the use of solar panels, which can be easily integrated to afford renewable energy for its users.

The acoustic and insulation performance of CLT were also considered in the design to reduce noise and improve thermal comfort in each unit. An exposed CLT panel (interior) with flexible insulation in between the external wall and cladding has an estimated u value of 0.13. Additionally, the design locates its spaces that require plumbing along corridors to reduce plumbing noise.

Rainwater may also be collected from the roof which leads to an underground water tank that stores and backs up water supply for landscaping irrigation, toilet flushing and laundry.

The overall building performance has been analysed to accommodate both passive and active design techniques to afford its users with thermal comfort, access to renewable energy and operate sustainability in its day-to-day activities.

References

Durlinger, B., Crossin, E., & Wong, J. P. (2013). Life Cycle Assessment of a cross laminated timber building. Retrieved from https://www.fwpa.com.au/images/marketaccess/PRA282-1112_Life-Cycle_Assessment_of_a_cross_laminated_timber_building_0.pdf

Hertz, K. D., & Halding, P. S. (2020). *CO2 emissions from building lifecycles*. Retrieved from Technical University of Denmark:

Minunno, R., O'Grady, T., Morrison, G. M., & Gruner, R. L. (2021). Investigating the embodied energy and carbon of buildings: A systematic literature review and meta-analysis of life cycle assessments. *Renewable & sustainable energy reviews*, *143*, 110935. doi:10.1016/j.rser.2021.110935

Executive Summary

The design response aspires to instigate its role in the green agenda with the adaptive reuse and redevelopment of the warehouse into a residential and mixed-use area as outlined in the City's Local Structure Plan. Applying environmental, economic and social sustainability by means of the passive design principles, biophilia, circular economy and the constructability of its design and construction. The design concept envisions to bring the outside in and taking the inside out. This signals the use of natural daylighting and ventilation, as well as enhancing the building performance for user comfort, by means of thermal comfort, reduced energy consumption and potential use of renewable energy resources.

The initial focus of the design is to minimise waste and create opportunities with the existing warehouse and materials found on site. Although aging, the aim is to retain and revitalise the existing structure and reuse most of the salvaged materials found on site. Based on the initial site assessment, the deteriorating structural components will be retained and reinforced, along with the preservation of the existing building's heritage component. Subsequently, it will reuse the materials that are salvaged or compromised as part of the building feature both as a sustainable and restorative element.

The proposed construction of a 3-storey residential building of build to rent apartments and student accommodation demonstrates the use of cross laminated timber (CLT) for its design response. CLT is innovatively growing as a construction material for both residential and commercial buildings, originally in Europe and progressively taking its place in Australia at present (Durlinger, Crossin, and Wong 2013). This response was taken from its aspiration to instigate its role in the green agenda. By using a life-cycle assessment, the design response aims to investigate the environmental performance of the building, focusing on CLT among other materials from its production, operation, and end-of-life impacts. Material selection across the building conforms to its design ethos of constructability for its environmental and economic value using a uniform and light-weight structure for ease of construction and minimizing potential waste and error in its construction. The premise of sustainability and constructability goes hand-in-hand to correspond added community and client value, as well as a conscious effort to minimize its environmental impact through passive and active design techniques including the use of solar panels and rainwater harvesting.

Overall, the merging and transformation should complement the old and new, transition the industrial elements to the natural elements, and blur out the public and private spaces through a series of shared and communal open spaces in between. Altogether, enhancing and creating user comfort socially, economically, and environmentally throughout the building's life cycle and beyond.