Final Report
Project NV053

NATIONAL INSTITUTE FOR FOREST PRODUCTS INNOVATION

Improving the Commercialisation of Post and Plate Mass Timber Building Systems via Digital Twin Simulation

2025

Gippsland Centre
Funded by the Australian Government, Victorian Government & Industry Partners.
nifpi.org.au

NATIONAL INSTITUTE FOR
FOREST PRODUCTS INNOVATION
GIPPSLAND

Improving the Commercialisation of Post and Plate Mass Timber Building Systems via Digital Twin Simulation

Prepared for

National Institute for Forest Products Innovation

Gippsland

by

Andrew Dunn and Perry Forsythe

Publication: Improving the Commercialisation of Post and Plate Mass Timber Building Systems via Digital Twin Simulation

Project No: NIF145-2122 [NV053]

IMPORTANT NOTICE

ISBN: 978-1-922718-59-4

Researcher:

Andrew Dunn
Timber Development Association NSW Ltd.
Unit 6/281 Pacific Highway,
North Sydney, NSW, 2060

Prof. Perry Forsythe
University of Technology Sydney
15 Broadway, Ultimo, NSW 2007

This work is supported by funding provided to Forest and Wood Products Australia (FWPA) to administer the **National Institute for Forest Products Innovation** program by the Australian Government Department of Agriculture, Fisheries and Forestry and the Victorian Government.

Australian Government
Department of Agriculture, Fisheries and Forestry

VICTORIA State Government

Executive Summary

The project aimed to develop a buildable and efficient construction sequencing, in digital form, of two new mass timber building system enablers, Rotho Blaas' Spider and Pillar system and XLam Australia's Band Beam system. Both systems were reviewed via two workshops of timber knowledgeable contractors and installers and a detailed investigation by the research team. The outcome resulted in three refined post and plate mass timber systems, utilising the Rothoblass and XLam systems, as demonstrated in digital form.

The process of conducting digital modelling and discussion with timber knowledgable installers and contractors functioned well to resolve issues. Issues identified include

- Carry out detailed milling and installation of fixing, firstly within the factory or adjacent to the building project, never at the work face
- Where it is not possible to avoid the installation of fixings at the work face, the preference is to install the fixings from the proceeding storey's floor
- Adhesive joining systems were not preferred as they potentially had on-site issues, such as difficulty to bond in wet weather or cold temperature, long curing time extending the building program's schedule, methods to confirm if bond adhesion had occurred, and the need to provide falsework for support until the bond had formed
- Rotho Blaas' Spider system required
    - An ability to be fixed to the proceeding storey column, allowing the Spider connection to be pre-installed onto the floor plate above
    - Use stud fixings to the next storey column base plate, removing the need to install bolts into blind holes
    - An understanding of the system's capacity, in the situation in which, for practical reasons, some of the arms of the Spider connection are removed, such as near external walls, voids or avoiding bathroom pods Chassis
    - The floor area load capacity of the Pillar system could be improved
- XLam Australia's Band Beam
    - The system's cost is suited to a large grid spacing. Work is required to develop solutions that suit grids spacing 8.4 x 8.4 m or greater
    - A system that utilises fewer screws to connect the floor plate to the band beam is preferred.
- Economies of post and plate systems were dependent on the reliance on the limited use of falsework for temporary support.

The cost of each post and plate superstructure was examined against a traditional concrete post-stressed flat plate system. Two of the systems were found to be substantially cheaper, while the XLam's Band Beam was slightly more expensive. Where the building's "Preliminary" costs (the building's expenses other than materials, labour or overheads) and scaffolding expenses were considered, all the post and plate systems, including the band beam option, were cheaper than the concrete option.

A cost-effective mechanical joining system of the CLT floor panels is a further limit that prevents these systems from being commercially established. Several mechanical joining systems were investigated, and the circular hollow section (CHS) coupler showed the most promise. However, the system's capacity is unknown and requires further research before it can be commercially used.

1 TABLE OF CONTENTS

1 ACKNOWLEDGEMENT

This work is supported by funding provided to Forest and Wood Products Australia (FWPA) to administer the National Institute for Forest Products Innovation program by the Australian Government Department of Agriculture, Water and Environment and the Victorian Government.

Furthermore, we acknowledge the support provided by Rotho Blaas Australia, Rotho Blaas SRL and XLam Australia.

2 CAVEAT

The suggested systems contained within this report are for research and development purposes using expected methods that have yet to be undertaken in reality. Users should adopt their own duty of care in converting these systems contained in this report to actual methods used on construction projects.

3 INTRODUCTION

The project aims to develop a buildable and efficient construction sequencing, in digital form, of two new mass timber building systems enablers, Rotho Blass' connector systems, including Spider and Pillar variants and Xlam Australia's mass timber Band Beam system. Both systems show promise in structural engineering terms but require further development to be efficient and practically achievable in terms of installation on site. The project aims to develop and design different onsite processes that can be tested and displayed virtually by building the systems digitally; this enables onsite production efficiency and costs to be modelled and, in doing so, assists the commercialisation of these systems.

3.1 BACK GROUND

Cross-laminated timber use has declined in recent years, i.e. 50 per cent volume decline since 2018 [1]. This decline is due to inadequate fire dynamic performance knowledge and the lack of cost competitiveness of the mass timber systems compared to concrete and steel.

This project deals with the second issue, improving the cost competitiveness of the current mass timber solutions. For instance, multi-storey timber structures have too many structural elements in fixed load paths and relatively low spans. This issue results in too many design constraints compared to the concrete frame approach, which utilises a rigid frame with flexible non-load bearing partition walls. Flat plate floors also allow freedom for running ceiling services without being impeded by deep beams. They have the lowest impact on floor-to-floor storey height, a critical attribute in building construction.

Furthermore, where cost savings using mass timber are small or insignificant, the switching costs for building owners to change their construction method from traditional concrete to mass timber are too high to justify the change. Mass timber is often limited to complex sites, but as alluded to above, these buildings require closely spaced load-bearing walls. This constraint results in a fixed room layout at a much earlier stage of the project's development cycle than concrete, thus preventing alterations to the building as market demand changes. Concrete framed buildings don't have these problems as they use non-load-bearing walls that can be re-positioned as required.

Consequently, the timber system must be equally flexible to compete with concrete framed buildings. To achieve this in mass timber requires a different system to the one described above. One such option is a post and beam system; refer to Figure 1. The post and beam system reduces the dependency on closely spaced load-bearing walls but still suffers problems where deep beams interfere with building services and add to the floor-to-floor height (in aggregated terms, this reduces the number of floor levels achievable within the building).

Figure 1: Post and Beam Timber Building System (Image credit: TDA)

However, the concept of "post and plate", where vertical support is via regularly spaced columns and no deep beams are used to support the floor, achieves this; refer to Figure 2. This approach mimics concrete framed buildings insofar as having a flat floor plate (or shallow band beams), which dispense with the need for deep beams. Two construction systems were investigated to execute the "post and plate" approach in practice.

Figure 2: Post and Plate Building System (Image credit: Rotho Blaas)

The first system was Rotho Blaas' steel connectors, including their Pillar and Spider connection variants paired with mass timber floor plates and columns.

The Pillar connection has a metal shaft and base plate that is fixed to the top of the lower storey's column. The metal shaft penetrates through the floor panel with a plate fixed on top of the shaft that provides a connection point to the next-storey column. The floor panel is supported by the Pillar's base plate; refer to Figure 3.

Figure 3: Rotho Blaas' Pillar Connection (Image credit: Rotho Blaas)

The Spider connection is similar to the Pillar connection, except it has a radial six-arm metal connector that sits on top of the mass timber floor plate in the location of the following storey column. The radial arms have two functions: increase the punching shear capacity of the system and provide greater capacity to support floor loads; refer to Figure 4. The floor panel is supported by the Spider's connection base plate and by the six radial arms.

Figure 4: Rotho Blaas' Spider Connection (Image credit: Rotho Blaas)

The second system considered is XLam's Band Beam system, which draws inspiration from a concrete band beam arrangement. It has columns regularly spaced, as with the Rotho Blass' system, and a mass timber floor plate. It differs from the Rotho Blaas' systems because it has shallow wide beams spanning between columns, fixed to the mass timber floor, enabling improved floor spans; refer to Figure 5.

The mass timber columns in this system are configured in a way where the top protrudes through to the next floor, creating a starter for the next column. Metal connectors lock the column to the floor plate, thus dealing with stability and robustness issues; refer to Figure 6.

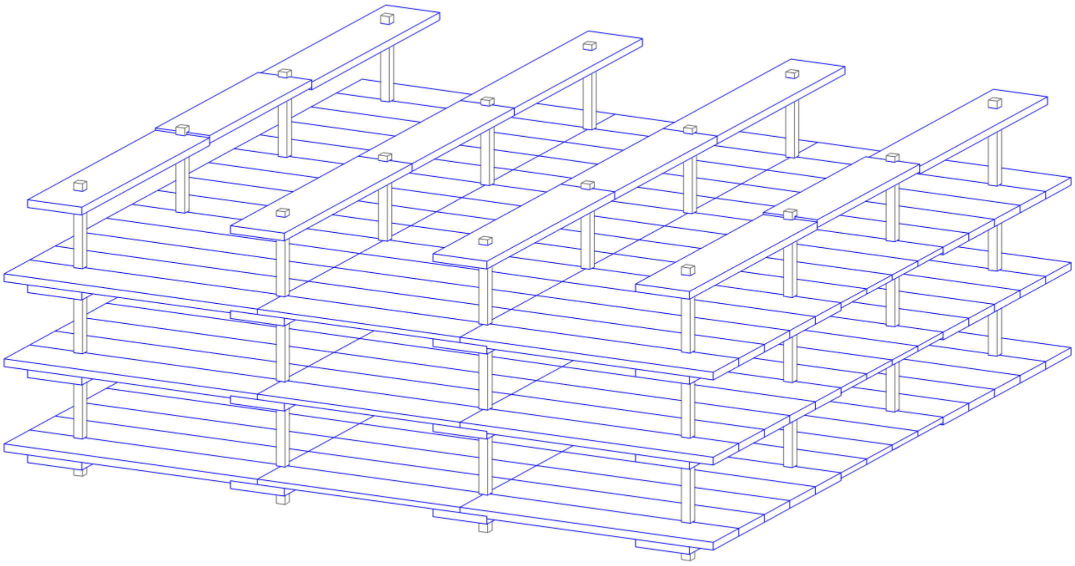


Figure 5: XLam's Band Beam System (Image credit: XLam)

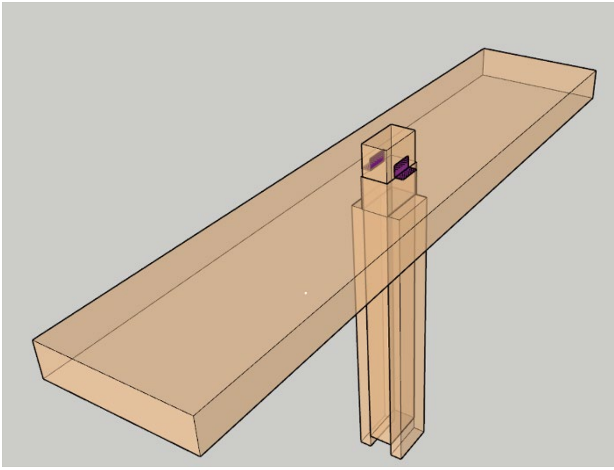


Figure 6: XLam's Band Beam System Column Connection (Image credit: XLam)

The issue with both systems is that they have not been tested in terms of viable and practical construction on-site and have not answered the question of, will they provide practical and efficient construction sequencing. For example, each system requires the joining of large panels (e.g. 15.0 x 3.4 m max.) and columns on the building site whilst being temporarily supported by a yet-to-be-defined system. Such support usually means the erection of falsework, shoring or props that add time, cost and increased logistics issues. Importantly, care must be taken not to lose the vital market advantage of speed associated with mass timber construction by simply mimicking temporary support systems used in much slower concrete framed processes.

Formwork is the most expensive part of the system in concrete placement and primarily involves significant amounts of temporary falsework and shoring. This temporary falsework and shoring remain in place for long periods whilst the concrete gains its design strength, typically 4 weeks. The temporary falsework and shoring prevent following trades from working on the otherwise completed floors. This time lag typically affects 3-4 floors below the floor under construction. It would be a competitive mistake if a timber post and plate construction system could not maintain a significant time advantage and keep temporary support costs to a minimum.

A successful post and plate forerunner project, Brock Commons in Canada, dealt with this issue cleverly by creating a (mainly) self-supporting system analogous to a common table. It utilised small spans and construction similar to four and six-legged tables – permanent columns were set in place with only temporary angled props and spacers to hold the column in line until panels (tabletops) were placed; refer to Figure 7.

Figure 7: Brock Commons Post and Plate construction System (Image Credit: clean50.com)

Whilst this provides a worthwhile lesson that worked well, the larger panel and column grid spans aspired to by the Rotho Blaas and XLam systems mean only one or two-legged tables are possible during the installation process. This issue is resolved once the floor plate is installed; until then, it creates stability problems that must be solved. The usual means to resolve this issue is by the use of falsework or expensive moment connectors to stabilise the floor plate and column. A one- or two-legged system also brings in issues of safety, program time, and back propping, making the system less attractive. These issues define a significant part of the problem that needs to be addressed via the execution of this project.

3.2 Project Methodology

The fundamental objective of the project is to practice, virtually, building the post and plate construction systems and work out a safe and cost-competitive procedure via digital simulation. The digital simulation allows various construction methods to be tested through a series of timed activities. Each activity feeds into the next activity. Digitising the process keeps the information flow rich throughout the exercise, leveraging knowledge along the way. These developmental processes used to create an onsite refined construction system are summarised in the following.

Background Knowledge and Constraints in the Construction of Post and Plate building Systems

Before commencing any detailed research work, a phase of conducting a background understanding of the two systems was undertaken. This background work enabled the researchers to be fully abreast of the systems before seeking feedback from participants attending Workshop One.

Workshop One

After this initial phase, a workshop was conducted with participants knowledgeable in timber design, construction and on-site installation in timber construction. The workshop aimed to guide construction logic, detailing and sequencing of the post and plate system. The emphasis was on achieving fast program times and exceeding site safety requirements.

First Draft Virtual Modelling (Digital Twin)

After the Workshop, digital models were produced that constituted the superstructure of a trial building, including the feedback from workshop participants and the research team. The modelling aimed to target an orchestrated workflow, including columns, support structures, connections and floor plates.

Workshop Two

After developing the preliminary digital models, a second workshop was held with the same design, construction and on-site installation experts in timber construction (similar participants to Workshop One) to review the digital twin's construction sequencing. The workshop aimed to seek feedback and suggestions to refine the modelling further.

Cost Analysis

A cost analysis of the resulting mass timber construction systems was conducted on each simulated building construction sequence to understand which method was more cost-effective. The cost comparisons were also compared against a traditional design post-stressed concrete frame system.

Final Virtual Modelling (Digital Twin) Refinement

From Workshop 2 outcomes, adjustments were made to the digital simulations as required, resulting in preferred methods. The preferred methods were then produced as an MP4 video version of the simulation, which could then be used to help contractors and others understand how to construct a post and plate mass timber system efficiently. The cost plans were also updated to reflect any changes made to the modelling.

4 RESULTS

4.1 BACKGROUND

Before undertaking any detailed modelling, an extensive investigation of the construction systems was undertaken.

4.1.1 Brock Commons

Brock Commons in Vancouver, Canada, is an 18-level student housing project that utilised post and plate construction; refer to Figure 8. It provided the project with an exemplar in terms of how to achieve speed, workflow, adoption of Design for Fabrication and Assembly (DFMA) and constructability onsite. As it was a student housing building, the project involved a standard rectilinear form with relatively small spans and which very compact kit of parts (as mentioned, this small span differed from the larger span systems in this project).

At each floor level, the "post and plate" system equated to 29 cross-laminated timber (CLT) panels and 78 glue-laminated (GLT) columns (approx.). The panels have two-way spanning action and are joined using 25 mm deep plank-like splines and fixed using nails and screws. Notably, no beams were required between columns, significantly simplifying onsite processes. Instead, column head shear was a controlling factor for the structural design, requiring a unique design of steel head and boot connectors for each column. The steel head and boot connectors also provided direct column-to-column transfer of load. Also, they dealt with other structural concerns, such as axial shortening and crushing of the CLT panels.

The onsite process achieved a fast two-day floor cycle (9.5 weeks to install 16-floor levels). Other salient features relevant to this study include:

- 5 ½ hrs approx. to drop in 930 m^2 of CLT, 29 panels

- Crane productivity for panel installation was 181 m^2/hour approx. (based on active hook time)
- Installation of posts became as quick as 78 columns in 2.5 hours for a floor level
- Crane cycle time and the number of lifts ruled the construction speed and productivity
- The more consistent the crane cycle, the higher the productivity
- The more lifts per hour, the higher the productivity
- The larger the panels, the higher the productivity
- The more panels delivered in the correct order, the higher the productivity
- The smaller the crew, the less to manage in safety and process (only 6-9 workers used)

4.1.2 Rotho Blass Spider and Pillar Systems

Understanding the Rotho Blass Spider and Pillar systems came about by meeting with Rotho Blass engineers and the research team at the Faculty of Engineering Sciences Institute of Design and Material of the Sciences, University of Innsbruck, and particularly with Dr Maderebner, in 2018. The researcher was fortunate to witness the Spider connection tested; refer to Figure 8.

Figure 8: Dr Maderebner explaining the testing of a Spider connection (Image credit: TDA)

4.1.3 XLam Band Beam System

Understanding the XLam Band Beam system came about through a discussion with Tom Watts, XLam principal engineer, and the system's inventor, Nick Hewson, the past principal engineer at XLam. In addition, the researcher also conducted a series of finite element modelling of the system; refer to Figure 9 to understand the issues of grid spacing and use in residential construction.

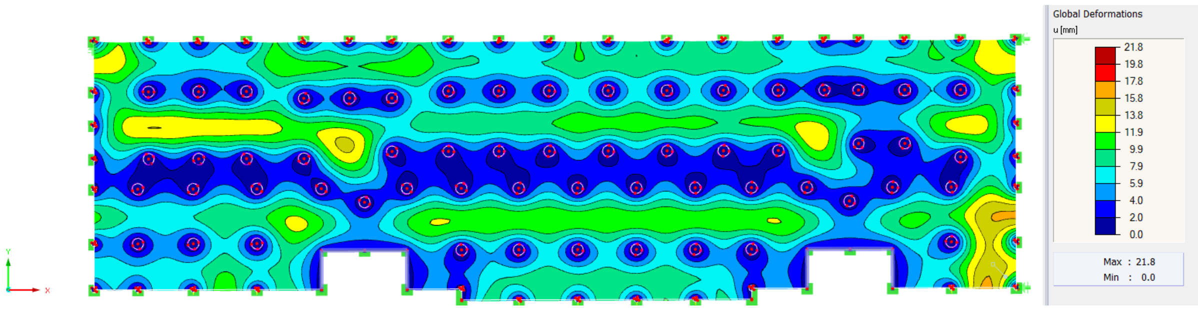


Figure 9: Finite Element Modelling Spider connection Floor Plate (Image credit: TDA)

4.2 WorkShop One - November 2021 - Learnings

This part of the project's objective was to discuss the various post and plate building systems with the knowledgeable construction sector. The purpose was to understand how they evaluate these systems to find desirable features on which to base the modelling.

4.2.1.1 Attendance

The following companies had a representative that attended the workshop.

Builders
AJP Constructions
Lendlease
Lipman
Mirvac

Timber Installer
Oriel Building Services
Savcon

Formwork
MetSquare

Fabricators
Viridi Group

Industry and the Research Team
Deakin University
Parametric Monkey
Rotho Blaas
TDA
UTS
XLam

4.2.1.2 Learning 1: Capital Connection

For safety reasons, there was a preference to use a system that could be installed working off the deck below. Working on the live deck (itself) required significant extra edge protection to be applied to individual panels, which was seen to be costly and required additional time. Therefore there was a preference to utilise systems that could be worked on without physically being on the live deck or until it was easy and practical to secure perimeter edge protection.

Timber to Timber Connection

The group liked XLam's Band Beam system as it is easy to understand, has little use of expensive connectors and could be fixed from the lower storey. However, it was recognised as limited to large column sizes laminated together to form the recess and starter for the next column; refer to Figure 10. Fixing the column to the floor plate from the deck below was limited by the long reach across the CLT panel, up to 700 mm in the example shown in Figure 10 – not ideal.

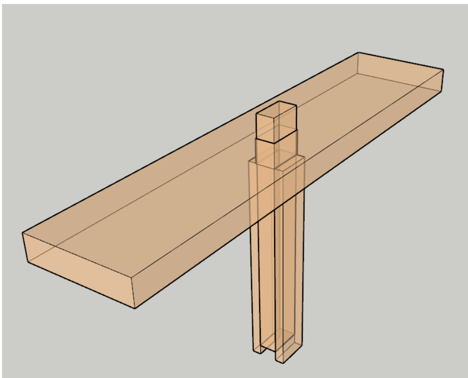


Figure 10: Band Beam to Column connection (Image credit: XLam Australia)

Pillar Connection

The Rotho Blass' Pillar system is an off-the-shelf column capital that supports mass timber floors and transfers column compression loads through the floor panel; refer to Figure 11.

Figure 11: Pillar Column capital System (Image credit: Rotho Blaas)

Generally, the system was liked by the group as being easy to understand but noted as

- Limited adjustment in x, y and z plan
- Limited bearing area, limited grid spacing capacity, i.e. not much better than timber to timber
- Hard to install the following storey columns using bolts from under the base plate.

The solution for installing the following storey columns included downward-facing metal threaded studs that would poke down from the column plate's bottom and fit into the slotted holes in the top plate of the pillar connector. Some participants were concerned about the threaded studs being damaged/bent in the process.

Comments focused upon:

a. Room to install bolts was not well understood and considered difficult.

b. Making it easier for the column to be correctly located over the Pillar plate. It was suggested that a locating stud or lug would assist. Also, make the lugs asymmetrical - to ensure there is no confusion on-site about installation direction.

   Another option was a so-called shark fin approach where the top of the plate would have a square fin welded across the centre of the connector plate, and this would be mated against a saw cut/slot in the bottom of the column above. Similarly, the cap could be tapered to allow rough placement to become precise placement at the full depth of the cut.

c. Adjustment of alignment of the column: it was discussed that rarely CLT panels are the precise size, and minor adjustments are required to align columns, both vertically and horizontally. It was further discussed that the vertical alignment could be addressed by installing metal shims on top of the base plate; however, this does not deal with the need to shorten the column. It would be necessary to provide a shorter column than estimated for this process to work.

Spider Connection

The steel core of the Spider system, referred to in Figure 12, prevents the CLT panels from being crushed and allows more than 5,000 kN of vertical load to be transferred between the columns. The arms of the system ensure the punching shear reinforcement of the CLT panels, allowing exceptional shear strength values. The Spider connection offers the possibility of creating free spans higher than 6.0 x 6.0 meters, even without unique connections between panels.

Figure 12: Spider Column capital System (Image credit: Rotho Blaas)

The Spider connection received mixed reviews, picking up some of the issues discussed for Pillar and specific Spider issues detailed below.

a. The audience saw that the Spider could only be installed once the column's shaft was through the CLT floor panel. This constraint meant that there was no other option but to work off the (live) CLT floor panel to install the spider's radial arms.

b. Some thought it was a good idea if used with a screed that would ultimately cover the Spider connection. Others were concerned about what would happen if there was a clash between a bathroom pod and the arms of the Spider connection. Could some of Spider's arms be removed to accommodate this?

c. Concerns were raised about the number and time involved in placing the 48 screws in each Spider connection. The issue was heightened by the need to install the screws at a 45° angle. The matter may be reduced somewhat if there are relatively few columns involved. If there are many columns, the time to put the screws may come onto the critical path within the workflow.

d. The fixing of the Spider connection on the working deck may require the use of falsework discussed later.

e. If some of the screws required for the Spider connection were deployed later, does this mean that falsework remains in place longer than otherwise necessary and does it mean that props cannot be removed?

f. There was also discussion about leaving out some of the arms of the Spider connection on the floor plate edges and corners; however, there was no evidence from Rotho Blaas to support this approach.

g. The arms of the Spider connection stand proud of the column - seen as a trip hazard until the floor has been installed and screed off.

h. It was recognised that the Spider connection had a greater floor span capacity than the Pillar connection.

j. The Spider connection prevented a smooth floor level transition from bathroom to habitable areas to balconies, becoming a dealbreaker for several participants.

A proposed solution was that the spider connection could be fixed to the floor panel before lifting it onto the building.

4.2.1.3 Learning 2 - XLam's Band Beam System

Figure 13 illustrates the Band Beam concept. A similar system is found in the Rotho Blass Spider connection, referred to as the Crossed Panels system.

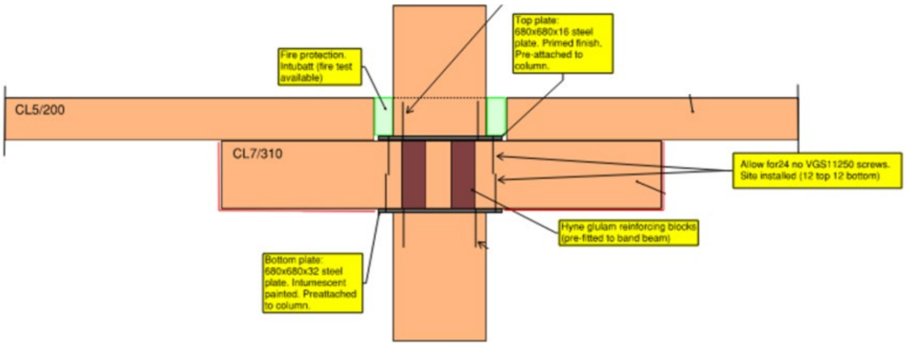


Figure 13: XLam's Band Beam System (Image credit: Xlam Australia)

The system was understood and thought to be novel with the use of glulam blocks transferring the column load onto the column below. Issues identified where:

a. Grid spacing remained unresolved, limited by the thickness of the CLT that could be manufactured.

b. Continuity of the tension force from column to the column was not detailed and likely not possible in the illustration given. This lack of tie creates issues with addressing robustness.

c. Exposed steel fixings created a fire-resisting issue.

4.2.1.4 Learning 3 - Two Way Action of CLT Panels – Joining the Panels

The longer span post and plate buildings system requires the two-way action of the CLT panels to be achieved. This two-way action requires a partial moment connection between the panels to form. The following discusses the various methods considered.

4.2.1.4.1 Glued in Plates

Rotho Blass engineers recommended glued-in plates. The system utilised a trench slotted into each CLT panel to be joined, where the trench is filled with adhesive (Xepox) and a perforated metal plate spanning between the two panels is inserted, refer to Figure 14. The metal plate and adhesive form the joint between the two elements.

Figure 14: Xepox Joining System (Image credit: Rotho Blaas)

There was limited support for the glue and perforated metal approach. Concerns were expressed in

a. The use of adhesives on a building site was not well received.
b. Depending on dimension creep and timber shrinkage or expansion, off-site milled slots into CLT panels would not always align.
c. Curring time affected critical program time as curing takes 2 to 3 days, depending on temperature.

d. Issues were also raised about the impact of wet timber on the ability to obtain the design bond strength or delay waiting for the timber to dry.

e. Methods to demonstrate strength in the joint were also required. Before removing falsework or moving onto another storey, a sign-off by an engineer would be required that the bond strength had been achieved. The workshop participants could not see a method of doing this without sampling the bond and off-site testing it. Sampling the bond and off-site testing would be considered time-consuming and considerably affect the construction program schedule.

f. Another concern was the sheer amount of this type of jointing involved, such as 450 mm spacings along the whole length of the panel joints. No design example was given to understand the true spacings needed. It was considered that this would significantly impact the critical path in either the pure time to execute or the time to allow for curing of the adhesive. Loading the next floor and removal of falsework can only proceed after the adhesive has been cured.

4.2.1.4.2 Concrete Composite Joint

Another system recommended by Rotho Blaas was a concrete-based joining method. This joining system utilises fully threaded screws into the panel's edge and the gap between adjoining panels filled with concrete; refer to Figure 15.

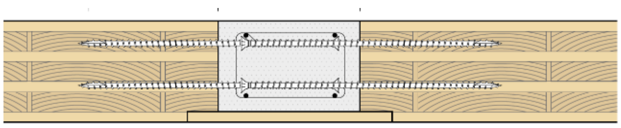


Figure 15: Concrete joining (Image credit: Rotho Blass)

There was a degree of acceptance of this method; however, the following issues were discussed.

a. How long will the falsework/bracing stay in place until concrete gains sufficient working load strength?

b. The concrete connection option would receive more support if it were poured simultaneously as the acoustic topping. However, due to curing time issues, higher strength concrete may be preferred becoming too expensive to do this simultaneously.

c. Concreting the joints was seen as too small of a job to use a standard concrete pump and too large to hand mix.

d. Suggest that the screws needed to be out of the way for transportation.

4.2.1.4.3 Concealed Mechanical Connection

There was a preference for a mechanical connection to be used to join the CLT panels. Interest in what this system contained was expressed by the workshop's participants. However, there were no options available for the workshop participants to review.

4.2.1.4.4 XLam's Top Slab to Band Beam Connection

The CLT floor was required to be joined to the Band Beam to increase the structural depth for an increased span capacity; refer to Figure 16.

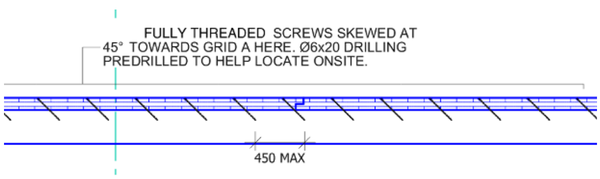


Figure 16: Connection of Floor Panel to Band Beam (Image credit: XLam Australia)

There was interest in the Band Beam system from several participants, but the remaining issues include:

a. Concerns about using screws for joining overlapping panels insofar as the sheer number of screws could take significant time to install. For instance, their recent model had four rows of screws at 450 mm centres using 300 mm long screws, which occurred along the entire length of every panel joint. Therefore a considerable number of screws and potentially a significant amount of time to execute this task.
b. A timber installer advised that screws may take about 30 to 45 seconds each.
c. XLam mentioned that they had CNC-created starter holes for all the screws, but there was concern that if this could be done commercially, it may take up valuable CNC time and would be better if it was unnecessary.

4.2.1.5 Learning 4 - Falsework

Falsework was of interest, as it was considered necessary that some of the more extensive span post and plate systems required support until the full structural action of the floor system could be achieved. The following discusses the various methods considered.

4.2.1.5.1 Peri Flexigrid system

Due to stability issues, falsework was considered necessary to support some of the proposed post and plate systems. The Peri's Flexgrid, a lightweight aluminium falsework system; refer to Figure 17, was presented as a viable option.

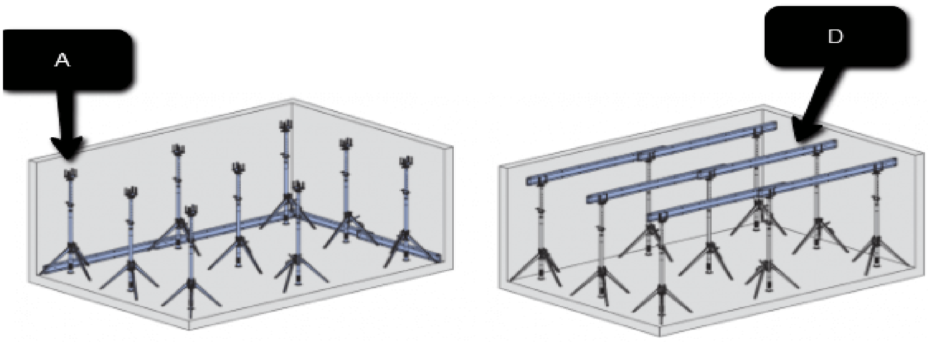


Figure 17: Peri's Flexgrid Falsework (Image credit: Peri Australia)

a. There was general support for the Peri Flexigrid system and its use as isolated towers (braced towers). However, it was limited to 3.6 m floor to floor height for safety reasons.

b. A six-man crew can typically place 500 m^2 of the flexor grid system in a day. A four-person crew is also appropriate but may get lesser installed in a day. Even so, this latter scenario would typically allow half of a mass timber installation crew to be deployed for shoring tasks without necessarily compromising the mass timber installation process

c. No clear outcome about how much falsework would be required.

4.2.1.5.2 Rotho Blaas Spacer Beam System

Rotho Blaas developed a minimalist and temporary support system focusing on bearers that can easily be installed and dismantled; refer to Figure 18. The system mainly consists of bearers supporting the floor panels, supported off the column using Rotho Blass Lock-T hook connector. The Lock-T connector has two parts: a more extended connector fixed to the column and a standard-sized Lock-T connector to the beam end. The connector can be dismantled after use as the screws are accessible to the extended Lock-T connector on the column. The tie part of the system acts as a spacer between columns to maintain alignment. It is not fixed hard against the floor panel, so it can easily be dismantled.

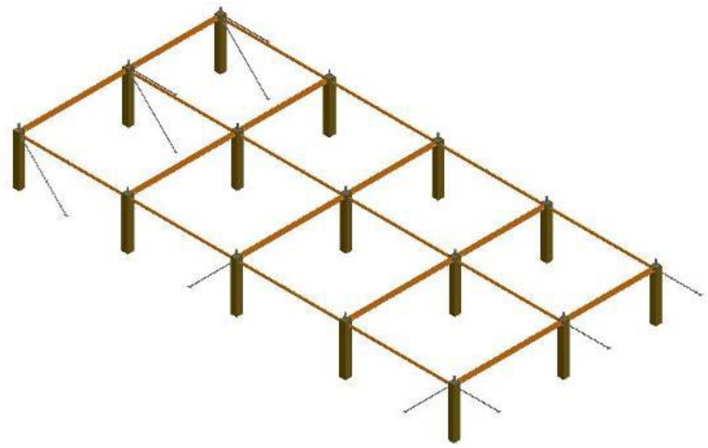


Figure 18: Rotho Blass Bearer and Tie System (Image credit: Rotho Blaas)

a. Concern was expressed that the spacer beam system may not work well due to CLT floor panels' tolerance creep. For instance, if panels are slightly oversize, they may begin to overshoot the column grid that is already fixed in place. Of note, this was not an apparent problem for the Brock Commons project.

b. The hook on spacer beams had merit as long as they could be easily removed by lifting upwards to get over the hook and did not require heavy handling equipment or excessive manual labour. For instance, it was unclear how large the beams would need to handle a 7 m span.

c. Push/pull props would likely be used for all columns, doubling up on the amount of support.

d. Push/pull props allow greater ability for adjustment on-site and are generally considered a positive approach.

e. The bearer and tie system would see further support if it could provide minor length adjustments.

4.2.1.6 Learning 5 - Edge Protection

Fall protection was the primary concern regarding most of the installation procedures. Below are some of the workshop's participants' concerns.

a. How do you screw off the floor panels if it does not have edge protection around it?

b. Handrail and fall protection raised concerns as needs to be a 1.6 - 2 m fall protection area. (i.e. Health Safety and Environment requirement - have to work 2 m away from the edge). An alternative to an edge protection handrail is extending falsework about 1-2 m beyond the edge of the panel, which becomes a no-go zone purely for fall protection. This method is apparently used when placing formwork but needs to enforce the no-go zone as there is no physical barrier to protect workers from falling.

c. Nets were derided as a solution and were dismissed as a variable option. However, the available solutions were not addressed appropriately due to time constraints. This solution should not be dismissed as a viable option.

d. Suggest handrail/fall protection being attached to the floor. Is there a way to have the handrail attached to the floor segment before arriving at the site or installed upon arrival before they are lifted?

4.2.1.7 Learning 6 - Crane Cycle and Install Sequence

a. The workshop participants suggested that the Spider connection could be attached to the floor panel and column as a prefabricated element, forming a T section (T-table), before lifting to the insitu building location. Push/pull props would be attached to the outer edges of the T – section using a hinged arrangement. The fabrication would likely take place on the ground. Once the T-table was lifted and placed (but still supported by the crane), the props would be hinged outwards to provide bracing support and general stability to hold it in place.

b. The issue around curing of the joints in the floor panels was raised by many as a concern because of its impact on the critical path timeline. More work was needed to determine the actual curing time for each system, as this impacted their viability.

c. Inspection, Testing Program (ITP) was pointed out as a critical issue. Before the next floor could be commenced, a structural sign-off by the project's engineer was required before any work could move on. Where adhesive-based systems are proposed, the glue must be cured and bracing removed. Therefore, quality control testing or procedure needed to be completed relatively quickly, preferably off the critical path.

d. A significant advantage of mass timber is that services trades can be set out and installing ductwork or services as soon as a floor level is completed. Concern that overuse of falsework compromises this advantage.

5 SELECTED POST AND PLATE SYSTEMS FOR DIGITAL MODELLING

The Workshop's outcomes helped identify three systems to be carried through to digital simulation. The systems have different grid spacing, which lent themselves to various products and methods. These systems are described as

- Panel Edge support system – 3.33 x 6.67 m grid
- Central Column and Panel Infil – 6.8 x 6.8 m grid
- Band Beam system – 7.8 x 6.8 m grid

A model floor area of 20 x 30 m was chosen as it allowed a comparison of each system without having an odd arrangement that could disadvantage a specific system. It also allowed a fair comparison against a concrete flat plate system utilising a 9 x 9 m grid. Notably, the number of storeys in the building is irrelevant to the comparison exercise, as the floors are identical cycles for each storey, except the first, which is on a concrete slab. Therefore the number of storeys in the building has been ignored, but for cost comparison purposes, a six-storey building was chosen.

5.1 Panel Edge Support System

This system copies the format of Brock Commons (18-storey student accommodation in Canada), discussed above, in that the columns support the edge of a maximum width CLT panel of 3.4 m. XLam Australia's maximum production panel width determined the short span spacing. The main difference was a larger column grid in one direction.

The columns utilise the Rotho Blaas' Pillar connection that ties the column to the CLT panel. The panels are joined in their short direction by a mechanical connection system. For discussion purposes, the Blind Bolt Metal plate connection system was selected (see discussion on panel connection system). The floor plate was supported on a falsework of temporary timber bearers and ties. Refer to Figure 19.

The CLT panels were connected along their long length using the standard cover board and screw method, commonly employed on most CLT floors.

The total number of CLT panels was 18, with a thickness of 220 mm. Forty 410 x 355 mm columns were used. The column size was determined by the cover required to provide 120 minutes of fire resistance to the Pillar connection's base plate.

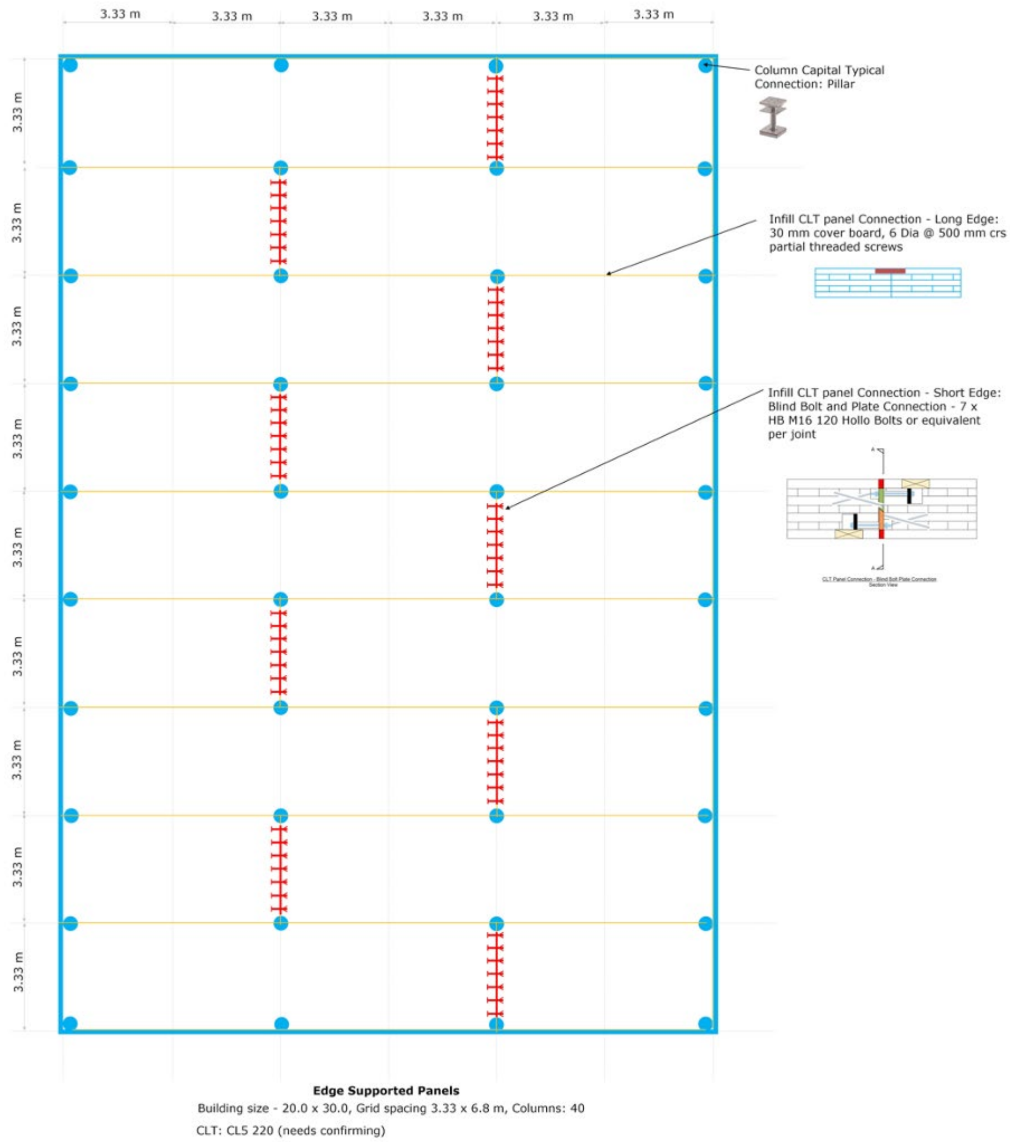


Figure 19: Panel Edge Support System Details

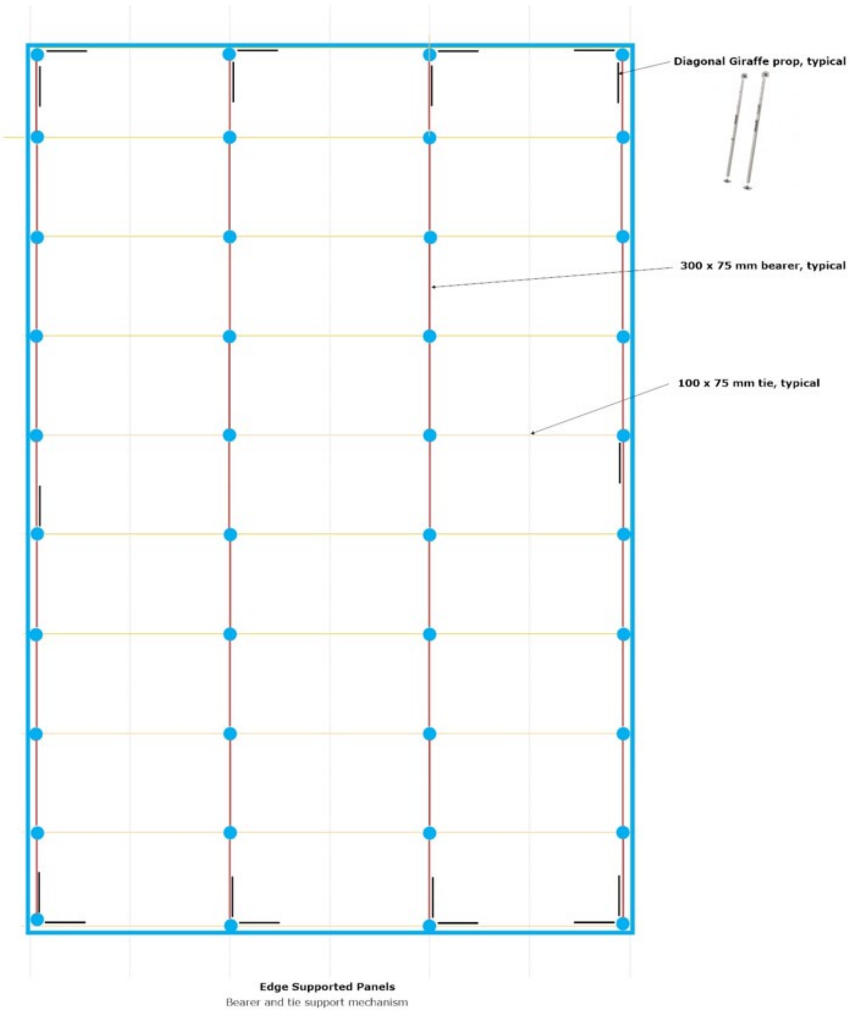


Figure 19 continued: Panel Edge Support System Details

5.2 Central Column and Panel Infil

This system has a maximum grid dimension of 6.8 x 6.8 m, refer to Figure 20, and was chosen as it again utilises the maximum width of the CLT panels available. The system is constructed with a row of columns supporting the centre of a CLT panel. The floor system's grid spacing was increased by using an infill panel between the centre-supported columns T-tables. This infill panel is again limited to 3.4 m wide, resulting in the 6.8 m maximum grid spacing.

The column connection to the CLT panel is via a Rotho Blaas' Spider connection. A full Spider connection is used in the internal columns, while a half Spider, i.e. only three radial arms, is used on the exterior wall columns. The Spider connection in its current form can only be installed on top of the CLT panel, which was highlighted as an undesirable feature at the first workshop. The mass timber installer prefers working on the CLT panel from the side of the CLT panel, off a scaffold or scissor lift, not on top of the panel.

The workshop participants identified that the columns could be connected to the CLT panels in pre-assembly bays before lifting into the building and removing the Spider connection's undesirable feature. The columns connected to the CLT panel make a T shape that needs support to prevent toppling over. The T system's stability is made by a series of push/pull props, partially installed to the CLT panel prior to lifting onto the building and the other end installed onto the floor below where the T section is to be installed. The push/pull props can simply be joined to provide stability to the T section floor panel.

Because the CLT panel manufacturing length is limited to 16 m, two T- sections of panels were required to complete the 20 m width of the building. The CLT panels were joined together, requiring partial moment connections. This connection was determined to be installed in the quarter-point between the columns to avoid interfering with the Spider connections. Again, a mechanical joining method was chosen, i.e., the Blind Bolt metal plate connection system.

Between the rows of T-section panels, a CLT infill panel was required. The edges of the CLT panel are connected by the same mechanical joining system, i.e., the Blind Bolt metal Plate connection system.

The total number of CLT panels is 18, and each panel is 260 mm thick. Twenty 410 x 355 mm columns were used. The column size was again determined by the cover required for the Spider base plate for 120 minutes of fire resistance. This arrangement has half the number of columns compared to the edge support method.

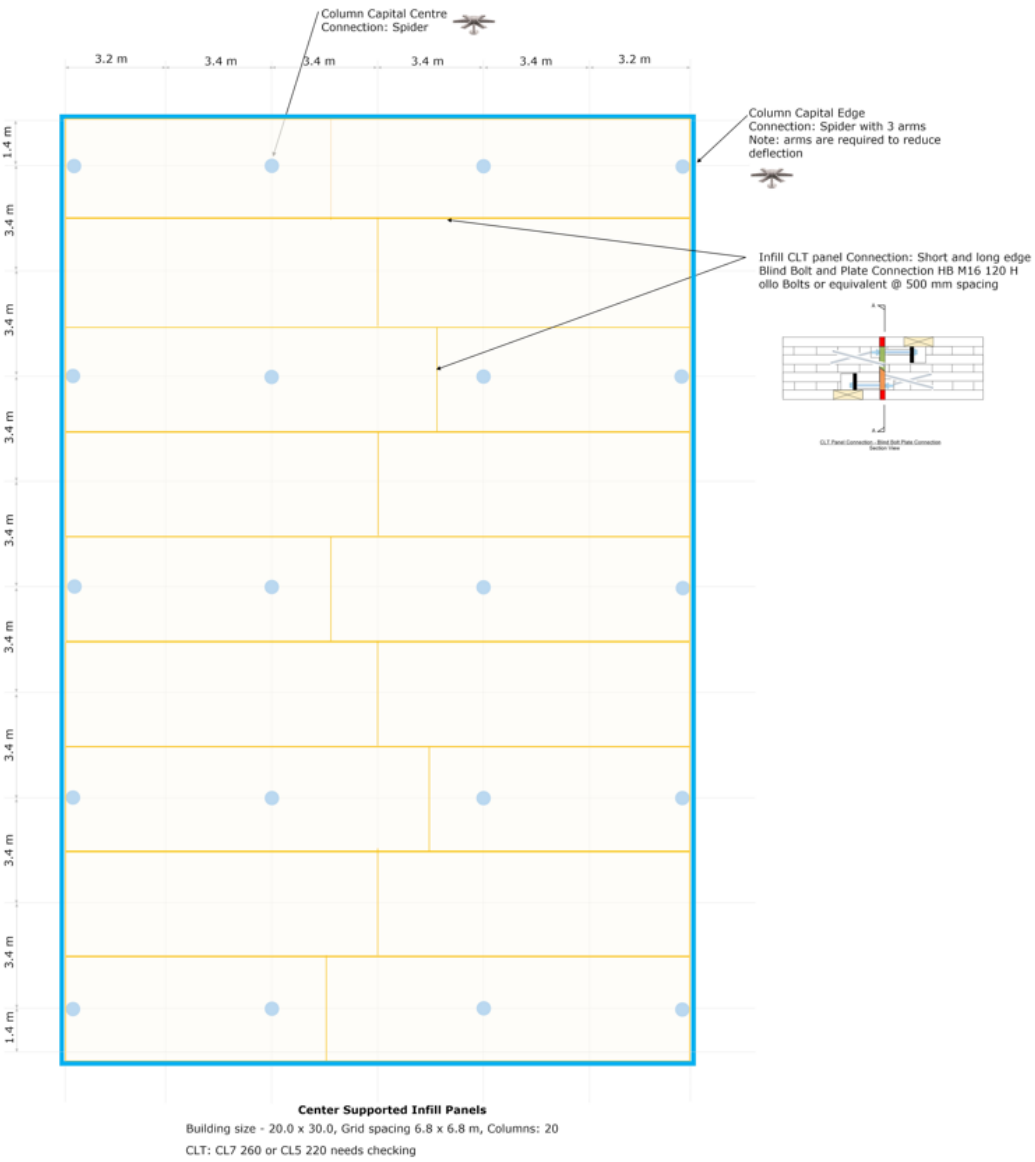


Figure 20: Central Support, Infill System Details

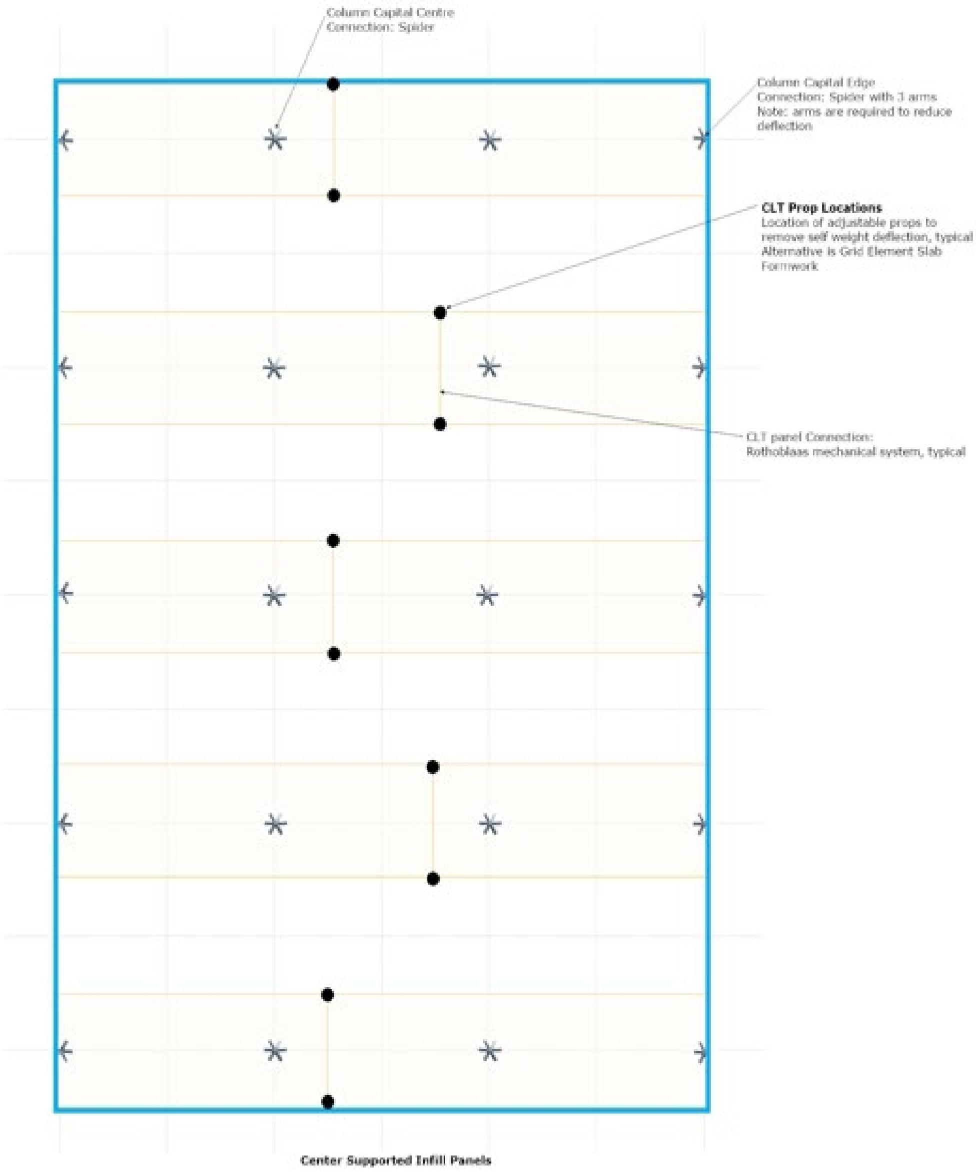


Figure 20 Continued: Central Support, Infill System Details

5.3 Band Beam System

This system has a maximum grid dimension of 7.8 x 6.8 m, refer to Figure 21. The system is constructed with a shallow wide CLT beam, called the band beam, spanning between the columns. The maximum thickness of the band beam is limited to 360 mm, due to the press opening size at XLam Australia. This panel depth restricts the band beam span to 7.8 m. The band beam was joined over the columns, and a mechanical joining system was chosen. A metal plate and welded connection system (discussed later) were used for discussion purposes.

The columns are made from three Glulam pieces laminated together with the centre part design to protrude above the CLT floor to become the start of the next column. The CLT floor sits on the shoulder of the Glulam column, supporting the centre of a CLT panel. The column is connected to the CLT panel via two-angle brackets and screws.

The Band Beam requires the use of falsework to stabilise it until the complete system is installed. This falsework is provided by Perri's GridFlex aluminium 2 x 1 m table formwork. They are placed around the column to both stabilise the column and support the Band Beam. A central falsework is added in the mid-span of the band beam to remove any self-weight deflection.

The CLT floor panels are run perpendicular and on top of the Band Beam. They are connected to the CLT band beam via rows of screws, making the Band beam structurally deeper in this section. At the joins of the CLT floor panels over the band beam, tension tie plates are used to transfer tension forces.

There are 10 CLT panels used as band beams having a thickness of 340 mm. Twelve 220 mm CLT floor panels are used above the band beams as the floor. Supporting the band beam are 15 columns, the lease amount used for all systems reviewed. This arrangement has the highest CLT volume compared to other systems reviewed.

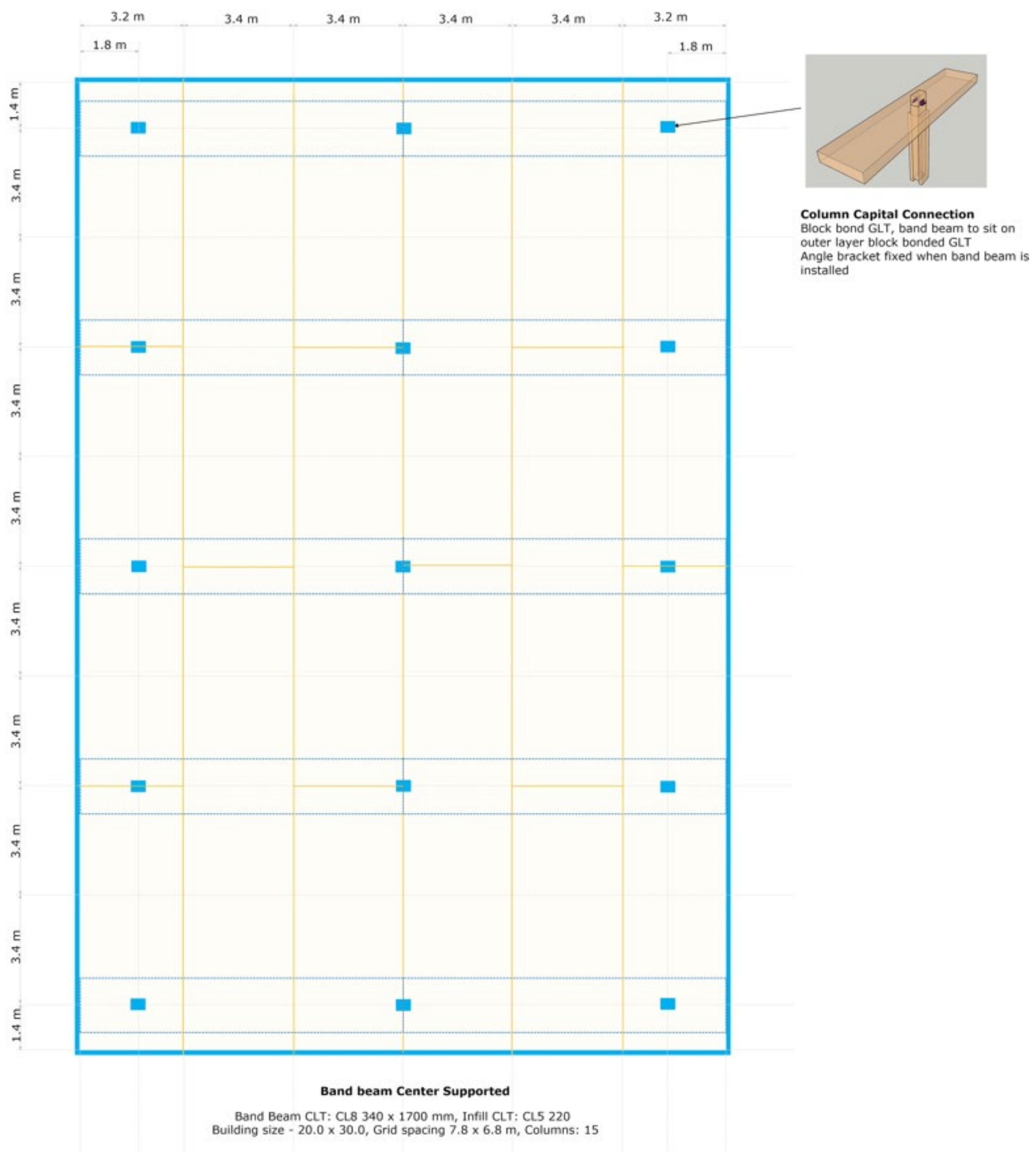
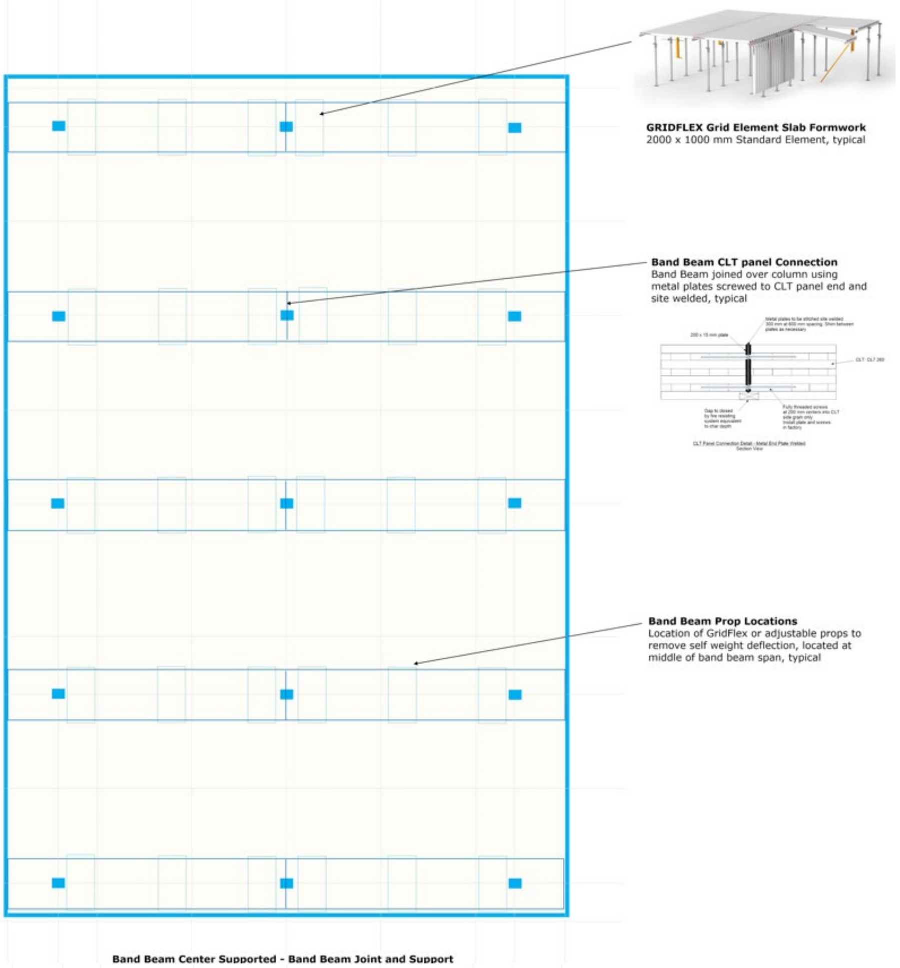


Figure 21: Band Beam System Details



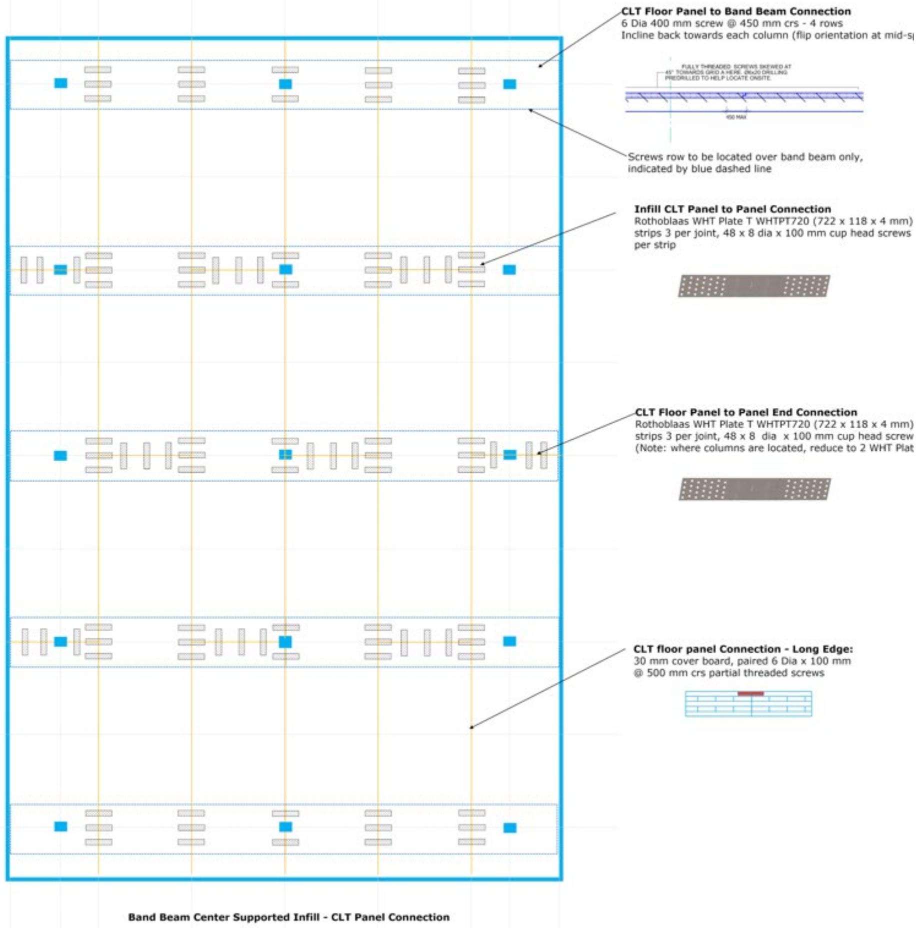
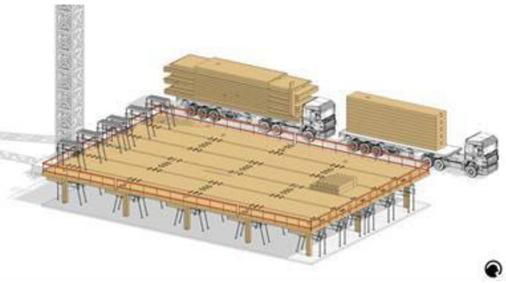


Figure 21 Continued: Band Beam System Details

5.4 DRAFT MODELS

Three draft models were developed. They can be found by following the link near Figures 22, 23 and 24.

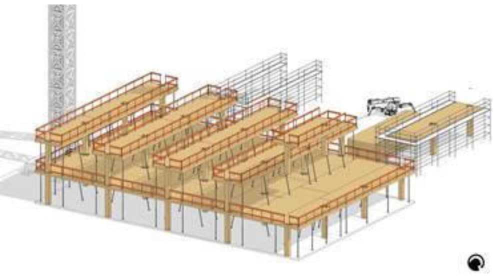
Band Beam System



https://www.youtube.com/watch?v=BV7a3RUHEgQ

Figure 22: Band Beam System

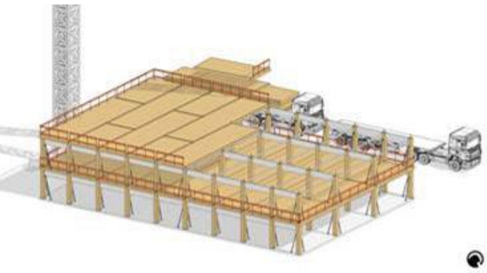
Centre Support System



https://www.youtube.com/watch?v=5uexvGHOIFo

Figure 23: Centre Support System

Edge Supported System



https://www.youtube.com/watch?v=VE1IIJ3d_sA

Figure 24: Edge Supported System

5.5 WORKSHOP TWO – MARCH 2022 – LEARNINGS

The purpose of Workshop Two was to review the three post and plate digital models and provide recommendations for further refinement of the final versions.

Attendance

Attendance was less in the second workshop due to participants having COVID or close contact restrictions. The following companies attendance.

AJP Construction			
Lipman	Parametric Monkey	TDA	Viridi Group
NeXTimber	Rothoblaas	UTS	XLam

The following summarises the recommendation for change to the various post and plate models resulting from Workshop Two.

5.5.1 Centre Support Infill System

The following is a summary of the comments made by the workshop participants.

Safety Handrails

Safety handrails should be continuous on the perimeter of the building. Where a gap occurs in the handrailing due to the column for the next storey not being in place, fill in this gap. This gap can be filled by moving the column 200 mm inwards and showing the handrails abutting the next bay.

Miss-alignment and Tolerance Issues of CLT floor plate

Identified by the workshop participants is the need for the CLT floor plate to be accurately aligned to accept the panel joining methods. The researchers decided to force the floor panel's alignment using X-Fit (https://www.x-fix.at/) connectors. Refer to Figure 25.

Figure 25: X-Fit connector (Image credit: X-Fit)

One workshop participant suggested that if the CLT panel's tolerance remains an issue, consider installing the infill panel between slightly tilted T sections. One suggestion was to temporarily prop the columns apart to widen the gap during the panel installation; refer to Figure 26.

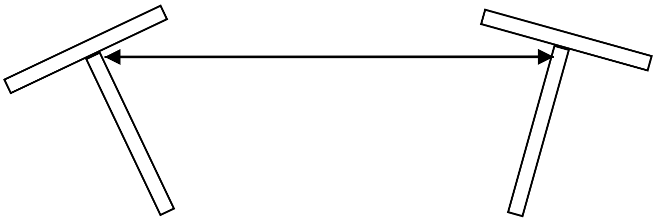


Figure 26: Temporarily prop T-sections a part

Labour efficiency

The costing exercise (discussed later) assumed a 50 % additional cost on labour to cover inefficiencies. This assumption was based on the labour force not being productive all the time they were on-site due to time to get to the work face, wait time between crane lifts, weather and other constraints discussed later. Some thought a 50 % addition to labour time was too conservative, while others stated the crane could only be used for 80% of the available time. Due to this feedback, the rate was reduced to 40%.

Off-site Construction Bays

The group was asked about the ability to have construction bays on the building site. The general consensus was that it was site-specific—unlikely available on CBD projects, but more likely in the middle to outer suburb locations.

Vertical Adjustments via a Spacer of (Pillar or Spider Systems)

A thin metal spacer should be available to remove or add to adjust column height. A site measure of the previous floor should be carried out to inform the spacers required for the next T-table.

Top Connection of Column to Spider or Pillar

A lengthy discussion was had on what would make it easier to install the two-legged T-table columns onto the Spider connection by using a combination of studs and bolt fixings. The thought was to align one connection before tackling the other. Thoughts circled around having studs on one column and bolts on the other. Where studs are used, one stud should be longer to act as a locator for the others.

Props to Columns

Props are generally regarded as the best means to plumb columns. Props that have fine-tuning capacity are preferred.

Inspection Testing Plan (ITP)

The group generally thought that the ITP should not be on the critical path and that action should be taken to ensure this occurs. On a large project, a full-time person would document the installation of connectors (photos and confirming screws were installed). Generally, three-quarters of the floor is the trigger point to commence/obtain signoff.

5.5.2 Band Beam System

The following is a summary of the comments made by the workshop participants.

Falsework

Concern that the Flexgrid falsework was not sturdy enough to support or align the columns. Preference is to use push/pull props.

The group also thought there were too many Flexgrids used; look at removing some and replacing them with props.

The minimum amount of falsework likely to be employed in a project is two-storey worth, i.e., leapfrogging up the building.

Connection of Band Beam

The connection system that used a welding method was not liked at all. The preference is to replace it with a tension plate and inclined screws.

Replace the screwed tension plate with a nail-on plate. Rotho Blaas and others have nailers that locate the nail hole in metal connectors.

Connection of floor edges preferred to be fixed from the top, i.e. not from the underside. This assumption assumes that safety handrails are installed by this time.

5.5.3 Edge Supported System

The following is a summary of the comments made by the workshop participants.

- A floor truss falsework bearer was seen as lightweight and able to be lifted by hand.
- The use of props provided better alignment of columns.
- The oversized Lock-T connector with normal-sized matching pair is easily seen as a solution to remove falsework.

6 FINAL DIGITAL MODELS

Each model was updated to include the feedback from the various workshops. The following includes a summary of the changes and links to the location of the digital modelling.

6.1 Panel Edge Support System

This system only had slight variations made to it from the original model developed; refer to Figure 27. The only changes were the mechanical join at the short edge of the CLT panel, using a circular hollow section (CHS) coupler and installing more props to support the columns during installation. This CHS coupler was considered the easiest to install of all the systems investigated.

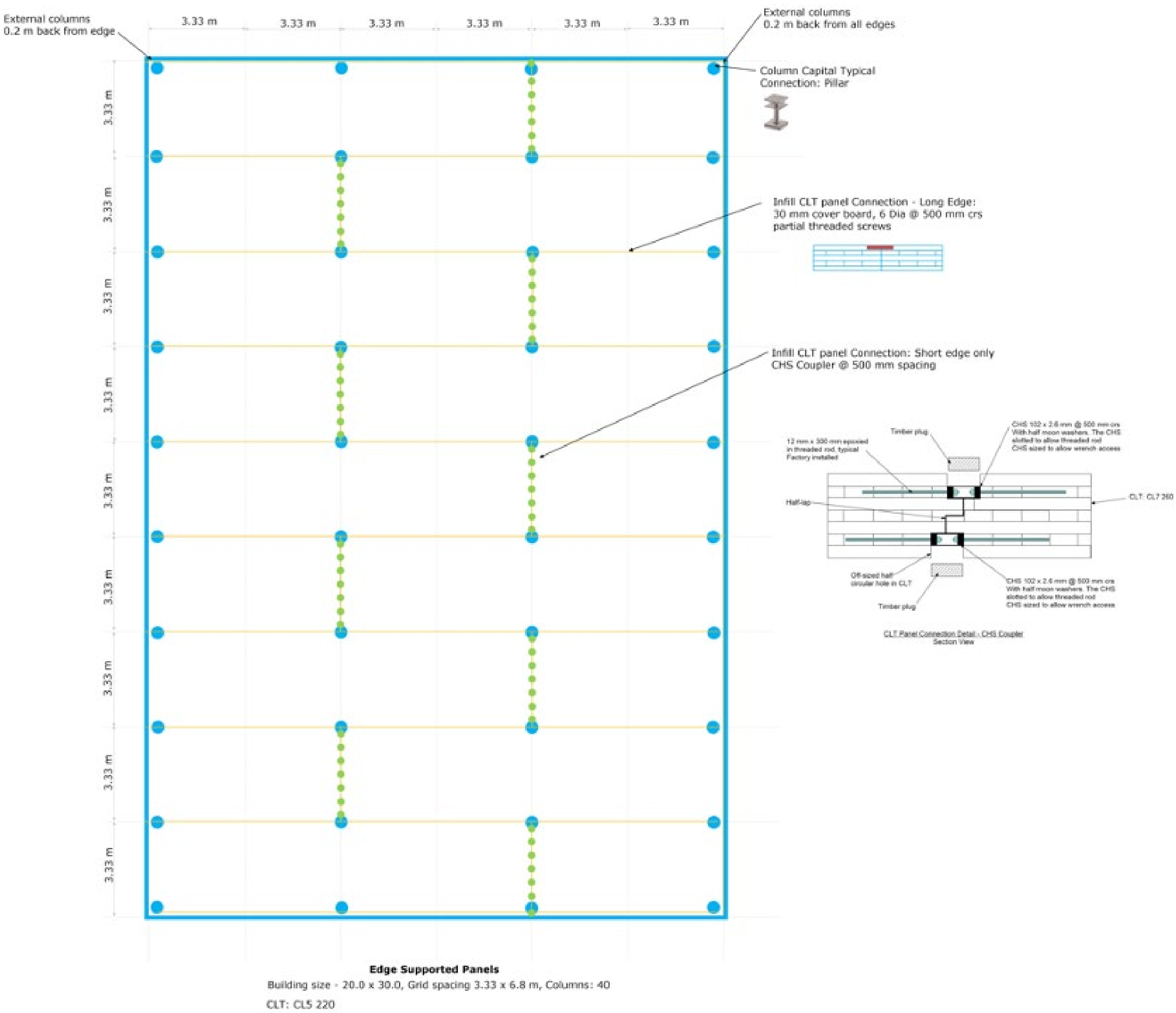


Figure 27: Edge Support Post and Plate System

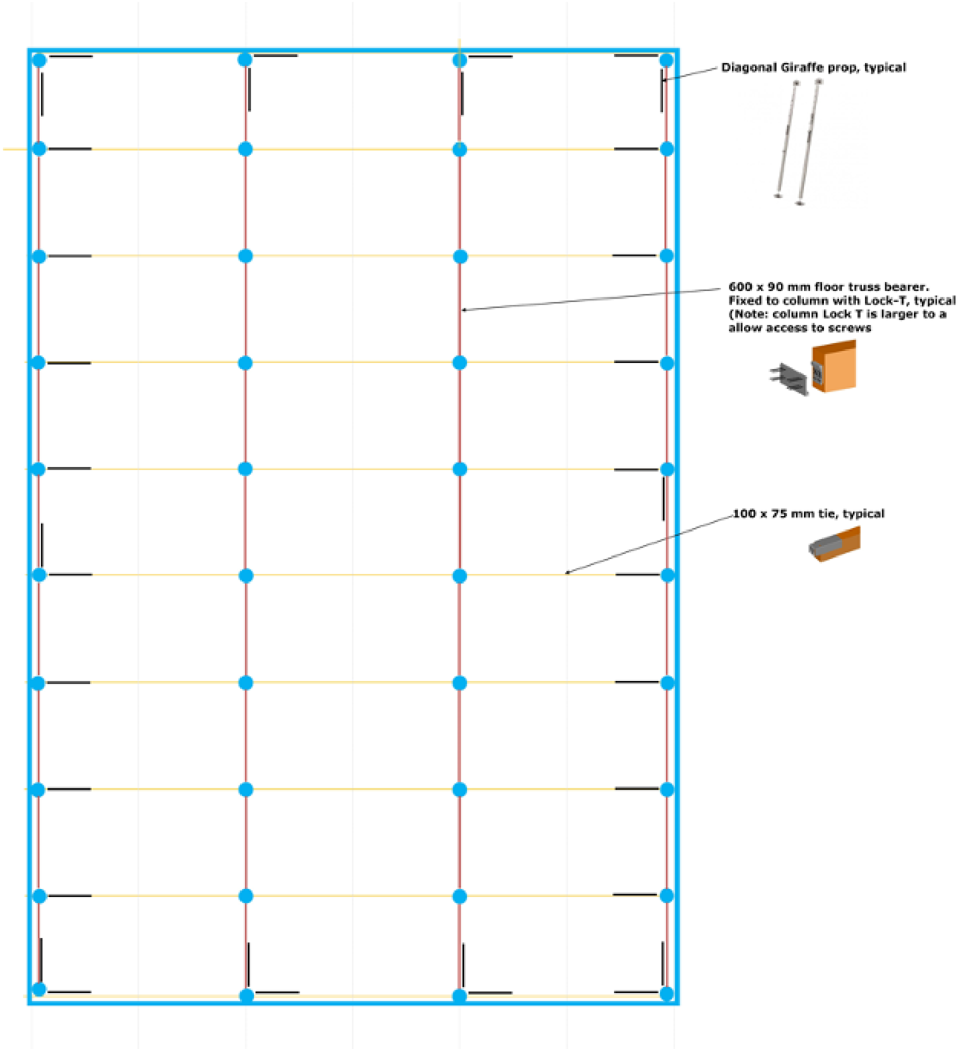


Figure 27 continued: Edge Support Post and Plate System

6.2 Centre Supported Infill System

This system was the most considered, and consequently, the most changes were made; refer to Figure 28. Changes include:-

Exterior columns: have been set in 700 mm, to allow for the full Spider connection to be employed and allow uninterrupted safety handrail placement.

X-Fit Connectors: X-Fit panel joiners have been included to manage the misalignment issue for installing the infill CLT panels.

Mechanical Connection: The circular hollow section coupler has been chosen as the most appropriate method to join the CLT panels.

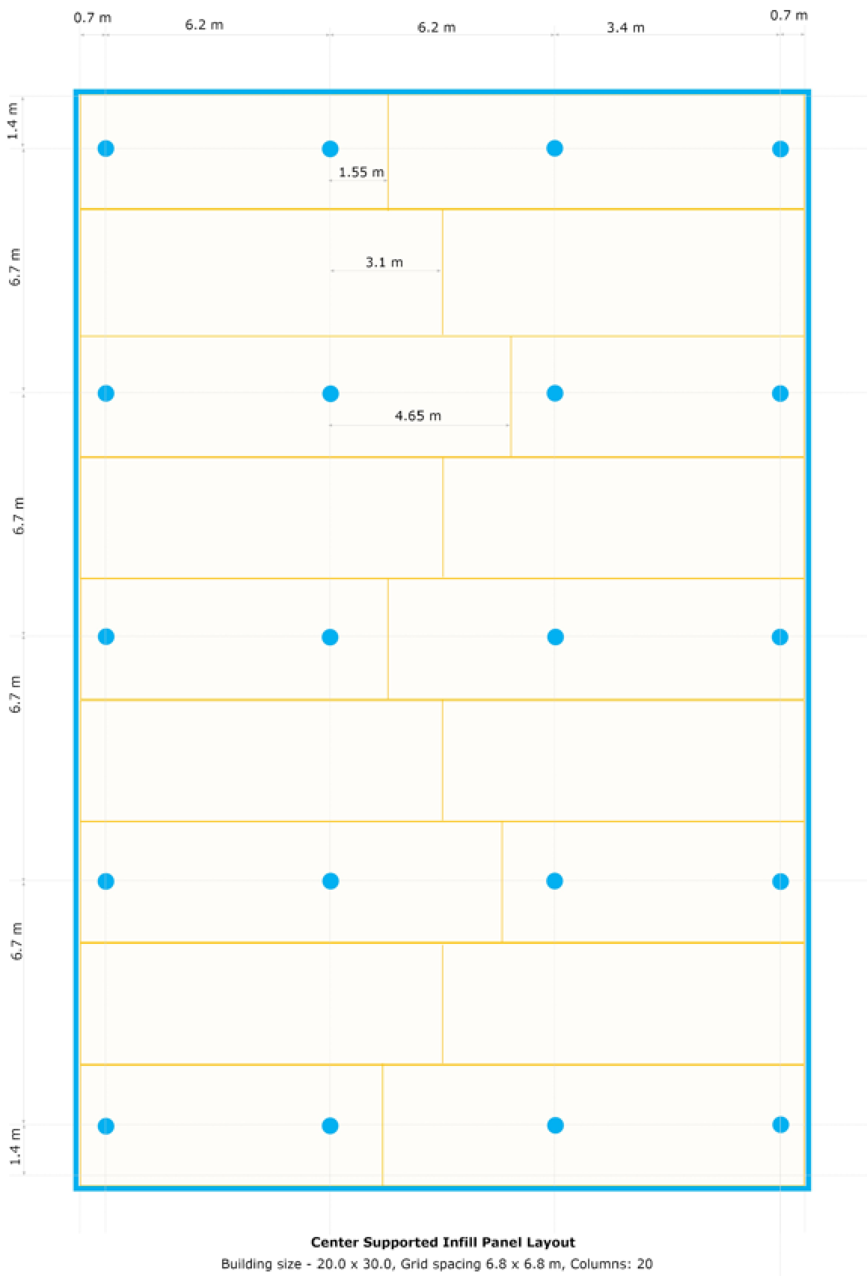
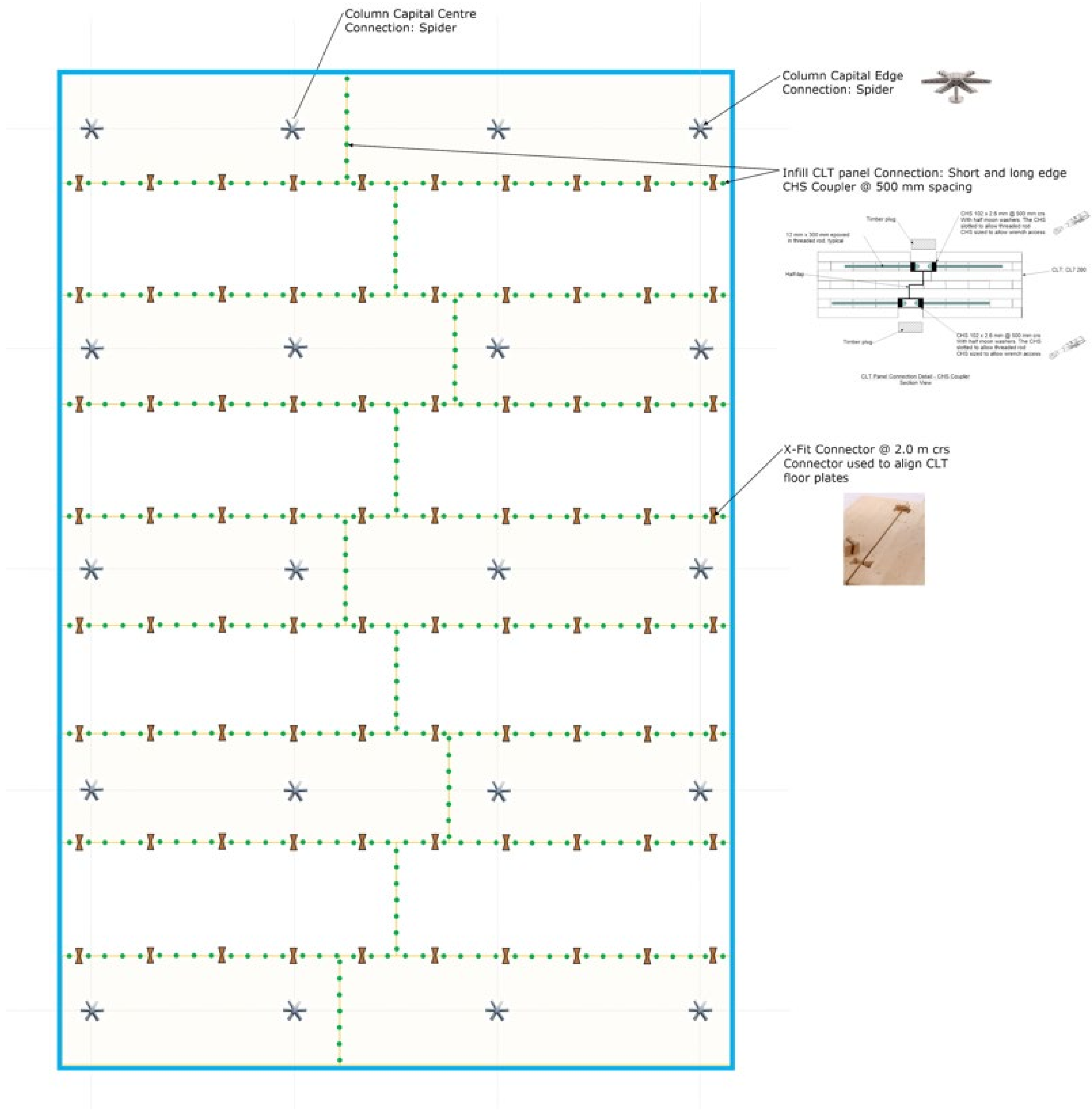


Figure 28: Centre Supported Infill System



Center Supported Infill Connector Layout

Figure 28 continued: Centre Supported Infill System

6.3 Band Beam System

This system has several changes made; refer to Figure 29. Changes include:-

Band Beam Join: The band beam is joining over the columns by placing two Rotho Blaas VGU Plates. These plates were preferred as they reduced the number of screws required to be installed. However, a nail-fixed option was considered; but it required more time to install than the VGU plate's screws and was therefore dismissed.

CLT Floor over Band Beam: The Rotho Blaas VGU plates were considered the best option for these joins.

Grid Flex Falsework: The falsework was strategically placed around the columns to support the columns during the initially installed and to support the band beam panels later.

Props to Centre of Band Beams: Temporary props were chosen over using more GridFlex falsework, as they are cheaper and quicker to install and dismantle. They also freed up the underfloor space.

Fixing of the Band Beam near the external wall: The fixing to the band beam and column near the external wall was considered impossible from the deck below. Fixing in this location could be achieved if scaffolding is installed adjacent to the building or where there is no scaffolding, a cherry picker or crane basket could be used.

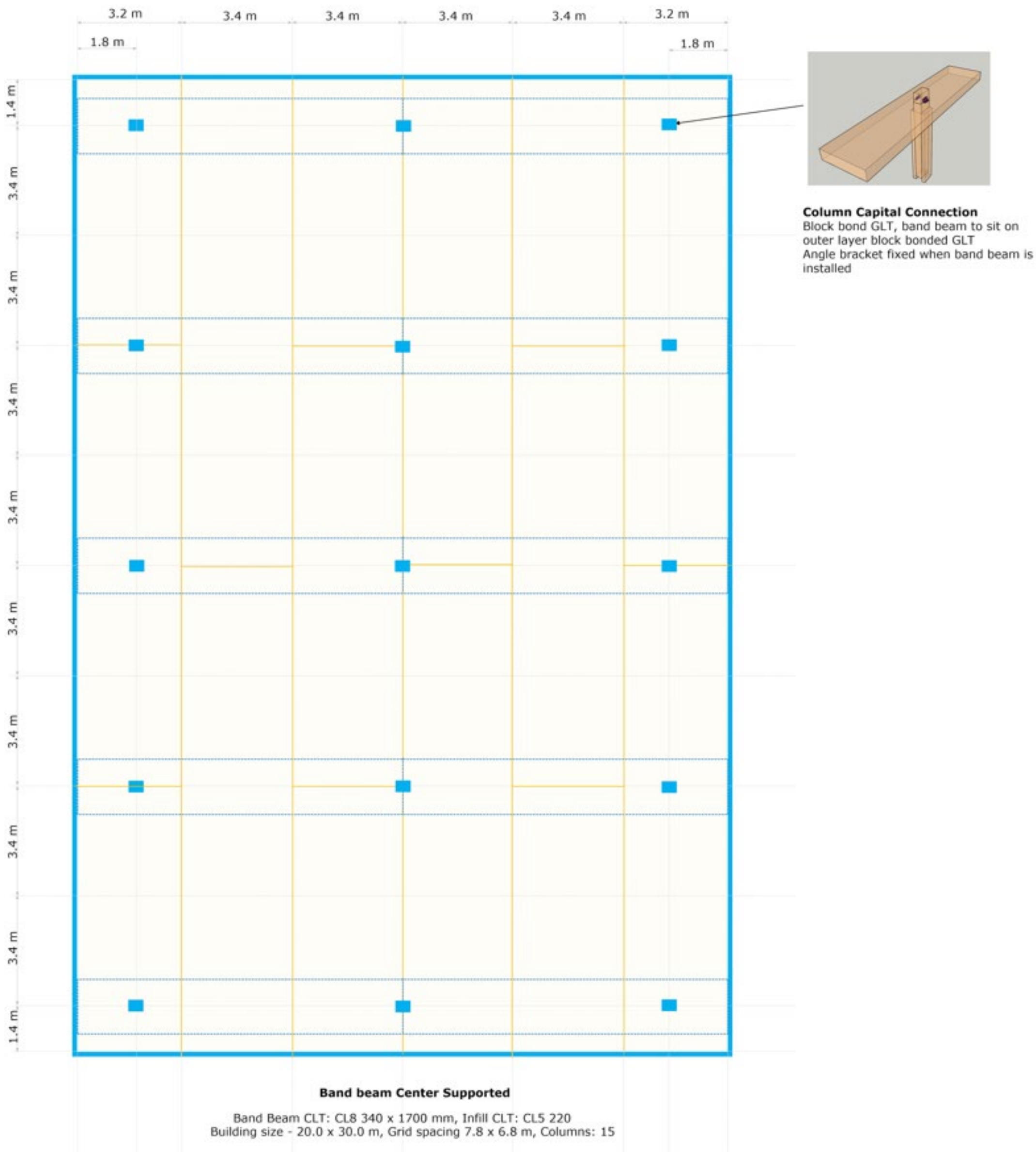


Figure 29: Band Beam System

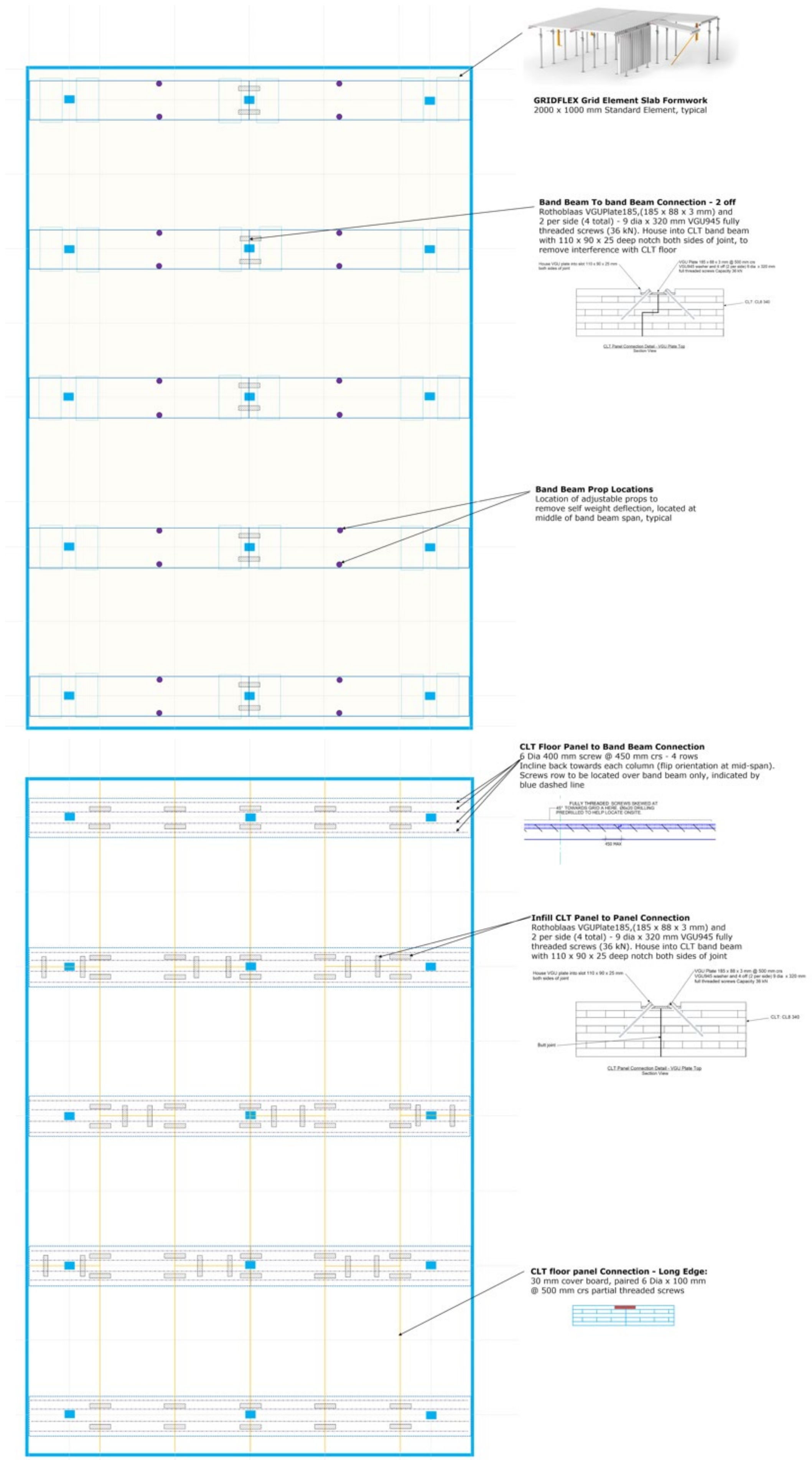


Figure 29: Continued Band Beam System

7 COST PLAN

A cost plan was carried out for each post and plate system and compared against a concrete post-stressed flat plate option to understand which system was the most economical. The previously mentioned 20 x 30 m floor plate was also used for this and applied to a six-storey high building. This configuration allowed the post and plate system to have an evenly spaced grid using relatively large panels. It also allowed the concrete design to utilise a typical 9 x 9 m grid, thus ensuring the layout did not favour one system over another. It is expected that actual building projects may have a much larger Gross Floor Area; however, the layout could be considered modular, and multiple footprints could be considered.

7.1 Labour Costs

This critical variable cost element was obtained by developing a program and labour force scheduled for all timber systems. A detailed program was undertaken for each system to understand this fully and is presented in Appendix A. The detailed program identified where personnel were being utilised, how long they were there, and the hook time required to lift and install a building element.

A 40 per cent extra overtime allowance was applied to the calculated task times for all timber-based systems – this was to allow for typical time losses that occur between the typical task times onsite. It includes an allowance for a degree of unexpected events covering things like changeover time between activities, lack of synchronisation between activities, Inspection and Test Plan implementation, waiting time, materials not ready, rework, confusion, daily setup time for work processes, replenishing stores of materials, workers getting to work face and the crane deployed from assembly installation.

A program was not needed for the concrete option as the labour costs were included within published costs sources, i.e. Rawlinson's Construction Cost Guide 2022 [2].

7.1.1 Material Cost

For Cross-laminated timber, glue-laminated timber and connectors, the material cost were established from market prices at the time of conducting the cost plan, these being;

- CLT – \$1,400 m^3 included simple milling, shop drawings and delivery to Sydney
- Glulam - \$3,000 m^3, included simple milling, shop drawings and delivery to Sydney
- Connector – quote from Rotho Blaas Australia

7.1.2 Concrete Cost and Other Elements

Concrete, scaffold, props, handrails, plant hire and labour costs were found in Rawlinson Construction Cost Guide 2022 [2]

7.1.3 Results

Only the superstructure cost of all systems was considered. The centre support system was found to be the most cost-efficient solution and the Band beam the most expensive; refer to Table 1.

Table 1: Cost Comparison ratio of various Post and Plate Systems against Concrete (cheapest to most expensive)

Cost ratio against Edge Support System	
Edge Supported System	1.00
Centre Supported System	1.04
Concrete	1.07
Band Beam	1.20

Table 2: Break up of Costs for the various Post and Plate systems and Concrete

Item	Edge Support	Centre Support/Infill	Concrete	Band Beam
Beams	NA	NA	$209,475	$485,520
Floors	$1,108,800	$1,310,400	$1,087,159	$1,108,800
Columns	$331,258	$193,873	$73,296	$259,200
Connections	$273,160	$283,376	NA	$246,144
Falsework	$39,976	$42,880	$604,858	$8,400
Labour	$97,200	$97,200	Included	$131,544
	$1,850,394	**$1,929,728**	**$1,974,788**	**$2,224,704**
Per m^2 Cost	**$514**	**$536**	**$549**	**$618**

Note: No margin or Preliminary costs have been included in the comparison.

7.1.4 Comparison of Cost when Preliminary cost and Scaffold are included

The post and plate timber options considered were considerably faster to construct than the concrete option. However, the above cost comparison ignored the cost effects of time savings. Now considering the inclusion of time-saving via the consideration of Preliminary costs, each superstructure cost now varied as each took a different length of time to construct.

An exercise was conducted that looked at the Preliminary cost being fixed and based on the Rawlinson Construction Cost Guide 2022 [2]. Therefore each system included this Preliminary cost based on the time it was required to construct six floors. In addition, the timber post and plate system did not require a scaffold (except for access stairs) for fall protection as the timber option utilised handrails installed on the floor panels. The concrete option used scaffold, a large cost item in construction.

Therefore, where the Preliminary and scaffold costs are considered, the timber options price gap to concrete increased considerably; refer to Table 3. So much so that the concrete option became considerably more expensive, even more, expensive than the Band Beam option.

Table 3: Cost Comparison ratio of various Post and Plate Systems against Concrete, including Preliminary and scaffold Expenses

Cost ratio against Centre Support System	
Edge Supported System	1.00
Centre Supported System	1.03
Band Beam	1.21
Concrete	1.34

8 DISCUSSION

Experience learnt from the Canadian's 18-storey, edge-supported post and plate building, called Brock Commons, indicates that post and plate construction is fast and deals with some of the limitations of post and beam buildings, i.e. taller floor-to-floor height, inability to route services, or requirements for expensive penetration holes within the beams. The three post and plate options investigated within this report follow the Brock Commons lead and show promise in the speed of construction and potential cost savings over concrete post-stressed flat plate solutions.

The main barrier to taking up these post and plate mass timber systems has been a method to erect the structure efficiently. The introduction of the Rotho Blass Pillar and Spider column capitals and the XLam Australian Band Beam system has taken these systems to the next step. However, the final commercialisation of the system requires a smooth and painless installation of the systems onsite, within the constraints of safe practice.

The project's workshop with contractors and mass timber installers recommended the need for the systems to be constructed with much of the complexity dealt with within the factory environment. Building sites need to utilise a low labour force and be fast. Issues identified were the preference to work off the proceeding deck, i.e. not to work on the live deck but rather from below it; avoid connection systems that require long curing time; ensure the Inspection and Testing Plan program is off the critical path. Other issues include the preference to work downwards, i.e., installing fixings should be from above, not below the item. Safety was also considered paramount, so systems must be mindful of working from height requirements, tripping hazards, etc.

8.1 Rotho Blaas Spider Connection

The Spider connection is seen as a revolutionary connector system, allowing greater grid spacing and load transfer through the CLT floor than traditional methods. However, several tweaks were identified that could enhance the connection system further. The primary issue was installing the spider connection after the floor plate had been installed, which made insitu installation time-consuming and awkward. The yoke that locks down the centre spike that transfers load through the floorplate must be installed after the floor is installed. This procedure prevents the pre-installation of the spider's radial arms, which were identified as time-consuming (48 screws), requiring additional safety barriers to be installed if fixed on site.

The preference is to install the Spider connection off-site or in an onsite fabrication bay (on the ground) and then lift the floor panel with it pre-installed. The project achieved this by installing the column and floor plate in such bays as prefabricated T-tables. This solution depends upon sufficient space within the building site and may prevent it from being used in crowded CBD locations.

Therefore if there were a means to connect the spider connection once installed to the floor plate to the top of the proceeding columns, this would be a much-preferred method. Rotho Blaas (in their technical brochure) presented an option that somewhat addresses this issue and shows a method for steel columns. This connection method could be adopted for all timber solutions, as shown in Figure 30.

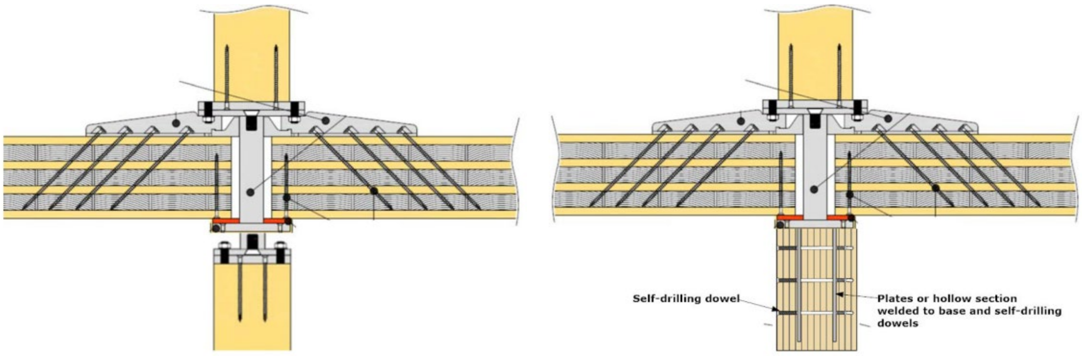


Figure 30: Concepts to fix Spider Connection to Lower Storey Column
(Image credit: Roth Blaas and modified by TDA)

Furthermore, the attachment of the following storey columns based on the spider connection was also problematic. Aligning the bolt to the column's base plate was seen to be difficult when the column is not vertically hung under the crane. Several suggestions were made; the first is the use of studs instead of bolts. The studs could be pre-installed on the column's baseplate, allowing the studs to align with the Spider connection's top plate quickly. It was also suggested that one of the studs should be longer to allow further alignment of the column's base plate. Alternatively, a tongue and groove slot arrangement is included in the column's baseplate to Spider connection to force the alignment of the connectors.

Another suggestion to increase the speed of installation and vertical alignment of the column is a purpose-made female eye bolt that fits the shaft thread diameter of the Spider connection; refer to Figure 31. The eye bolt connected to a crane hook allowed the column to sit straighter, making alignment easier.

Figure 31: Female Eye Bolt to fit Spider Shaft Thread

Vertical height was also seen as an issue, as most mass timber elements seem only to have positive tolerances, i.e., length or width greater than the nominated dimensions. In this case, pre-made metal shims of various thicknesses could be included with the Spider connection to allow on-site adjustment to height. However, shims only allowed the addition of column length; therefore, columns would need to be planned shorter to allow this to occur.

Finally, issues include the ability to remove some of the radial arms of the Spider connection when required to fit in bathroom pods or adjacent to openings for services, stairs or the external walls, is required. The effect on the Spider connection capacity was unknown.

8.2 Rotho Blaas Pillar Connection

This column capital is straightforward and has very few issues. The main concern is that the bearing area of the Pillar base for the floor panel is small and limits the capacity of the connector to support the adjoining floor panels. Maybe a plate to increase the bearing area is required that could be fitted when needed—otherwise, the same issue as the Spider connection regarding height adjustment. Again shims of multiple thicknesses could be made available to allow adjustment to height, as needed.

8.3 XLam Band Beam System

This system was the most expensive of all the investigated post and plate systems. The additional cost is due to the extra CLT required for the band beam. This cost significantly increases the system cost; however, it was recognised as cheaper than the post and beam mass timber system.

It was seen as a system that had merit when the centre infill system was exceeded, i.e. when the width of the CLT panel limits the grid spacing in one direction - two CLT panel widths. Only the Band Beam system could provide a solution for grids greater than this. However, there are limitations on the Band Beam's grid spacing as the Band Beam itself is limited to the maximum press depth of the CLT manufacturer. Block bonding (gluing together) the CLT, Glulam or LVL billets is seen as a solution to this issue; refer to Figure 32.

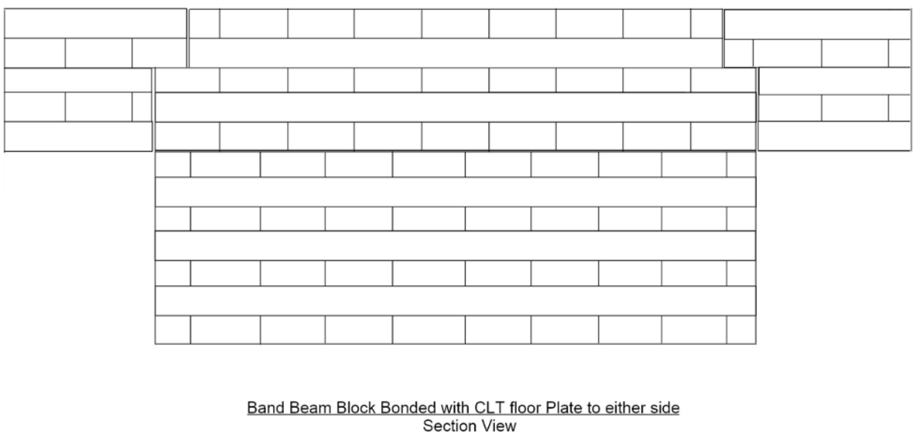


Figure 32: Block bonded Band Beams (Image credit: TDA)

The other aspect is the number of screws needed to bind the CLT floor plate to the Band Beam. In the design example, each Band Beam required 900 screws to be installed at approximately 60 to 90 secs each. The installation of the screws was seen as a significant time consumer. A bigger crew size can increase the speed of installation; however, this means a lumpy work schedule, with peaks and troughs in demand for the extra labour.

An alternative connection system was considered using Rotho Blaas Shape Metal; refer to Figure 33. To achieve the clamping force to squash the two wood surfaces together requires screw spacing at 12 diameters or around 100 mm centres. This solution does not reduce the number of screws required; it increases the number of screws required and consequently was not considered a viable alternative.

Another solution is to create a block bonded CLT Band Beam, made from two CLT elements glued together; refer to Figure 33. The floor panels can be fitted between the deep band beams using standard half-laps.

Figure 33: Rotho Blaas Sharp Metal (Image credit: Rotho Blaas)

8.4 MECHANICAL PARTIAL MOMENT CONNECTION OF CLT PANEL

The project's partners proposed to use adhesive bonding to connect CLT panels, where a moment force must be transferred. The workshop participants identified that building site adhesive bonding is uncommon and often avoided. Various reasons were given, such as the need to prove that a bond has formed before moving onto new work, i.e., part of the Inspection Test Plan required on building sites. The adhesive system also had issues with the long curing time required. This extended curing time potentially caused the installation to take longer than a competing concrete superstructure.

Furthermore, no formal method of proving a bond had formed in the adhesive joint. Sampling and off-site testing were likely to extend further the program time required. Rothoblaas suggested a concrete connection system; however, this had similar issues to adhesive bonding.

A fully mechanical connection was found to be the way forward; however, no practical solution was available. The team embarked on investigating a series of mechanical connections for discussion purposes. The mechanical connection has several functions to achieve; they are

1. It needs to be simple,
2. Have most of the elements installed or the milling occurring within the factory,
3. Use mostly commonly available low-expense materials,
4. The joint must also be able to be fire-rated while retaining the exposed ceiling. Therefore, the connecting elements must be embedded within the CLT or easily covered by fire-resisting materials,
5. The connection must allow for on-site tolerance, such as variation in panel width,
6. The connection system must be easy and quick to install, allowing Inspection Test Program activities to be conducted quickly and efficiently, and
7. The joint does not form a mechanical hinge.

Balancing all of these issues is difficult. The project considered several systems, and they are presented in the following.

8.4.1 Metal Plate Top and Bottom of CLT – Screwed fixed

The system uses a metal plate top and bottom screwed fixed to either side of the CLT panel joint; refer to Figure 34.

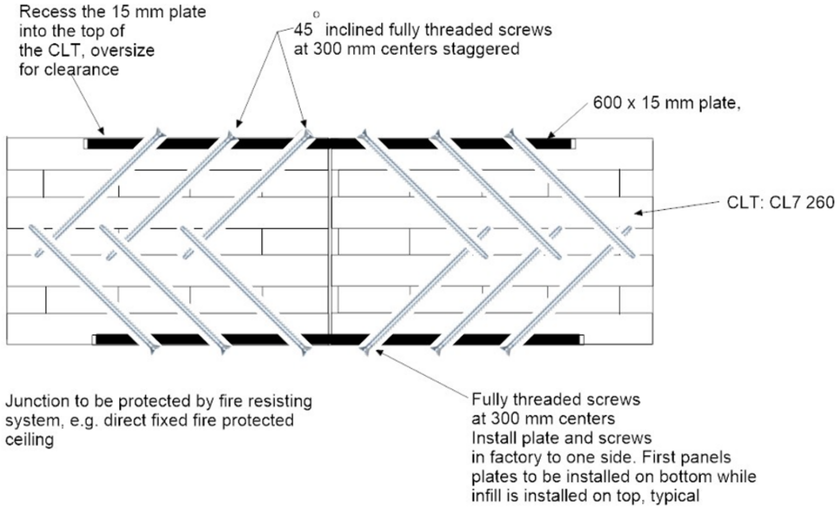


Figure 34: Mechanical Connection using Metal Plates and Screws

Pros	Cons
Simple and available	Dependent on the installation of many screws
Utilises commonly available materials	It needs to be joined top and bottom of the panel
It caters for some misalignment of panels	Shear capacity unknown
	Not able to be fire-resistant without fire protective coverings

8.4.2 Metal Plate at CLT Edge Connection - Bolt Fixed

The connection uses a metal plate screw fixed to the edge of the joining CLT panel. The joint is formed by bolting the two plates together. One option is with the CLT, and the other is outside the CLT; refer to Figure 35.

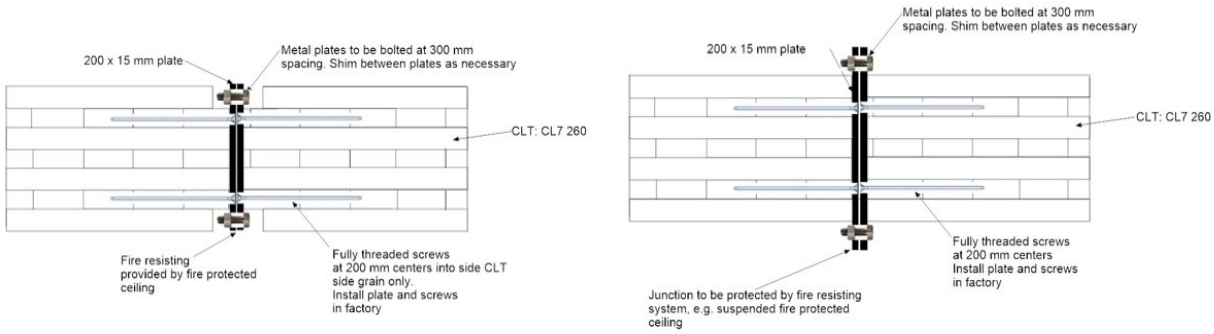


Figure 35: Mechanical Connection using Metal Plates and Bolts

Pros	Cons
Simple and available	It needs to be joined both top and bottom of the panel
Utilises commonly available materials	Shear capacity unknown
	Not able to be fire-resistant without fire protective coverings
	The connection may protrude the top surface of the CLT, becoming a trip hazard

8.4.3 Metal Plate at CLT Edge Connection – Welded

This connection is similar to the bolted plate method described above, but the connection is formed by welding the plates together; refer to Figure 36.

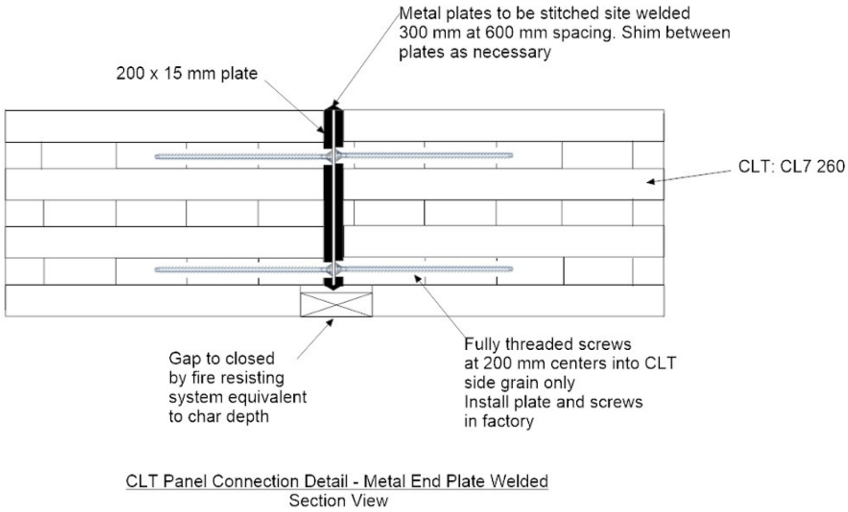


Figure 36: Mechanical Connection using Welded Metal Plates

Pros	Cons
Simple and available	It needs to be joined both top and bottom of the panel
Utilises commonly available materials	Shear capacity unknown
Able to be fire-resistant	Welding on-site adjacent to timber is considered hazardous
Accommodates some misalignment or tolerance issues	

8.4.4 Metal Plate at CLT Edge Connection – Screw and Bolt Fixed

This method uses a plate screwed to each edge of the CLT panel, and the top connection bears on the lower plate via a diagonal slot. A bolt holds the two plates together; refer to Figure 37.

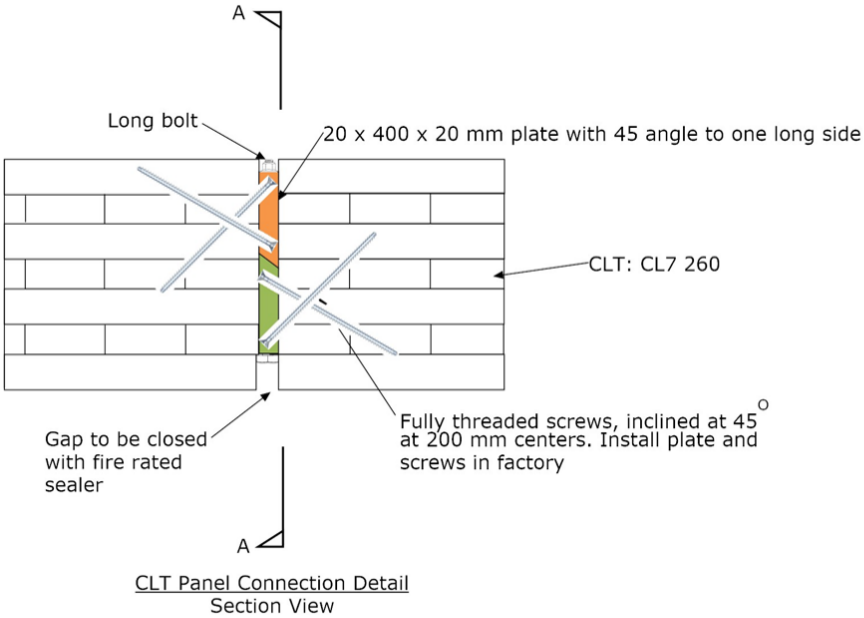


Figure 37: Mechanical Connection using Metal Plates and Screw and Bolt Fixed

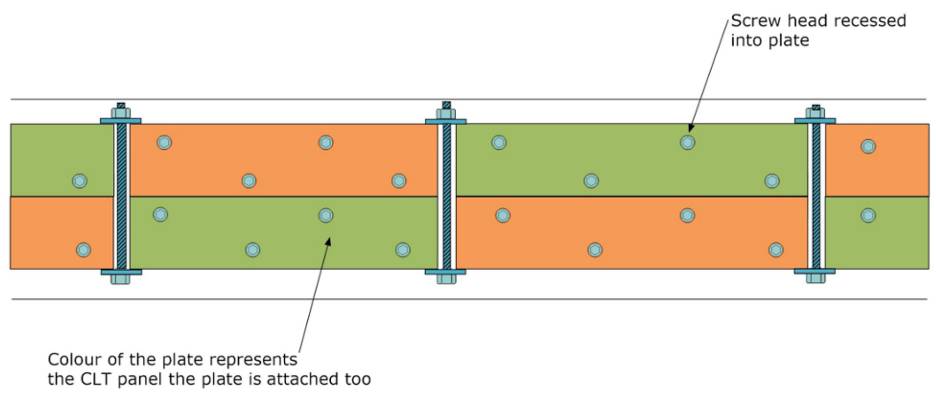


Figure 37 continued: Mechanical Connection using Metal Plates and Screw and Bolt Fixed

Pros	Cons
Simple and available	It needs to be joined both top and bottom of the panel
Utilises commonly available materials	Unknown capacity
Able to be fire-resistant	It does not account for tolerances or misalignments
Shear capacity improved	

8.4.5 Metal Plate at CLT Edge Connection – Quick Connect Fixed

This system utilises a tension tie formed by the Quick Connect moment joint concept, developed by the Structural Timber Innovation Company. The compression force is transferred by CLT panels bearing onto each other; refer to Figure 38.

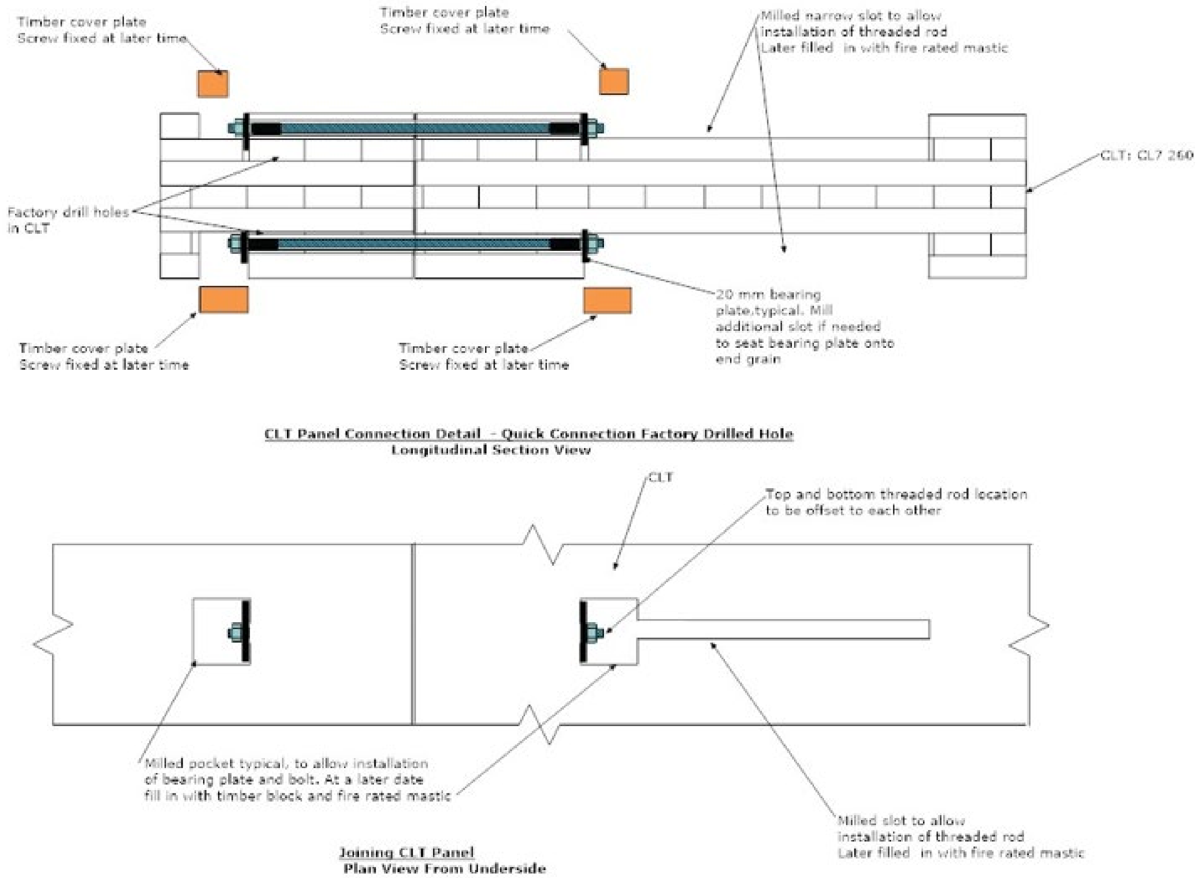
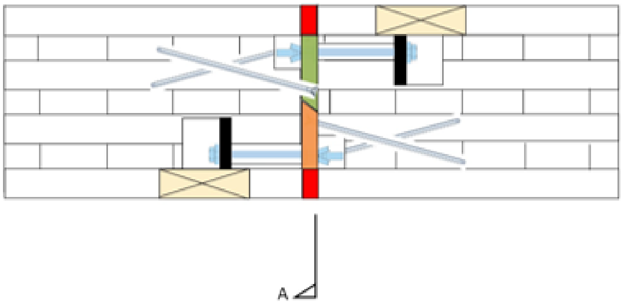


Figure 38: Mechanical Connection using Quick Connect Tension Tie

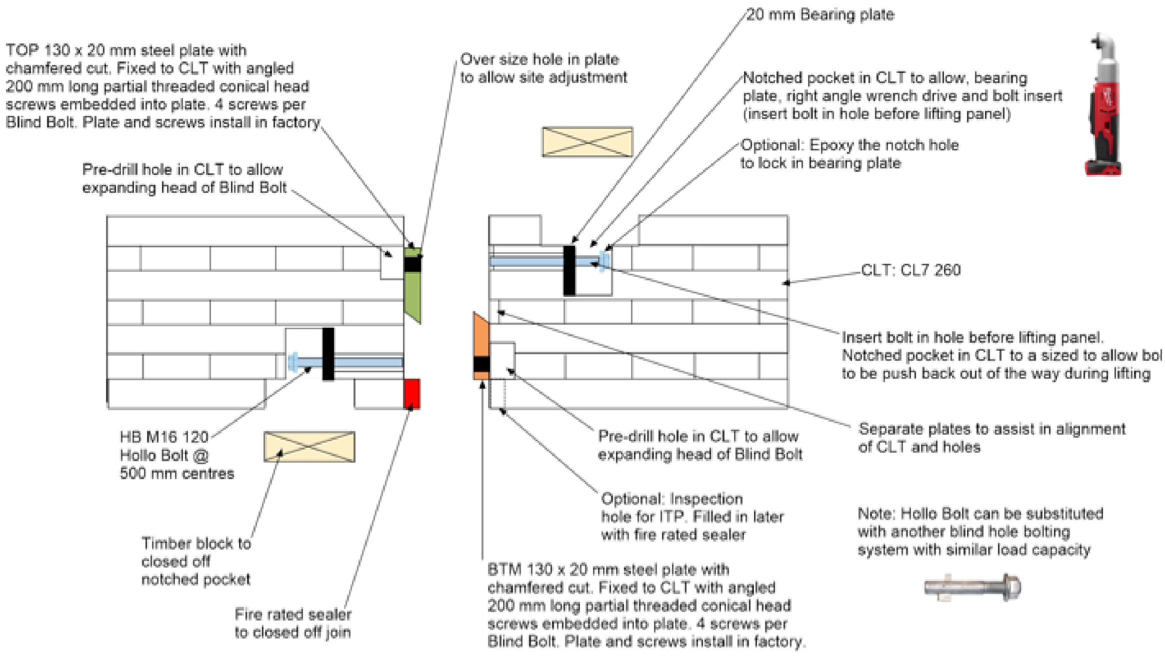
Pros	Cons
Simple and available	It needs to be joined both top and bottom of the panel
Utilises commonly available materials and components	Unknown capacity
Able to be fire-resistant	Shear capacity unknown
	It does not account for tolerances or misalignments

8.4.6 Metal Plate at CLT Edge Connection – Blind Bolt Fixing

This method utilises a metal plate connected to the edge of the CLT panel. A connection is formed by the neighbouring panels utilising a blind bolt through the metal plate that is screw fitted to the adjoining panel. The bolt end expands by tightening the blind bolt, locking it into the plate and drawing the joint together. The connection is located top and bottom of the CLT joint, and compression forces transfer by relying on the bearing of the edges of the CLT. The metal plate edges are designed to lock together and provide bearing and shear support. Refer to Figure 39.



CLT Panel Connection - Blind Bolt Plate Connection
Section View



CLT Panel Connection - Blind Bolt Plate Connection Details
Section View

Figure 39: Mechanical Connection using Metal Plates and Blind Bolt Fixing

Pros	Cons
Utilises commonly available materials	It needs to be joined both top and bottom of the panel
Able to be fire-resistant	Connection capacity unknown
Accommodates some misalignment or tolerance issues	Complex connector
Shear capacity improved	The blind bolt may not be easy to insert

8.4.7 TimberLinx Tube and VGU Plate

This system utilises the TimberLinx tube, a proprietary system that utilises an expanding pin into a metal tube. The top connection uses a Rotho Blaas VGU plate, refer to Figure 40. The CLT panels are half-lapped for alignment and shear transfer.

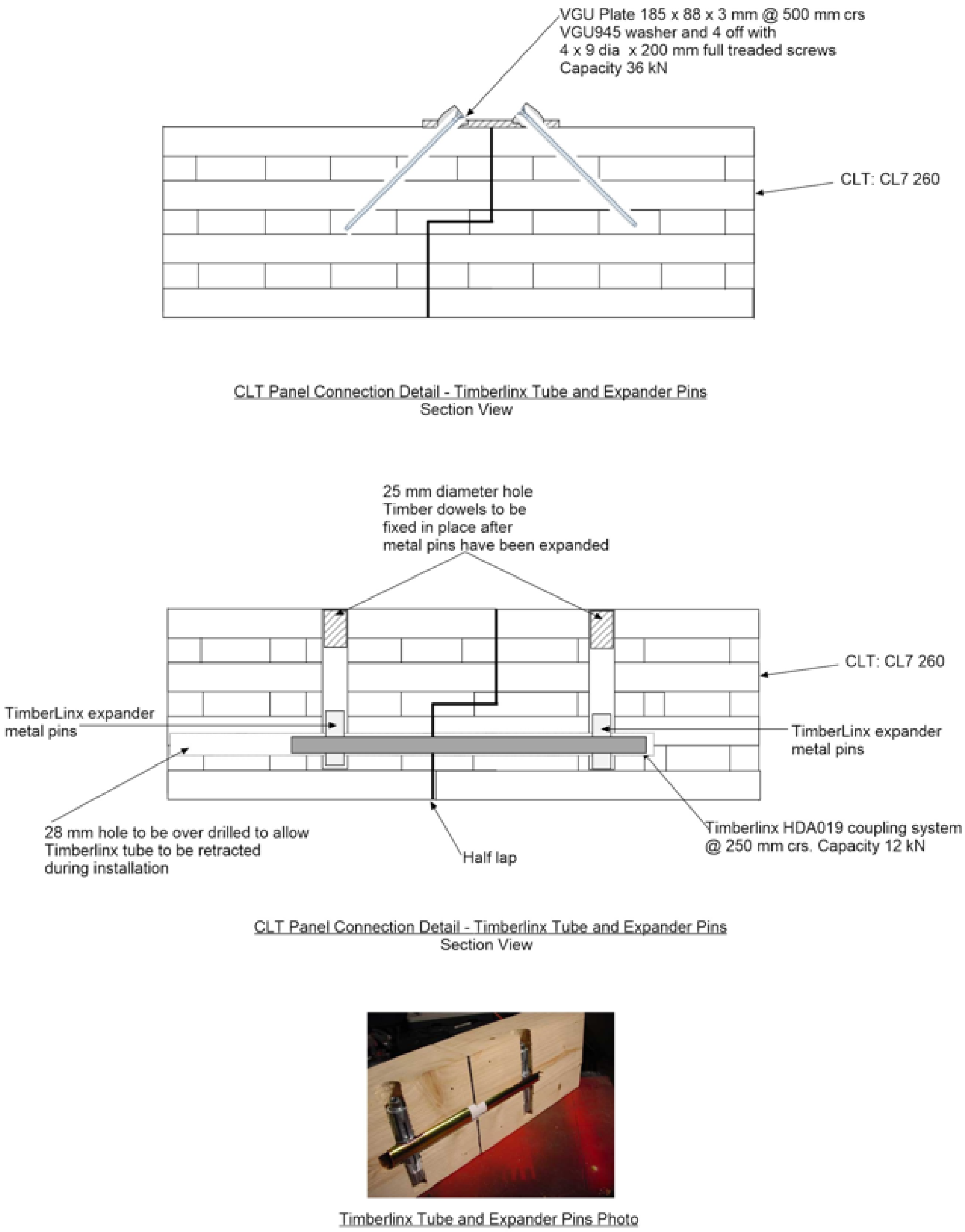


Figure 40: Mechanical Connection using TimberLinx Tube and VGU Plate

Pros	Cons
Can be joined for above the panel	Connection capacity of TimberLinx in low
Able to be fire-resistant	Complex connector system
Accommodates some misalignment or tolerance issues	Feeding the tube into the neighbouring panel when being installed may be difficult
Shear capacity improved	

8.4.8 Circular Hollow Section Coupler

This system is based on the Stalhylsa circular joiner discussed in the Swedish Wood Manual [3]. It features two large circular hollow sections slotted to fit over a threaded rod epoxied into the end of the CLT panel. The CLT panels are half-lapped for alignment and shear, and a half-moon washer and nut are placed over the threaded rod to form the connection. Refer to Figure 41.

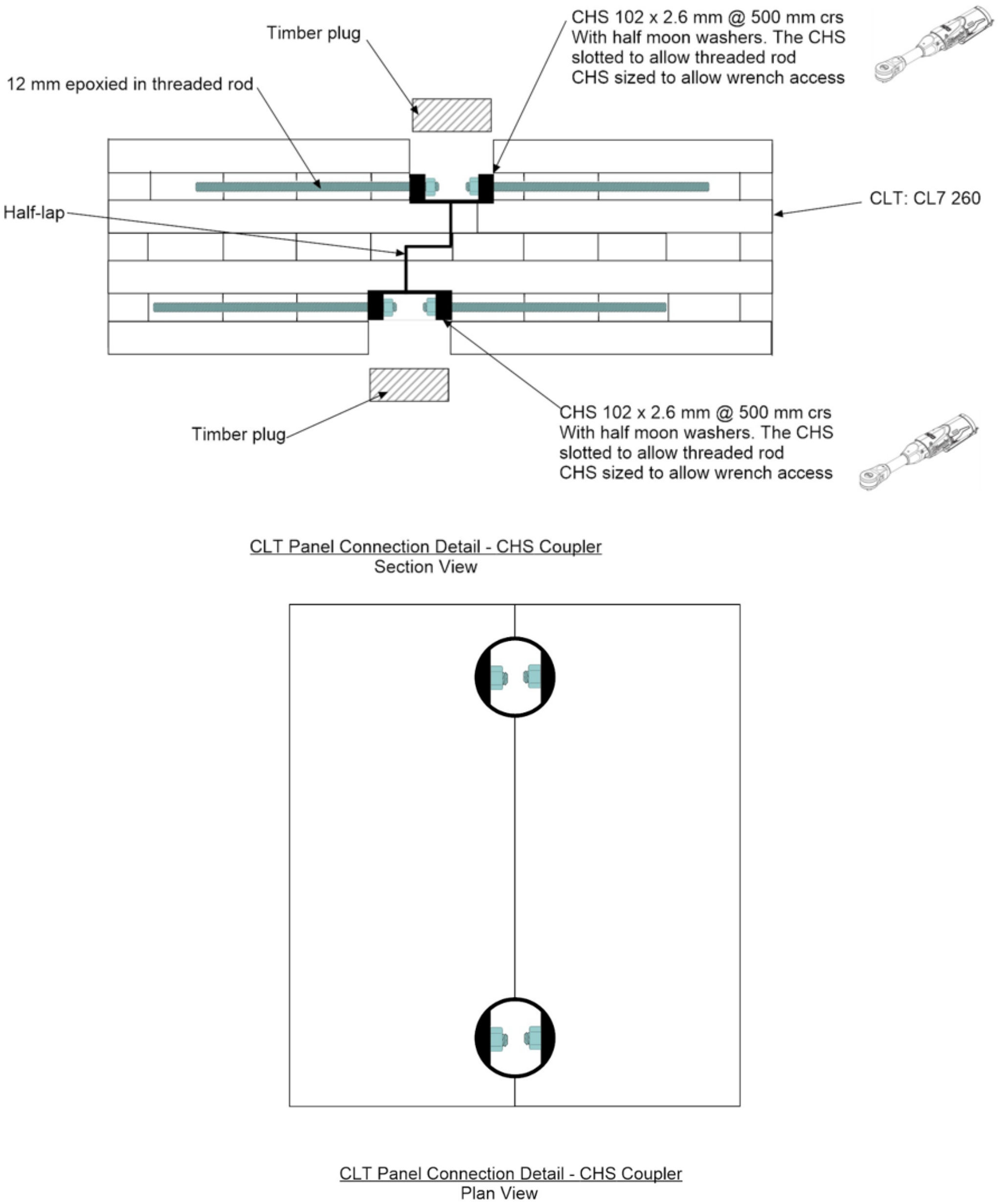


Figure 41: Mechanical Connection using CHS Coupler

Pros:	Cons
Simple and easy to install the system	Connection capacity unknow
Able to be fire-resistant	
Use readily available parts	
Accommodates some misalignment or tolerance issues	
Shear capacity improved	

This system was preferred and used through the final design option for the various post and plate mass timber systems.

8.5 COSTS PLAN

The cost plan conducted for the project just considered the cost to erect the superstructure of all systems considered against a traditional concrete post-tension slab system. No costs were considered for preliminary expenses or margins. The Edge Supported system proved to be the cheapest of all the systems considered, followed by the Centre Supported /Infill system. Both these systems were cheaper than the concrete system. However, the Band Beam system was more expensive than all systems, including concrete.

The Band Beam system was expensive because it had more material, connectors to install, and labour requirements than the other timber-based systems. The Centre Support/Infill system program time was less than for the Band Beam of Edge Supported system; however, it had a larger crew size than the Edge Supported system, but the same size for the Band Beam System.

Furthermore, a 40 per cent inefficiency penalty was applied to all timber options, which increased labour costs considerably. However, the labour cost percentage against the total superstructure cost was only around 5 to 6 per cent. This finding suggests timber-based systems are less prone to program inefficiencies than labour-intensive construction systems, such as concrete. This finding is crucial as it points to the risk of labour cost blowout using timber is less when compared to other non-timber systems.

All timber options program time was considerably faster than the concrete option. Where the Preliminary costs and scaffold costs were included, the timber options price gap to concrete increased considerably, even for the more expensive Band Beam option.

8.6 DIGITAL MODELLING AS A DESIGN AID

The research team found that developing digital models required more thought than required for the typical design process. So much so that it was comparable to the amount of thought required to construct an actual building. The process enabled the discovery of clashes, trying out various methods to construct and establish detailed programs. All of this allowed the refinement of the tasks that improved the overall system.

Therefore, the digital modelling process resolved many potential issues before they occurred. The research team recommends that this approach is utilised where a new construction system is being considered, such as the post and plate systems discussed in this report.

9 CONCLUSION

The project aimed to develop a buildable and efficient construction sequencing, in digital form, of two new mass timber building system enablers, Rotho Blaas' Spider and Pillar system and XLam Australia's Band Beam system. Both systems were reviewed via two workshops of timber knowledgeable contractors and installers and a detailed investigation by the research team. The outcome resulted in three refined post and plate mass timber systems, utilising the Rothoblass and XLam systems, as demonstrated in digital form.

The process of conducting digital modelling and discussion with timber knowledgable installers and contractors functioned well to resolve issues. Issues identified include

- Carry out detailed milling and installation of fixing, firstly within the factory or adjacent to the building project, never at the work face
- Where it is not possible to avoid the installation of fixings at the work face, the preference is to install the fixings from the proceeding storey's floor
- Adhesive joining systems were not preferred as they potentially had on-site issues, such as difficulty to bond in wet weather or cold temperature, long curring time extending the building program's schedule, methods to confirm if bond adhesion had occurred, and the need to provide falsework for support until the bond had formed
- Rotho Blaas' Spider system required
  - An ability to be fixed to the proceeding storey column, allowing the Spider connection to be pre-installed onto the floor plate above
  - Use stud fixings to the next storey column base plate, removing the need to install bolts into blind holes
  - An understanding of the system's capacity, in the situation in which, for practical reasons, some of the arms of the Spider connection are removed, such as near external walls, voids or avoiding bathroom pods Chassis
  - The floor area load capacity of the Pillar system could be improved
- XLam Australia's Band Beam
  - The system's cost is suited to a large grid spacing. Work is required to develop solutions that suit grids spacing 8.4 x 8.4 m or greater
  - A system that utilises fewer screws to connect the floor plate to the band beam is preferred.
- Economies of post and plate systems were dependent on the reliance on the limited use of falsework for temporary support.

The cost of each post and plate superstructure was examined against a traditional concrete post-stressed flat plate system. Two of the systems were found to be substantially cheaper, while the XLam's Band Beam was slightly more expensive. Where the building's "Preliminary" costs (the building's expenses other than materials, labour or overheads) and scaffolding expenses were considered, all the post and plate systems, including the band beam option, were cheaper than the concrete option.

A cost-effective mechanical joining system of the CLT floor panels is a further limit that prevents these systems from being commercially established. Several mechanical joining systems were investigated, and the circular hollow section (CHS) coupler showed the most promise. However, the system's capacity is unknown and requires further research before it can be commercially used.

The final digital models can be found through the following hyperlinks.

- Band Beam
- Centre column support and Infill
- Edge Supported

10 REFERENCES

1. Cross Laminated Timber Sales Volume Report, TDA, 2022
2. Rawlinson Construction Cost Guide 2022, Rawlinsons, 2022
3. The CLT Handbook, Swedish Wood, 2019

APPENDIX A

This Appendix contains workflow for the three Post and Plate timber systems investigated, including a Gant chart for each, used to determine the floor cycle and overall construction time.

A.1 ON-SITE INSTALL PROCESS FOR EDGE SUPPORTED SYSTEM

Overview

- Overall floor cycle resources:
    - 8-person crew (possibly 9), including
        - 2 workers on the ground (in the loading area), finding and hooking up columns and panels. One person will act as a crane dogman. Potentially, one of these workers can also be deployed to screw panels late in the floor cycle process
        - 6 workers on the deck were installing the floor level above, as follows
            - 4 installing columns, panels and screwing of CLT edge joints and pillar connections (this crew includes Dogman on the main deck and crew supervisor)
            - 2 installing bearers, ties, end jointing and then removing bearers/ties
    - Single tower crane which does all lifting to insitu

- The overall floor cycle breaks down into 5 sub-cycles (sometimes overlapping) and is to be read in conjunction with the Gant chart:
    1) Column lifting/install cycle
    2) Temporary bearer and tie placement (shown in Gant chart as 2a for installing and 2b for removing)
    3) Panel lifting/installing cycle
    4) Joining cycle (shown in the Gant chart as 4a for panel end joints, 4b for screwing long edges together)
    5) Execute Inspection and Test Plans (ITPs) for primary structure/screw count at brackets/screw strength/glue joint strength check)
- Total floor cycle 2 days approx. (i.e. 860 minutes of minimum process time). This may vary depending on experience/pre-planning/ITPs time. The 2-day cycle described in the Gant chart may need extra time commensurate with the level of team experience. In the order of an extra 40 per cent is a speculative amount for wasted/indirect time, which may include: poor floor cycle changeover time, lack of synchronisation between subcycles, unwanted waiting time, materials not ready, rework, confusion, daily setup time for work processes, replenishing stores, workers getting to work face, crane deployed from the intended install process.
- The edge support system has relatively low spans, increasing the number of columns required. This small grid spacing adds significantly to installation time. Columns are relatively slow to install by crane, and each column base bracket requires 12 screws plus the installation of the disc plate (probably only be fixed by one or perhaps two workers due to confined space). It is recommended to develop a non-crane based method to increase the speed of columns (potentially labour based, combined hand operated forklift technology)
- Permanent Bracing: Not allowed at this stage, but the same for all building schemes considered.

Subcycle 1: Column lifting/installation cycle

Features and assumptions

- Assumes bundles of columns are craned onto the deck and then secondarily craned individually into position (Note: faster and easier for the crane operator to see what he is doing in the second lift than lifting every column from the ground individually).
- Assume Columns are 3.6 x 0.4 x 0.4 m. The Pillar connector will cover a 240 mm base area.
- Allow 13 min per column cycle; 40 columns in total.
- GLT column has part of Pillar connection pre-installed off-site - refer to detail below. For instance, the bottom of the column has a "top plate" with protruding studs pre-installed offsite, and a "bottom plate with cylinder" is also pre-installed offsite on the top of the column.
- On-site, the "fastening plate" is fitted over the cylinder of the column on the floor below and screwed (12 off) to the CLT floor, and then the "disc" is screwed to the top of the cylinder head.
- The following storey column is dropped onto the disc such that studs poke through 4 holes into the disc. Site workers then screw this off, tighten it immediately to secure it, and allow it to be freestanding until bearers and ties are placed (refer to Pillar diagram for greater clarity).
- Columns can be temporarily self-supporting (as advised by Rotthoblass) until push-pull props, bearers and ties are installed and adjusted
- Appropriate removal time of temporary props is assumed in the Gant chart.
- Assume the tower crane is used to lift columns.

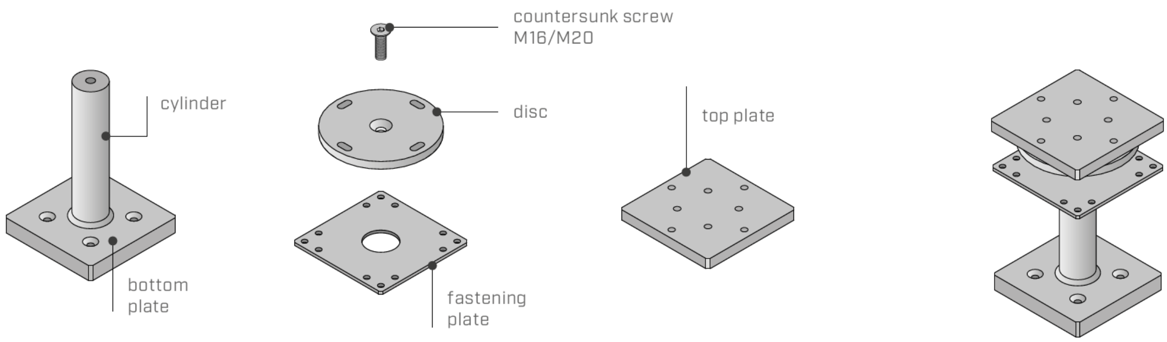


Figure A1: Pillar Connection Components

Process

1) Crane delivers bundles of 10 columns approx. to the deck (10 minutes x 4)
2) Typical column lifting/install cycle (12 minutes)
    a. Install the fastening plate (12 screws) and disc (1 screw) with a 1 or 2 man crew. Allow 4 minutes in total.
    b. Concurrent to A, hook up a column from the stack. Assume 1 minute of cycle time using 2 workers.
    c. Air time to insitu location. Assume 0.5 minutes of cycle time (Note: this is a conservative average).
    d. Land column insitu. Assume 1 minute of cycle time and 2 workers, i.e. workers use tag-lines or similar to locate column base into lower Pillar holes
    e. Nuts are applied to column base studs. Assume 3 minutes of cycle time (assuming 2 workers).

f. Concurrent to the above, two other workers prepare and attach the push/pull props and plumb to perimeter columns. Assume 2.0 minutes concurrency with previous items and 2.0 minutes of extra cycle time.
g. Crane releases column. Assume 1.0 minutes of cycle time and 2 workers
h. Return to the appropriate stack and repeat. Assume 0.5 minutes of cycle time

Cons/Comments

- Pillar connection takes a long time to install insitu due to the many screws and number of separate pieces involved
- Is it realistic that the Pillar base connection is able to support the columns as safe and freestanding columns until bearers/ties are in place?

Subcycle 2: Bearer, tie installation cycle

Features and assumptions

- Bearers (36 in total) and ties (30 in total) are (tower) craned onto the deck in mixed bundles, at 22 per bundle x 3 bundles; delivered at 25%, 50%, 75% points (approx.) along the centre line of the floor plate length.
- Potentially use a motorised pallet trolley to move bundles around on the deck.
- Bearers are 3,300 x 350 x 75 mm lightweight softwood floor trusses, and ties are solid timber 6,600 x 100 x 75 mm. Both aim to be lifted manually into position.
- Bearers and ties are dropped into Rotho Blass's Lock T connectors – used as temporary connectors.
- The Gant chart shows the appropriate removal time of temporary bearers and ties.

Process

Bearers and ties are installed as a continuous flow at a staggered start after column installation commences, i.e. after 3 rows of columns are installed. This process, therefore, happens mainly, concurrently with the column installation:

1) Crane delivers bundle to the deck (12 minutes)
2) The work cycle for bearer/tie install is 4 min average per piece (36 bearers, 30 ties), including:
   a. Moves trolley to bearer/tie locations;
   b. Workers lift bearers/ties vertically into position; hook bearer/tie ends onto pre-located T Lock connectors (methods do not require lifting from height; therefore, no edge protection).
3) Repeat until all bearer/tie rows are installed.

Cons/Comments

- Bearers and ties are time-consuming if using mechanical lifting, i.e. must load genie lift, move it around, and weave in between the column grid. Removal of bearers and ties also takes considerable time.
- Adopt the use of lightweight deep floor trusses that are light and can be manually lifted by hand, resulting in faster installation. Also, consider rigid cross "X" brace assemblies that use a quick fix to column faces and don't require working at heights

Subcycle 3: Panel lifting/installation cycle

Features and assumptions

- Panels are lifted/landed on top of columns assuming Pillar connection is pre-installed on columns at the factory.
- Takes approximately 12 mins per panel cycle (max panel size 13.33 x 3.33 x 0.220 m deep). Crane cycle time will be similar for similar sizes.
- Outer edge panels have edge protection added on the ground (assume a similar temporary fabrication bay around the truck, as used for “centre line, infill system”). Due to overlap with other tasks, it should not impact crane cycle time.
- Edge protection is applied around the perimeter and cuts across the halfway line in the floor plate. This configuration allows the end jointing and screwing-off of panels to safely proceed in the first half of the floor plate installation whilst the second half of installation proceeds.
- Assume the same crew as Subcycle 1.

Process

1) On-ground, install edge protection to each panel on top of the stack (assume a temporary fabrication bay around the truck/stack, similar to that used for the “centre line/infill” version). Assume:
    a. No extra time was given for the end panels, as the edge protection was the only item added to the floor panel. This activity will take about 4 minutes but can be done whilst the crane cycle below is proceeding
    b. No extra time was given for the side panels (8.2 m), as the edge protection was the only item added to the floor panel. This activity will take about 7-8 minutes but can also be done whilst the crane cycle below is proceeding
    c. No extra time was given for the side panels (13.6 m), as the edge protection was the only item added to the floor panel. This activity will take about 10-12 minutes but can be done whilst the crane cycle below is proceeding
2) Hook up panel off the stack. Assume 2 minutes of cycle time using 2 workers on the ground.
3) Air time to insitu location. Assume 2 minutes of air time (Note: this is an average but will vary due to the height of the building).
4) Land panel onto column heads. Assume 5 minutes of cycle time and 3-4 workers
5) Crane releases panel. Assume 1.0 minutes of cycle time
6) Air time to return to stack and repeat. Assume 2 minutes of cycle time

Cons/Comments

- Panels need to be positioned from below. Doing this accurately may take some extra time setting up the first line and then some further manipulation and accuracy checks to get the setout right.

Subcycle 4: Jointing cycle

Features and assumptions

Two types of jointing used:

- Joining type 1: CHS coupler connectors at 500mm centres at joints between end panels. Bolts sit in pre-machined slots in CLT panels undertaken offsite. Allow 7 couplers, top and bottom, per end panel joint. This activity can be handled by 2 man crew after they complete the bearer and tie installation.

- Joining type 2: 100 mm long 6 mm dia. screws at 300 mm centres to either side of spline board; 8 spline boards. This activity is handled by a full 6 man crew after completing panel installation.

Process

1) Joining type 1.
    a. Assume 2.0 minutes to insert each bolt on top of the panel and tighten, per worker. Therefore, 7 bolts (at 500 crs) at the top of each end joint x 2 minutes/2 workers = 7 minutes per joint
    b. Assume 3.0 minutes to insert each bolt on the underside of the panel and tighten. Therefore, 7 bolts per panel x 3 minutes/2 workers = 10.5 minutes per joint
    c. Assume workers start underneath (as there is no complete edge protection until column row 6); then proceed to start on top once finished.
    d. Since there are 9 end panel joints in total, therefore all underneath joints will take 95 minutes, and the top joints will take 63 minutes (assuming 2 workers),

2) Jointing type 2: 100 mm screws at 500 mm crs, including 2 rows on either side of 20 m capping plate. Therefore, assume (20/0.5 + 1) x 2 screws = 80 screws per plate. Also, assume screws@0.5minutes to insert. Therefore if using 4 men crew, it means 10 minutes/plate x 8 plates = 80 minutes.

Cons/Comments

- Underneath joints, assume 1 man is holding the ladder and moving it whilst the other is doing the tightening. It's probably an awkward task, but it can be made easier by using a cordless wrench power tool.

Subcycle 5: Execute Inspection and test plans (ITPs)

Features and assumptions

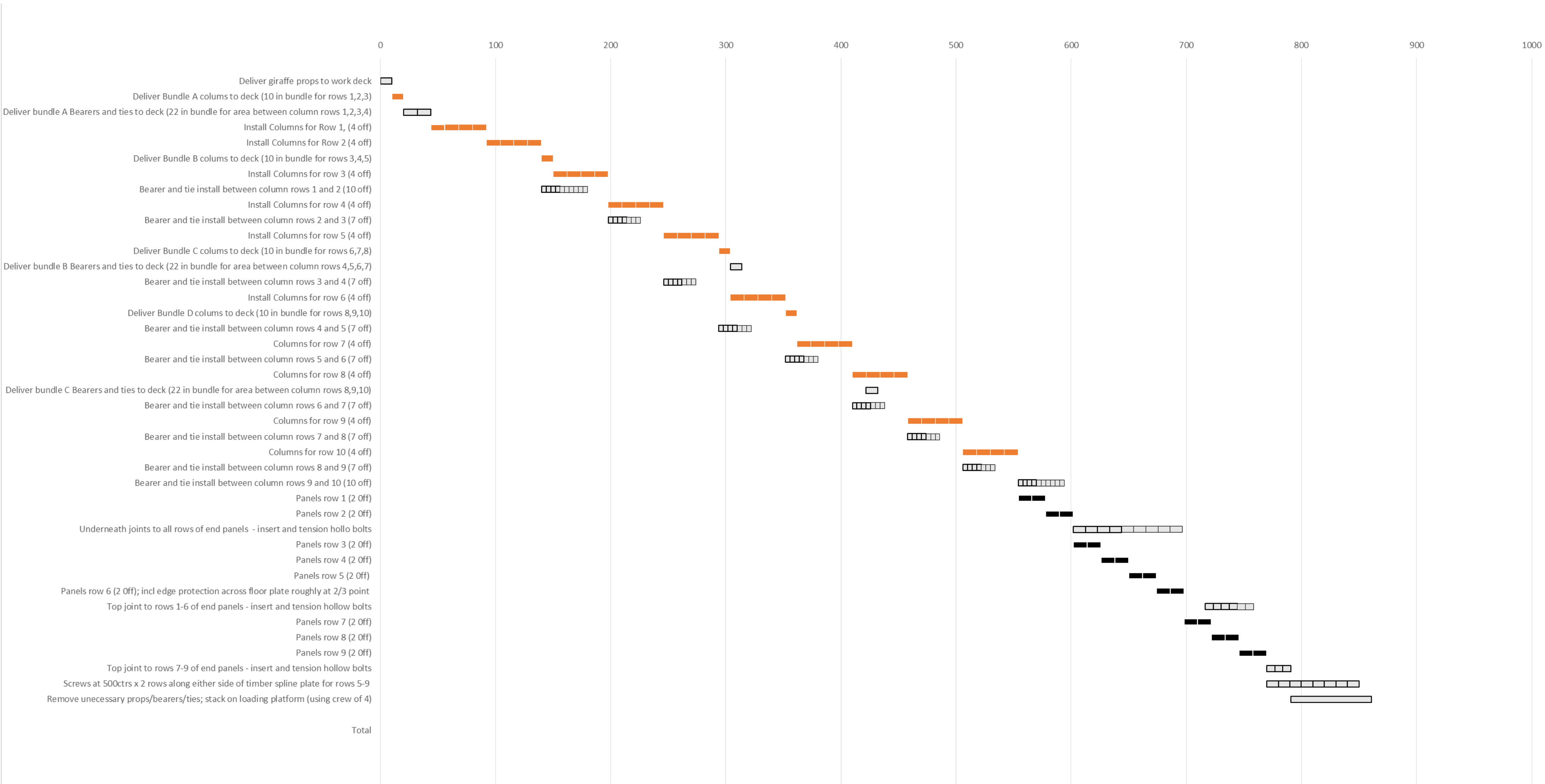
- Probably needed for main structural members and the joint connectors
- Bracket screw count/screw strength check
- Inspection is currently not shown in the Gant chart but is assumed to occur towards the end of screwing-off and/or during bearer/tie removal.

Process

1) A structural engineer comes to the site to inspect – probably upon completion of Sub-cycle 4.
2) A formal engineer's certification is required before starting on the next floor.

Cons/comments

- The timing of the engineer's inspection may be on the critical path. It needs to be timed to occur before it affects safe loading on the next floor.



Legend: Subcycle 1: lifting/installing columns (crew of 4)
Subcycle 2: Lifting/installing bearers and ties (crew of 2)
Subcycle 3: Lifting/installing panels (same crew as subcycle 1)
Subcycle 4a: Jointing of panel ends (same crew as subcycle 2)
Subcycle 4b: Screwing of spline boards along panel edges (same crew as subcycle 1)
Subcycle 2b: removing bearers and ties (same crew as subcycle 2)

Note 1: Bars in the gant chart show separate segments where multiple crane lifts

Note 2: Bracketed items means number of segments lifted

A.2 ON-SITE INSTALL PROCESS FOR CENTRE SUPPORT INFILL SYSTEM

Overview

- Overall floor cycle resources:
  - 12-person crew including 4 in fabrication bay 1, 4 in bay fabrication bay 2, and 4 on the live deck
  - Tower crane, which does all lifting from fabrication bay to insitu
  - Mini crane for on-ground fabrication only (i.e. small remote control crane used by fabrication crew, refer to Figure A2.

Figure A2: 10 Tonne mobile crane (Image credit: Melrose Cranes)

- Overall floor cycle breaks down into five (sometimes overlapping) sub-cycles to be read in conjunction with the Gant Chart, as follows:
  1) On-ground fabrication cycle of the floor plate and column assembly (T-table fabrication). Two fabrication bays were used (Note: a single fabrication is also possible, albeit not modelled in this report)
  2) "T-table" lifting cycle (should occur concurrently to subcycle 1)
  3) Infill panel lifting cycle. Note: Before the last floor infill panel is placed, use the tower crane and stillage to re-locate temporary hardware from the floor level (remove unnecessary fall protection and return to fabrication bays; lift shoring props, ladders, and other ancillaries to next floor level).
  4) Jointing cycle Note: this includes CHS couplers and X-fit connectors; jointing time may affect the beginning of the next floor level, and if so, should begin jointing as soon as possible.
  5) Execute Inspection and Test Plans (ITPs) for primary structure/screw count at brackets/screw strength/joint strength check)

- The total floor cycle is 1-2 days (i.e. 645 minutes minimum process time). This cycle time may vary depending on experience/pre-planning/ITPs. The upper end in the range may be needed commensurate with team experience. In the order of an extra 40% per cent is a speculative amount for wasted/indirect time for relatively inexperienced oeratives, which may include: poor floor cycle changeover time, lack of synchronisation between subcycles, unwanted waiting time, materials not ready, rework, confusion, daily setup time for work processes, replenishing stores, workers getting to work face, crane deployed from the intended install process.

- The chosen method assumes sufficient site space for two fabrication bays is available, from which the crane will continually lift/install. For instance, the two bays will keep the crane busy as it will install at roughly double the T-table fabrication speed. This two-bay arrangement may not be possible in dense CBD project locations, so utilising a single fabrication bay is also conceivable. However, infill panels must be placed in an intermingled way between T-table fabrication and installation processes to keep the crane busy.

- Permanent Bracing: Not allowed for at this stage, but the same for all building schemes considered.
- The system utilises Rothoblass's Spider connection system for the floor plate to column jointing; refer to Figure A3.
- The overall amount of fixing in this system creates the need for a larger crew to maintain the speed that would otherwise be unnecessary for other tasks.

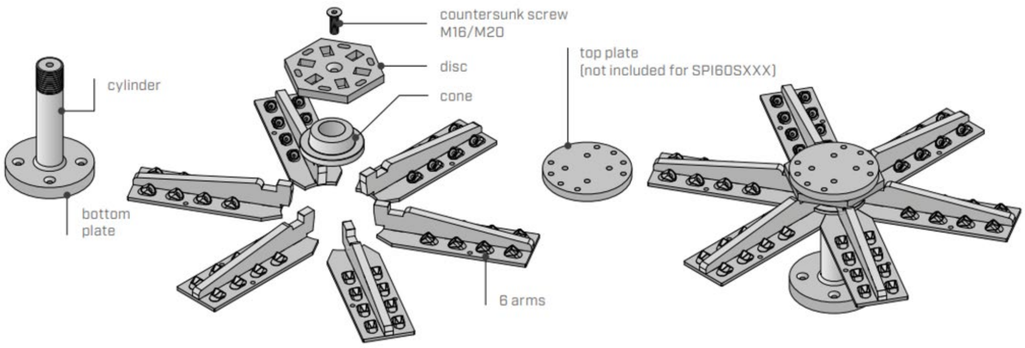


Figure A3: Spider Connection (Image credit: Rotho Blaas)

Subcycle 1: On-ground fabrication cycle to make "T-table" as upright tables (54 minutes)

Features and assumptions

- The proposed method of on-ground fabrication is primarily used because Spider connectors cannot be fixed insitu from beneath. Fixing from beneath is a safe work requirement preferred in Australia rather than fixing on top of the panel. Fixing from beneath also saves on the extent of edge protection required. As a result, T-tables are fabricated on the ground and then lifted into place.
- The proposed method of on-ground fabrication means that only panels involved in "T-table" fabrication require fall protection, i.e. not required on infill panels except for perimeter ends of infill panels.
- 54 minutes per cycle for 10.0 x 3.4 x 0.260 m "T-table". Fast erection of edge protection is critical in achieving this cycle time.
- The process makes use of two staggered fabrication crews. This arrangement means one "T-Table" is produced every 27 minutes (target time only) to feed the crane lift/installation of a similar cycle time.
- The "T-table" is lifted with fall protection in place.
- Assume each fabrication bay includes a 4 worker crew.
- Assumes panels are pulled from a horizontally packed stack nearby.
- Upright "T-table" means it is easier to keep assembly stable when lifting it, i.e. table and especially the columns are already in the vertical position; therefore, no rotation of assembly occurs.

Process

1) In the fabrication bay, prepare two columns using the mini crane to place columns into upright jigs ready to accept the panel on top. Assume each column is 3.3 x 0.5 x 0.5 m. Assume 2 x 4-

minute lifts; 8 minutes in total. Crew member(s) assist while others check/prepare/restock during this period.

2) Mini crane moves panel from stack to fabrication bay. The bay has a scaffold set up to about 2.7 m off the ground, plus 1.0 m edge protection handrails. Assume scaffolding is on a minimum of 3 sides and is wide enough for workers to walk around and for the storage of fall protection panels, Spider connections and ancillaries (1.5 m approx.). The panel sits about 600 mm above walkway height for convenient work height and to allow access beneath for fixing prop brackets. To stabilise the "T-table," the scaffold is designed to take some of the temporary load of the panel. Assume 7 minutes to lift the panel onto columns. Crew member assists while others check/prepare/restock during this period.
3) Four crew members begin fixing the Spider brackets. Begin by moving pieces to the installation location and then hand install the cone, disc and Spider's arms. Then fix 24 screws into each Spider (Note: this is only half of the required screws for the full Spider; the rest will be completed later, once the T-table is insitu). Assume 12 minutes of total time-based on 2 workers per Spider.
4) Following Step 3, four workers fix the push-pull props brackets onto the underside (near the edge) of the "T-table" panel. (Note: scaffold support of panel needs to be clear of this location, and the actual push-pull props will slip into these brackets once insitu, during subcycle 2). Assume 6-8 brackets fixed by 4 workers. Assume 3 minutes added to the total time.
5) Following Step 4, 4 crew members begin placing fall protection. Note: each fall protection panel is 2.4 x 1.1 m; each vertical post in the panel (2 per panel) has a flange requiring 4 x screws face fixed onto the top of the panel. Assume 4.0 minutes to install each panel if using 2 workers to install. Assume 12 panels @ 4.0 minutes/2 crews; therefore, 24 minutes are added to the total time.

Cons

The system arguably uses more edge protection than the minimum due to the full perimeter of each T-table requiring edge protection.

Subcycle 2: "T-table" lifting and insitu positioning cycle (29 minutes)

Features and assumptions

- Takes approximately 29 min per cycle for 10.0 x 3.4 x 0.260 m "T-table".
- This sub-cycle leads the overall floor cycle process in so far as it is working continuously, and so other Subcycles (1 and 3) are tailored to meet this need. For instance, this cycle represents the unit of time (the tempo) that Sub-cycle 1 and 3 must synchronise with.
- Assumes the tower crane is used.
    - Assumes 4 man crew on the deck, i.e. the deck where "T-table" will land.
    - Assumes one Dogman will also be on the deck (preferably part of the main crew if possible)
    - Assumes another Dogman will be on-ground (preferably part of the on-ground crew)

Process

1) Hook up "T-table". Assume 4 minutes to total time.
2) Air time to insitu location. Assume 2 minutes of total time (Note: this time period will vary due to the height of the building).
3) Concurrent with steps 1 and 2, the insitu work crew are securing the base bracket for 8 push-pull props on floor level already in place. Assume 4 workers where 1 worker per bracket takes 3

minutes, therefore 6 minutes if assuming 2 brackets per worker. Note: this does not add to total time due to concurrency with Steps 1 and 2. This task may also take longer and if so, can be completed concurrency to step 5.

4) Hover and then land panel insitu. While the panel is hovering, assumes 3-4 workers use drag straps or similar to locate column bases into the Spider's disk plate. Assume 5 minutes total time (inclusive of 2 columns).
5) Secure tops of push-pull props to the underside of "T-table" panels to stabilise the "T-table". Assume 4 workers, each completing 2 props. This process includes: clicking the prop head into the pre-fixed bracket and adjusting for the plumb of the "T-table". Assume 6 minutes total time.
6) Crane releases panel. Assume 1.0 minutes of sequence time.
7) Return to the appropriate fabrication bay. Assume 1.0 minutes of sequence time.
8) Concurrent to Steps 6 and 7, workers on the deck fix nuts between the bottom plate and Spider's connection disc.
9) Complete the remaining 24 screws of Spider's connection (12 minutes).

Cons

- The crane is not working hard for the entire 29 minutes, but of note, this only impacts a relatively small number of lifts (i.e. 10 "T-tables" in total)
- The above lifting and installation cycle can be reduced/regulated by reducing the number of Spider screws executed during the lift/installation cycle. Instead, increasing the number undertaken on the ground in the fabrication bays.
- Unclear how fast/simple it is to land columns onto the disc into small holes.
- Ditto fixing of push-pull props – adjusting for plumb may take extra time.
- Any bracing at 90 degrees to push-pull props is not dealt with at this stage.

Subcycle 3: Infill Panel lifting cycle (17 minutes)

Features and assumptions

- Similar process but faster than Subcycle 2, i.e. not dependent on constraints of "T-table"; instead, panels are lifted directly off the truck then placed insitu between the rows of "T-tables directly". Therefore, a simpler process; allow 10 min per cycle irrespective of panel size.
    - Assume the same 4 man crew but now reduced to 2; the other 2 are deployed for jointing cycle on live deck.
    - Assume the same Dogman arrangements as for Subcycle 2.
    - X-fit connectors are used to help align the CLT panels (at joints) during installation.

Process

1. Install fall protection handrails at the ends of the panel (two at each end). This process will be done directly off the stack of panels on the truck (and will have similar scaffolding to Subcycle 1) but will be done whilst the last panel is being lifted/installed (Steps 3-4), so there is no impact on the total time.
2. Hook up panel direct off the truck (2 minutes).
3. Lift to insitu location (1 minute).
4. Nestle the halved joint of the panel down into the halved joints of "T-tables." Assume 3 minutes. As an additional part of this process, install X-fit connectors to pull infill and T-tables joints together. Assume 20 connectors at 1.5 minutes each, adding up to 30 minutes. Therefore, if using 4 man crew, then 7.5 minutes total time to cycle schedule. Note: some additional time is also available whilst the crane is returning to stack and hooking up the next panel to complete X-fit processes

5. Release panel (2 minutes)
6. Return to repeat (1 minute)
7. Before the last floor infill panel is placed, use the tower crane and stillage(s) to re-locate temporary hardware from floor level (e.g. remove unnecessary fall protection and return to fabrication bays; lift shoring props, ladders and other ancillaries to next floor level). Assume this crane lift is included in the 50% efficiency time mentioned previously.

Cons

- Exact tolerances are required to get a neat fit between fixed edges of "T-tables" and drop-in infill panels. Could cut halved joint with slight splay to provide some tolerance.

Subcycle 4: Jointing cycle (331 minutes, most of which is concurrent to other sub-cycles**)**

Features and assumptions

- CHS coupler connectors at 500 mm centres at joints between panel ends and panel sides.
- The CHS coupler has two oversized machined slots/holes in the opposing CLT panels, with preinstalled threaded rod bonded into each hole; all of this is undertaken offsite.
- Onsite, the coupler is dropped into an oversized hole formed by two semi-circular holes in the opposing floor panels (also machined offsite).
- For each connection, allow for the installation of individual half-moon washers, load indicator washer and nut to each threaded rod, i.e. two per coupler. The CHS coupler is installed onsite at the top and bottom of the panel to form one joint.
- This activity can be handled by 6 man crew deployed after T-tables has been completed.

Process

1) For each connection, assume 2.0 minutes to insert a CHS coupler, two half-moon washers, and two load indicator washers onto the pre-installed threaded rods. Furthermore, assume 1.0 minutes to insert two nuts and tighten both nuts. Therefore, 1 connections (at 500 crs) = 3 minutes per connector. For the underside fixings, assume each coupler takes 2.0 minutes extra. Time to install componentry includes moving to the next joint.
2) Apply 391 CHS coupler connectors to the underside of the floor :
   a. centre line panels, end-to-end: 7x5 couplers x 5minutes each = 175 minutes in total. Assume 6 crew, therefore 29.5 minutes of sequence time; this can start 29.5 minutes before infill panel installation begins.
   b. Infill panels at end-to-end joins and also side-to-side joins with centre line panels: (41x8)+(7x4)=356 couplers *5 minutes = 1780 minutes in total. This task can begin immediately after infill panel installation using 6 in the crew. Since the infill panel takes 170 minutes to complete, then for 6 crew x 170 minutes means 1,020 minutes of 1780 is complete by the time infill is complete. The remaining 760 minutes can be done by the entire 12 crew (deployed after infill panel installation is complete); therefore, 63 minutes - this is the only part that adds to increased schedule time. Therefore entire process for bottom is 170 (concurrent) + 63 (extra schedule time) =233 minutes for entire task.
3) Apply 391 CHS coupler connectors to the top of the floor (same as above i.e. (7*5)+(41x8)+(7x4)=391 couplers x 3 minutes each = 1,173 minutes. Assume 12 workers (each working individually); therefore, 98 minutes of program time.
4) Assume workers start underneath (as no constraints waiting for edge protection to be completed); then proceed to start on top once finished.

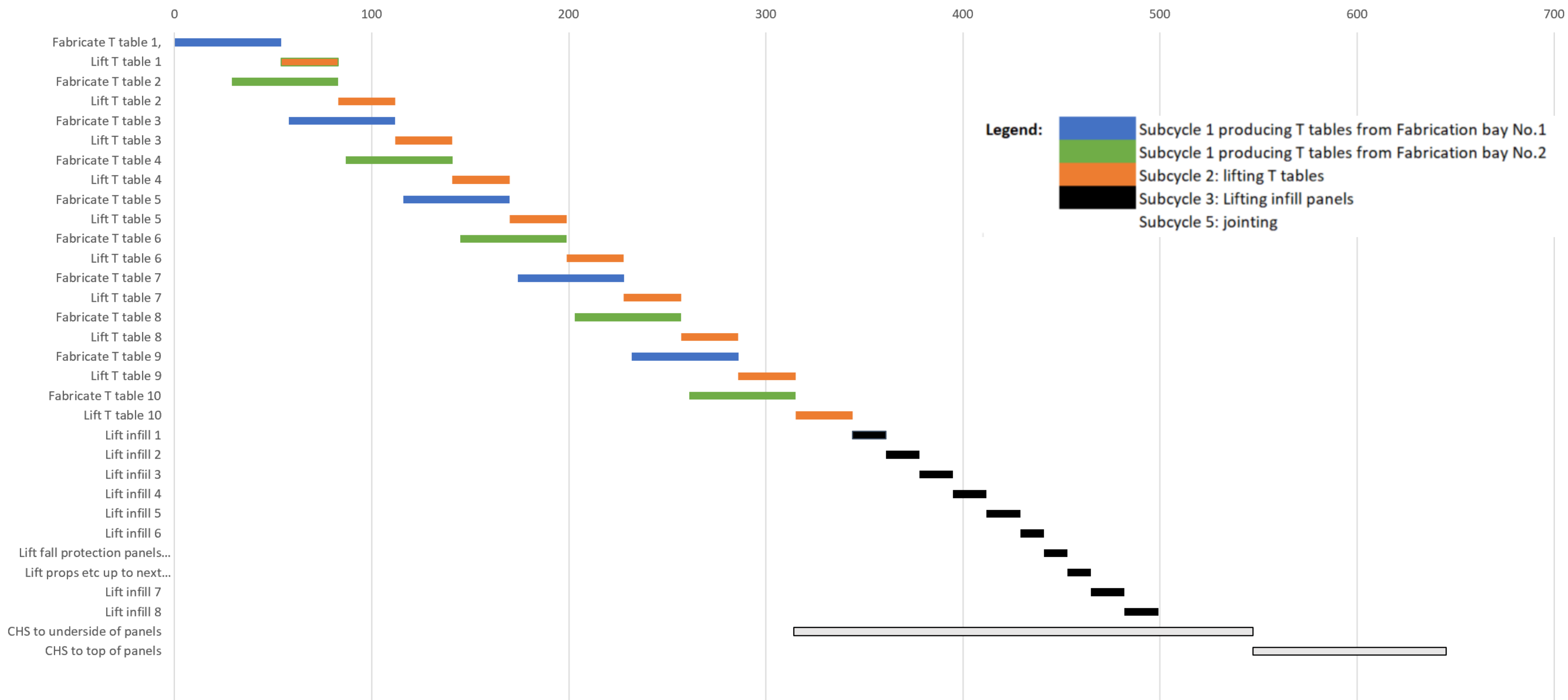
Subcycle 5: Execute Inspection and Test plans (ITPs) (nil minutes)

Features and assumptions

- Most likely needed for column connection and the joint connectors.
  - All nuts need to be checked, aided by a load indicating structural washers.

Process

1. A structural engineer comes to the site to inspect – probably slightly ahead of the completion of Sub-cycle 4.
2. A formal engineer's certification is required before starting on the next floor.



Notes:

1. Finishing Subcycles 1 and 2 completely before introducing subcycle 3. This means half the crews in Fabrication bays 1 and 2 can be released to other tasks such as jointing on the live deck. This method also provides potential buffer time for Subcycle 1 (see Note below)

2. if Subcycle 1 is falling behind in meeting fabrication times, a buffer can be created by introducing a subcycle 3 (infill) earlier than planned. Each subcycle 3 (each infill panel placed) allows 10 minutes extra time to fabricate T tables

A.3 On-site Install Process for Band Beam System

Overview

- Overall floor cycle resources:
  - 12-person crew, including
    - 2 workers on the ground (in the loading area), finding and hooking up columns and panels. One will act as a crane dogman.
    - 4 on the main install deck for placing of columns and panels above (this crew includes Dogman and crew supervisor)
    - 6 workers on Gridflex setup and removal and screwing at joints.
  - Single tower crane, which does all lifting to insitu.

- Overall floor cycle breaks down into 7 sometimes overlapping sub-cycles, to be read in conjunction with Gant Chart, as follows:
  1) Setup Gridflex shoring to temporarily support band beams
  2) Column lifting cycle
  3) Band beam lifting cycle
  4) Joining of band beams to columns and joining of band beams end-to-end
  5) Cross panel lifting cycle
  6) Joining of cross panels to band beams and joining of cross panels to each other
  7) Execute Inspection and Test Plans (ITPs) for primary structure/screw count at brackets/screw strength/joint strength check)
- Total floor cycle 2-3 days (i.e. 905 minutes minimum process time) depending on experience/pre-planning/ITPs/curing time. The upper end in the range may be needed commensurate with team experience. In the order of an extra 40 per cent is a speculative amount for wasted/indirect time for relatively inexperienced operatives, which may include: poor floor cycle changeover time, lack of synchronisation between subcycles, unwanted waiting time, materials not ready, rework, confusion, daily setup time for work processes, replenishing stores, workers getting to work face, crane deployed from the intended install process.
- With regard to this time, the relatively long floor cycle duration (caused mainly by the amount of joining time involved between band beams and cross panels) is thought to create an overly long overall cycle time unless this is offset by any increased spanability relative to other methods.
- Permanent Bracing: Not allowed at this stage.

Subcycle 1: Setup Gridflex Bays to stabilise columns and support band beams

Features and assumptions

- Two Flexigrid bays are set up on each side of each column and cross-braced as required
- It takes approximately 10 minutes per bay to set up (2.0 x 1.0 m); 6 bays per band beam; 30 in total.
- At the midspan between bays, two push/pull props temporarily support the beam's midspan
- Columns are placed and temporarily tied/braced against the Flexigrid shoring bays.

Process

1. Crane delivers bundle (2 loads) of Flexigrid frames to the deck; (15 minutes of scheduled time)
2. Install Peri Gridflex system (Note: formply is not required).
   a. Every 2.0 x 1.0 m bay will be braced; refer to Figure A4.

   b. Assume 10 minutes for 2 man crew to erect a bay and brace it where 3 crews will erect two bays each; therefore, 20 minutes of the scheduled time to erect 6 Gridflex bays
   c. Leave Gridflex bays in place until after the floor level is structurally complete and then lagging workers will remove and lift to the next level (e.g. using Prestons loading platform or similar)
3. Install intermediate push/pull props at panel mid-span (2 spans) between Gridflex bays; assume 4 props in total; allow 5 minutes of scheduled time using the above crew.

Figure A4: Gridflex bracing bays (Image credit: Perri)

Subcycle 2: Column lifting/installation cycle

Features and assumptions

- Assumes bundles of columns are delivered onto the deck (2 bundles) and then individually craned into position from there (Note: faster and easier for the crane operator to see what he is doing from the deck than picking up every column from the ground).
- Columns are 3.6 x 0.5 x 0.5 m approx.
- The main deck crew undertakes work; it takes approximately 9 mins per column cycle, 15 columns in total.
- Columns are dropped into square holes in floor panels.
- Columns are temporarily tied/braced against adjacent Flexigrid shoring bays. Bays measure 2.0 x 1.0 m next to the column and facilitate cross bracing (from one bay to the other).
- The column base is screw fixed to the top of the proceeding column.
- Assume the tower crane is used to lift columns.

Process

1) Crane delivers a bundle of 8 columns approximately to the deck (16 minutes of the scheduled time).
2) Typical column lifting/install cycle (9 minutes of the scheduled time)
   a. Hook up a single column from the stack. Assume 2 minutes of cycle time using 2 workers on the ground.
   b. Air time to insitu location. Assume 1.0 minutes of cycle time (Note: this is a conservative average).
   c. Land column insitu and make plumb by tying/bracing against adjacent Gridflex bay. Assume 4 minutes to cycle time and 2 workers, i.e. workers use drag straps or similar to locate column base into the hole in floor panel below, and then 1-2 workers brace near the top of Gridflex.
   d. Crane releases column. Assume 1.0 minutes of cycle time and 2 workers.
   e. Return to the appropriate stack and repeat. Assume 1.0 minutes of cycle time

3) Concurrent to steps 1 and 6, 2 workers plus any other free workers will erect Gridflex bays and screw off the column base. 4 x 300 mm screws at 1 minute per screw, 4 minutes (but concurrent to above tasks).

Cons/Comments

- Nothing obvious in terms of cons

Subcycle 3: Band beam lifting/installation cycle

Features and assumptions

- Band Beams are lifted/landed onto GLT column heads.
- Takes approx. 12 min per panel cycle (max beam size 12.0 x 1.7 x 0.34 m deep; min 7.3 x 1.7 x 0.34 m deep).
- Assume the same crew as Subcycle 2.

Process

1) Hook up a panel off the stack. Assume 3 minutes of the scheduled time using 2 workers on the ground.
2) Air time to insitu location. Assume 2 minutes of the scheduled time (Note: this is an average but will vary due to the height of the building).
3) Land beam onto column heads and adjacent Gridflex bays. Assume 4 minutes of scheduled time and 4 workers
4) Crane releases column. Assume 1.0 minutes of the scheduled time and 2 workers.
5) Air time to return to stack and repeat. Assume 2 minutes of the scheduled time.

Cons/Comments

- Nothing obvious in terms of cons

Subcycle 4: Joining cycle

Features and assumptions

- All joining is handled by the Gridflex crew, who are deployed to join mass timber once Gridflex work has finished
- Joining at the ends of band beam panels is undertaken using Rothoblass VGU plate connectors.
- Joining of columns to band beams is undertaken using steel L brackets, one per side of the column.
- The brackets on the exterior wall line are installed via workers in a crane basket to facilitate workers' safety.

Process

1) Install column-to-beam L brackets for end beams (only).
    a. Single worker using a crane basket for worker’s safety on the external side of beam, i.e. the crane moves the basket to locations above.
        i. Assume the time to move the basket 3 times is 24 minutes in total.
        ii. Install end panel connectors along exterior wall line using 1 x VGU plates, including 6 minutes/bracket = 6 minutes.
        iii. Installs 3 columns x 1 bracket/column x 18 minutes/bracket = 54 minutes.
        iv. 84 minutes in total (2 off for each end of the building)
    b. Singel worker, working off a ladder platform for the inner side of the above column line

        i. Install 3 columns x 1 bracket/column x 18 minutes/bracket = 54 minutes.
        ii. Install band beam end panel connectors using 1 x VGU plates, including 6 minutes/bracket = 6 minutes.
        iii. 60 minutes in total
    c. Above items = 144 minutes in total to complete jointing for the end band beam, but since item, a and b happen concurrently, only the 84 minutes impacts on added schedule time
    d. The above occurs twice, at either end of the building, i.e. 2 x 144; 2 x 84 minutes.
2) Concurrent to the above, assume 2 crews (of 2 workers each) are working on other band beams once placed.
    a. Assume each worker in the 2 worker crew) is working off a platform ladder; each works on different sides of the beam, and each installs 3 x brackets and 1 x VGU plate per beam row.
        i. 3 brackets x 18 minutes/bracket = 54 minutes.
        ii. 1 VGU plate x 6 minutes/plate = 6 minutes
    b. Move ladder 3 times, assume 6 minutes.
    c. The total schedule time to install each band beam row is 66 minutes per beam row.
    d. The above is applied to 3 separate rows of band beams, therefore 198 minutes of total schedule time.

Cons/Comments

- Whilst the joining method uses contemporary methods, the amount of joining time is generally thought to be slow and, therefore, not ideal.
- The use of a crane basket for safety aims to reduce the need for significant amounts of edge protection that would otherwise be required around the band beams and would then need to be removed before cross panels could be placed (which would be overly time and resource consuming)

Subcycle 5: Cross panel lifting/installation cycle (12 minutes/cycle)

Features and assumptions

- Panels are lifted/landed on top of band beams (i.e. at 90 degrees to band beams).
- The main deck crew undertakes work; it takes approximately 12 minutes per panel cycle (max panel size 15.0 x 3.4 x 0.22 m deep; min 8.2 x 3.4 x 0.22 m deep). Crane cycle time will be similar for both sizes.
- Most panels have partial edge protection added on the ground, which occurs whilst the crane cycle is in process.
- Assume the same crew as Subcycle 1.

Process

1) On-ground, install edge protection to each panel on top of the stack (assume a temporary fabrication bay around the truck/stack, similar to that used for the “infill” version). Assume:
    a. No extra time for end panels. These will take about 4 minutes but done whilst the crane cycle is in process
    b. No extra time for side panels (8.2 m). These will take about 7-8 minutes but done whilst the crane cycle is in process
    c. No extra time for side panels (13.6m). These will take about 10-12 minutes but done whilst the crane cycle is in progress
2) Hook up panel off the stack. Assume 2 minutes of cycle time using 2 workers on the ground.
3) Air time to insitu location. Assume 2 minutes of air time (Note: this is an average but will vary due to the height of the building).

4) Land cross panels beam onto band beams. Assume 5 minutes of cycle time and 4 workers.
5) Crane releases panel. Assume 1.0 minutes of cycle time.
6) Air time to return to stack and repeat. Assume 2 minutes of cycle time.

Cons/Comments

- Cross panels need to be positioned from below. Accurately doing this may take some extra time setting up the first line and then further manipulation and accuracy checks to get the setout right.

Subcycle 6: Joining cycle

Features and assumptions

- All joining is handled by the Gridflex crew, who are deployed to join mass timber once grid flex work has finished
- Joining type 1: Cross panels VGU plate connections are used where cross panels pass over band beams.
- Joining type 2: 4 rows of 300 mm long inclined screws at overlaps between cross panels and Band Beams
- Joining type 3: 2 rows of 100 mm screws are used for capping plates joining adjacent panels

Process

1) Install VGU plates where cross panels pass over intermediate band beams. 16 brackets per beam x 6 minutes/bracket (96 minutes/ band beam/2 workers=48 minutes). Apply to 3 beams
2) Install VGU plates where cross panels pass over end band beams. 10 brackets per beam x 6 minutes/bracket (60 minutes/ band beam/2 workers=30minutes), apply to 2 band beams.
3) Install 300 mm inclined screws at 450 crs x 4 rows; therefore, assume 180 screws @ 1 minute each x 5 band beams divided by 4 workers = 225 minutes
4) Install 100 mm screws at 500 ctrs to 30 m long capping plate x 2 rows = 122 screws @ 0.5 minutes/screw = 61 minutes; apply to 5 capping plates = 305 minutes; divide by 4 crew (deployed after cross panel shave been installed) = 77 minutes

Cons/Comments

- Whilst the above represents contemporary methods, the amount of time taken to execute is thought to be slow and labour intensive, therefore not ideal. A compressed method that is less reliant on labour would be useful.

Subcycle 7: Execute Inspection and test plans (ITPs)

Features and assumptions

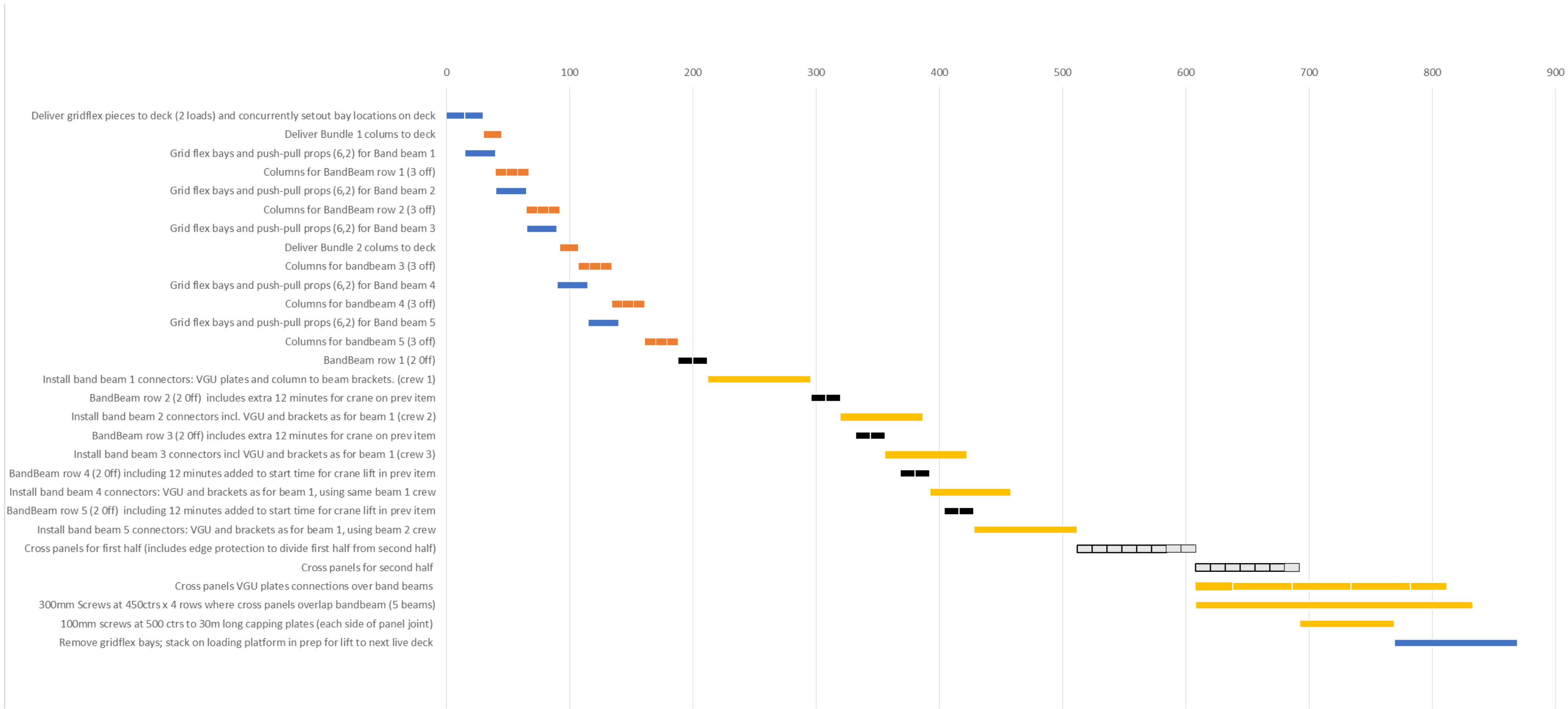
- Needed for main structural members and the joint connectors.
- Bracket screw count/screw strength check

Process

1. A structural engineer comes to the site to inspect – probably upon completion of Sub-cycle 5.
2. A formal engineer's certification is required before starting on the next floor.

Cons

- Moved away from adhesive-based solutions because cure time followed by testing time likely takes longer than the rest of the entire construction process.



Legend:

- Subcycle 1: setting up Gridflex and removing
- Subcycel 2: lifting columns into place
- Subcycel 3: Lifting/installing Band Beams
- Subcycle 4: Lifting/installing cross panels
- Subcycle 5: Connecting Band Beam sections; screwing cross panels; quick connect cross panels

Note 1: Bars in the gant chart show separate segments where multiple crane lifts

Note 2: Bracketed items means number of segments lifted