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NZ Wood Design Guides

CONSTRUCTION GUIDANCE FOR TIMBER BUILDINGS

Chapter 7.1 | June 2020

NZ Wood Design Guides

A growing suite of information, technical and training resources, the Design Guides have been created to support the use of wood in the design and construction of the built environment.

Each title has been written by experts in the field and is the accumulated result of years of experience in working with wood and wood products.

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- Post and Beam Buildings
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NZ Wood Design Guides is a Wood Processors and Manufacturers (WPMA) initiative designed to provide independent, non-proprietary information about timber and wood products to professionals and companies involved in building design and construction.

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FRONT PAGE PHOTO

Nelson Airport Terminal under construction (Photo: Daron Graham)

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1. INTRODUCTION

1.1 OPENING REMARKS

Construction is a key contributor to the national economics of New Zealand. The construction industry accounts for 6.3% of the GDP as of April 2020 [21]. The construction sector provides 40%[21 / 2014] of all capital formed in New Zealand.

> *Half the time elapsed on traditional building sites is lost to wasteful activities.*[20]
>
> *The construction industry has performed poorly compared to the New Zealand economy overall since 1978....*
>
> *The target ... is to lift productivity. Our analysis ... suggests that to do this, the focus will need to be an improving MFP (Multi Factor Productivity), including improving quality, uptake of innovation including prefabrication and standardisation, and management expertise.* [21]

Producing significant capital value for New Zealand with low productivity receives more and more criticism. The industry is facing challenges.

Internationally, pioneering firms adapt streamlined manufacturing philosophies and increasingly implement standardisation and automation. Construction processes are relocated into factories with the support of robotics and computer technology. With 'Industrie 4.0', the European construction industry now experiments with digitisation of the entire production value stream, aiming at self-learning optimisation with artificial intelligence.

Figure 1: Cathedral Grammar. (Photo: Patrick Reynolds)

Figure 2: Nelson Airport. (Photo: Daron Graham)

Increasing environmental awareness focuses on timber's benefit to store carbon: 1 tonne of dry wood has sequestered approximately 1.8 tonnes for CO^2 [46]. Europe has experienced productivity increases with prefabricated timber solutions: off-site production and automation have entered the engineered timber postproduction processing and timber construction sector. Precision CNC prefabrication equipment gradually replaces manual work and creates highly accurate products. Machines execute repetitive tasks tirelessly, achieving consistent high-quality results with safer work practices. Valuable labour can be utilised for more complex tasks.

The construction industry evolves from manual on-site construction to off-site production and on-site assembly. It is essential to keep up with the development of this evolution and sensible to explore the options with timber prefabrication. Prefabricated wood products can be a solution for higher quality and more efficient construction in New Zealand.

It is the focus of this document to endorse productivity increase with prefabricated timber systems:

- Heavy Post and Beam (LVL, Glulam).
- Mass Timber Panels (CLT, PLT).
- Light Timber Framed Systems (Wall, Floor, Roof).
- Volumetric structures (bathroom pods, entire buildings).

1.2 AUDIENCE

This guide is aimed at builders and contractors, commercial or residential, investigating the opportunities and challenges in working with prefabricated timber systems:

- What are the risks and opportunities with timber prefabrication?
- How does the compliance process handle prefabrication?
- Does prefabrication increase productivity?
- What are the essential requirements to be successful when building with prefab timber systems?
- What is Lean construction and why is it crucial in timber prefab construction?
- Which timber prefab systems are available and what are the need-to-know-basics?

This guide is one volume in the NZ Wood Design Guide series. To access other guides please visit: https://nzwooddesignguides.wpma.org.nz/. Examples of other NZ Wood Design Guidelines:

- Chapter 4.1 - Costing Timber Buildings.
- Chapter 5.1 - Designing for Prefabrication.
- Chapter 5.3 - Working Safely with Prefabricated Timber.
- Chapter 6.1 - Consenting Process for Timber Buildings.

1.3 HOW TO WORK WITH THIS GUIDE

This guide assumes in-depth knowledge of construction processes and systems, good knowledge of available Engineered Timber Products (ETP) and basic knowledge of prefabricated timber systems. Building with prefabricated timber solutions and all associated considerations are vastly complex, this guide will only provide tips and pointers over off-site production theory and its application in on-site timber construction.

1.4 ACKNOWLEDGEMENTS

Just like any successful prefab construction project, these guidelines too were a product of ***collaboration***. The author would like to acknowledge the generous support of following individuals:

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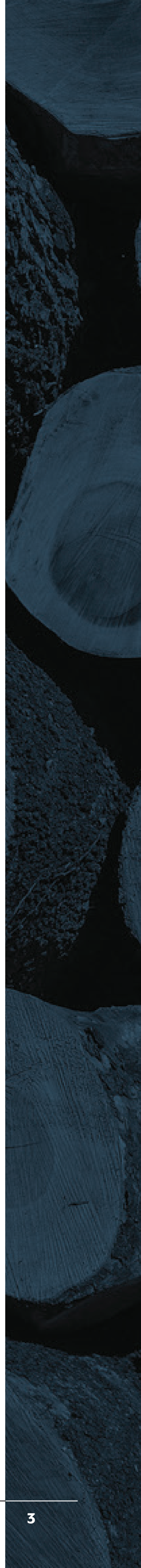


1.5 USE OF TERMINOLOGY

Prefabrication or Modular Construction or OSM	Building work being undertaken away from the final building site. This guide also utilises the following terms: off-site manufacture, off-site production, pre-built construction, manufactured building solutions, prefab.
Components	Individual elements of a prefabricated system, i.e. wall panels, floor panels, columns, beams, stairs, doors, roof panels.
CAD	Computer Aided Design – use of computers to create, modify, analyse or optimise a design.
CAM	Computer Aided Manufacture – use of computers to manufacture.
Fabrication Model	3D CAD model which can be utilised for manual manufacturing and/or CAM.
Modules	Similar to a component but volumetric and self-contained, i.e. pods, hybrids thereof, or entire prefabricated buildings.
Assembly	The combination of different parts and modules in part (subassembly) or in full (assembly). This guide refers to the final assembly as the construction process on site.
Manufacturer	Factory based producer of materials.
Prefabricator	Factory-based producer of parts, components and modules usually off-site. In some instances, the prefabricator can also be the manufacturer, e.g. the manufacturer of CLT panels also undertakes prefabrication work, e.g. post-processing (CNC) work and partial pre-assembly.
Contractor	A firm that undertakes a contract to provide materials or labour to perform a service to do a job. This guide also utilises the term main contractor, builder, assembler.
Lean Construction	Customer focused optimisation process, reducing wastes in the building project delivery (refer to chapter 5)
DfMA	Design for Manufacture and Assembly (refer to chapter 4).
BIM	Building Information Modelling is the digital representation of physical and functional characteristics of a building.
QA	Quality Assurance system, establishing and maintaining set requirements for manufacturing reliable products.
BCA	Building Consent Authority, officials who enforce New Zealand's regulatory building control system.
TWE	Temporary Works Engineer, a professional structural engineer or organisation responsible for the temporary works during erection.
ETP	Engineered Timber Products (LVL, Glulam, CLT, GLT, PLT etc.) Other literature utilises the abbreviation EWP (Engineered Wood Products) which may lead to confusion with the familiar term Elevated Working Platforms.
TTPS	Temporary Timber Protection Strategy (refer to 6.4).

2. CONSTRUCTION WITH PREFABRICATED TIMBER SYSTEMS

Timber is a key construction material in New Zealand. As a locally grown and harvested product, most New Zealand contractors are familiar with timber. The material can be easily processed, manually or via machine. Small and large contractors are utilising timber on residential and commercial projects.

Figure 3: Dovedale Student Accommodation, Prefabricated Light timber frame Panels and Bathroom Pods – Naylor Love. (Photo: Concision)

Figure 4: Quest on Manchester, Prefabricated Light timber frame Panels and Bathroom Pods – Miles Construction. (Photo: Concision)

2.1 THE SOLUTION

The familiarity of wood products in New Zealand's industry is its advantage. Utilizing the most familiar product in the evolution of construction is the next logical step. The wood processing industry has recognised the trend and provides a growing and evolving product range. LVL, CLT, Glulam, PLT, light timber framed wall and floor panels and many other complimentary products are offered to realise various structural and architectural solutions. Components become larger and more precise, providing the opportunity for more efficient construction processes. Although timber is a familiar product, large scale timber components made from timber and their assembly methods are not.

The scope for contractors is changing with prefabricated timber products, an unfamiliar terrain for most. Risks have increased, however, the opportunities are substantial. At the end, higher productivity will convince and ensure the success of the most versatile companies and change the approach to the delivery of construction projects.

Timber prefabrication can replace complex on-site workflows and construction methods to simpler and repetitive tasks in controlled environments and streamlined on-site assemblies. Higher quality buildings are delivered faster and more cost efficiently.

To endorse productivity increase with prefabricated timber products, we need to reconsider the way buildings are designed and constructed. The challenge is the transition from the traditional design, tender and construction process to design for an on-site assembly and off-site manufacture process.

Contractors need to be educated and prepared for this evolution.

2.2 OPPORTUNITIES AND CHALLENGES

Prefabricated timber systems are not necessarily the only answer for every project. The best system for the project should get the preference and prefabricated timber systems must be on the list of available and familiar products for designers and contractors.

Building with prefabricated timber systems opens a range of opportunities and challenges to those contractors choosing to work with them. Broadly speaking, prefabrication aims for a leaner construction process achieved through a shorter build time coupled with reduced labour requirements on site. However, due to the different nature of the construction methodology using relatively novel systems this also means new challenges for the contractor including exposure to new types and different levels of risks: assuming risk without due consideration and management can lead to significant rework, compliance issues, or even company failures.

This chapter intends to outline a range of opportunities and associated challenges from the contractor's point of view. Broadly speaking the opportunities for contractors fall into two categories: a) increasing value, and b) reducing risk.

OPPORTUNITIES	CHALLENGES
HEALTH & SAFETY	
• Safety by design. • Remove risks by degree and method of prefabrication. • Efficient, clean and quiet construction. • Reduced man hours and smaller teams, reduced risk of incidents. • Reduced traffic and movements on/to site, exposure to public.	• Designers to realistically consider safety aspects. • Large components and new methods introduce new H&S risks. • Skill shortage for design and on-site assembly. • High organisational and thorough planning skills required.
ENVIRONMENTAL	
• Higher performing designs, e.g. passive housing. • Reduce CO_2 emissions, use timber and reduce waste: material, transport, energy, travel. • Sustainable homes with low carbon footprint.	• End of building life and demolition – consider the reuse or recycling of material at design stage. • Skill shortages in design (DfMA) and execution.
QUALITY	
• Virtual coordination via BIM (clash detection, constructability etc). • Less defects from prefabricator: - Standardisation and consistency of factory production. - Automation through CNC. - Continuous improvement. • Less defects on site: - Standardisation of assembly, higher density of supervision. - Continuous improvement. • Quieter and cleaner, no wet or hot trades. • Fewer compliance requirements.	• True understanding of continuous improvement: root cause analysis and elimination, Lean Jidoka principle. • Repetition may result in repeat errors. • Consistent QA systems. • Compliance for components built off- site. • Traceability of materials and workmanship. • Increased logistics: installation, delivery and loading. • Skill shortage for design (DfMA) and on-site assembly. • Temporary protection from weather / wind / damages.
TIME	
• Quick and efficient design with DfMA. • Shorter construction periods. • 4D planning, sequencing and constructability checks: - Better assembly predictability. - Opportunity for concurrent workflows. • Less trades → less disruption. • Less on-site coordination management. (equipment, material, labour and waste). • Fast off-site production through CNC and Lean production. • Fast enclosure and weathertightness reduces risks for extension of time claims. • Initial standardisation (DfMA) takes time to develop.	• Skill shortage programming - critical paths in design and off-site production phase, lack of understanding by customers, project managers, designers, programmers. • Skill shortage subcontractors understanding prefab systems: - New sequencing and assembly methods. - New trade and product interfaces. - Speed and adequate resourcing. • Skill shortage logistics – Lean continuous flow, importance of thorough information, site and prefabricator coordination. • Secure supply - lock in production slots with prefabricators. • Delays due to design, production capacity issues, constructability etc.

COSTS

- Shorter construction and delivery time:
  - Savings in project finance usually not considered.
- Manufacturing, logistics and assembly maybe based on new cost calculation methods (rates, labour constants etc).
- Centralised purchasing; more trades and services from one source.
- BIM – better planning detail and 4D ➔ lesser risk for cost explosions in later project phases.
- Lower skilled labour for manufacture.
- Higher productivity via repetitive tasks, digitisation and CNC technology.
- Smart and cost-effective transport and logistic solutions
- Savings through less or fewer:
  - Equipment, tools, material, labour and material waste.
  - Transport to/from site.
  - Company vehicles.
  - Movements on site: equipment, material, labour, waste, vehicles, temporary works.
  - Electricity on site.
  - Temporary work (scaffold, falsework, propping, TMP etc).
  - Non-productive time, travel during paid working hours.
  - Site management and site facilities.

- Skill shortage financial advisors and client project managers:
  - Understand holistic delivery work flow, constructability, P&G.
  - Do not focus savings on one single material/module - reduce the cost of the overall production and build flow.
  - Lack of constructability or badly considered logistics in design may cause significant cost increases.
  - Very high costs for late design changes.
- Difficult to justify value for money:
  - Potentially higher design fees vs shorter assembly periods and costs.
- Early costs for:
  - DfMA - standardisation phase.
  - Planning and detailing phase.
  - Procurement of long lead time materials.
- Prefabricators and manufacturers demand contractual agreements with no relation to construction contracts, creating various risks for all parties.
- Off-site prefabricators may require off-site claims or deposits, customer needs to be aware, terms must be agreed upfront.
- High risk with one source prefabricator:
  - Costs, time, quality, business failures.
  - Technical solutions may have copyright.
- Partnership/alliancing with designers/prefabricators.

THE TEAM

- Innovative owners with vision and environmental consciousness.
- Undecided owners with no knowledge about timber and prefab.
- Trust, collaboration, cooperation and continuous improvement.
- Engage competent people and their skills early.

- Lack of trust, aggressive and contractual construction market.
- Owners typically not risk sharing, not embracing integrated deliveries.
- Resistance by designers, project managers, contractors, subcontractors, authorities.
- Owner anxiety re acoustic and fire performance.
- Skill shortage design: efficient timber and prefab design.
- Expectations re finishes; defects and looks of natural timber.
- Fragmented design and construction industry, working in silos.

DESIGN AND PLANNING

- How are we going to design to be built off-site?
- Standardisation through DfMA.
- Design process efficiencies via integrated design (BIM):
  - Build twice: once virtually – once in reality.
  - Interface coordination and planning.
  - Shared knowledge, transparency and accountability.
  - Solve problems on the virtual model - clash detection.
  - Mass customisation.
- Better documentation, communication, time and cost certainty.
- Better, smarter, safer and healthier homes and buildings.

- How decide if the project lends to prefab?
- Design can't compromise on manufacture and assembly methods, must be guided by prefabricator and contractor.
- Lack of standardisation.
- Lack of accountability.
- Vulnerability: sharing/finding solutions together.
- No standards and new area for building consent authorities.
- Tangible metrics to measure claims against actual for better / faster / less wasteful / sustainable and safer.

OTHER

- "Mountable, repairable, replaceable and demountable."
- More competitiveness across the nation.
- Material independence: timber can be sourced locally.
- Trade independence: timber can be erected by builders.
- Lighter buildings result in lighter foundations.
- Lighter foundations may enable construction on currently unsuitable land.
- Seismic advantage of timber buildings.

- Dynamic/fledgling industry: ups/downs for contractors => risk => work with prefabricators to lock down price/timing.
- Working across multiple building consent authorities (BCA) with differing approaches.
- Early commitment to a prefabricator and potential con sequences from early insolvency, dependence on capacity and costs.
- Difficult interface management between several prefabricators.

Table 1: Risks and opportunities from contractor perspective for timber prefabrication systems.

3. COMPLIANCE PLANNING

3.1 GENERAL COMMENTS

For systems like light timber framed wall, floor, roof panels or volumetric solutions like bathroom pods or entire buildings, this section outlines some aspects and potentials for inspection and compliance strategies through the development of a streamlined design process. It is based on material published by MBIE [15] and the *Good Offsite Guide* [14].

NZ Wood have published Chapter 6.1 - *Consenting Process for Timber Buildings* available for public download.

3.2 THE CONSENTING PROCESS

The building consent and compliance process is a two-step process:

STEP	PURPOSE	RESULT
1 Design Evaluation	**... to check compliance against the building code.**	**Building Consent is granted.**
2 Construction Evaluation	**... to ensure the building complies with the consented documentation.**	**Code Compliance Certificate is issued.**

Table 2: Building Consent and Compliance process.

The Building Consent Authority (BCA) traditionally decides during Design Evaluation (Step 1) how to gather compliance evidence for Construction Evaluation (Step 2). The consenting process provides the opportunity for the applicant to propose to the BCA a method on how Construction Evaluation is conducted rather than leaving this process for the BCA to determine.

For customers, designers, prefabricators and contractors this provides the opportunity to collaboratively propose and inform the procedure for gathering this evidence.

3.3 APPLICATION FOR BUILDING CONSENT

The goal of the consenting process is to ensure the building owner, the BCAs and other project team participants can be satisfied that all obligations have been met and the project is compliant as per the consented design and specifications.

The NZ regulatory systems are flexible and able to cater for innovative designs and alternative delivery models as required for prefabricated timber systems. Making use of this flexibility requires thinking strategically about compliance and taking appropriate advice early. For more complex projects, a regulatory advisor can assist to develop a regulatory risk plan and identify ways to mitigate any risk. They could also help manage the relationship between the BCA's as well as the regulatory aspects of the work of design professionals and prefabricators.

A *Design Supplement* will go a long way to answer the BCA's questions regarding the use of prefabricated construction methods. The supplement explains the modular design, performance, how the system and QA will help to collect evidence for compliance during prefabrication and assembly. By better understanding a prefabricator's product assurance and QA systems, applicants for building consent are better positioned to demonstrate compliance to BCAs.

Evidence of compliance needs to be submitted with the consent application. The application should include evidence for both, on-site and off-site building work. The consent is usually best granted by the BCA in the area where the final building site is located. This consent application should clearly identify any components that are constructed off-site (including offshore).

	B1	B2	C1-6	E1	E2	E3	F2	F4	F7	G1	G2	G3	G4	G7	G9	G12	H1
Prenail	●	●															
Panels	●	●	●		●	●									●	●	●
Volumes	●	●	●		●	●	●		●				●	●	●	●	●
Hybrid	●	●	●		●	●	●	●	●				●	●	●	●	●
Complete Building	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Table 3: Increasing compliance complexity from component to complete buildings.

Designers can demonstrate design compliance with several methods:

1) Acceptable Solutions ("standard designs")
2) Verification Methods (test and calculation methods)
3) Evaluation of Compliance (Alternative Solution)

For instance, NZS3604 is an acceptable solution for B1. For modular timber buildings, a range of design compliance methods can apply. Most commonly Alternative Solutions will apply and can be demonstrated in multiple ways:

- Comparison with an acceptable solution or verification method.
- Calculation or test method not contained in the acceptable or verification methods.
- Comparison with another solution previously accepted by a BCA.
- Independent assessments, i.e. certified testing laboratories or chartered professional engineers.
- Appraisals, i.e. product testing, test reports, performance claims etc. through independent recognised bodies, certifiers or expert opinion.
- Product Technical Statement, i.e. technical information and independent verification.
- Trade literature, i.e. manufacturers literature and technical data for proprietary products.
- Industry schemes, products are assessed on specified industry requirements.
- Membership of relevant industry schemes (for example, the Window Association of New Zealand, WANZ).
- In-Service history for material and system performance.
- MBIE determination, i.e. multiple use approval (MultiProof).
- A Product Certificate (Code Mark).

3.4 CODE COMPLIANCE CERTIFICATE PROCESS

Code Compliance Certification is the demonstration of compliance with the project documentation. The tools to demonstrate Code Compliance Certificate can include a mix of:

- Inspection of the building or modular component production by BCA staff (the "classic" model).
- Site observation by design professionals (Producer Statements).
- Subcontractor and Prefabricator Statements (Producer Statements).
- Product Certification (Code Mark).
- Use of a formal Quality Assurance system.
- Evidence provided by the "builders" e.g. photographs, invoices, delivery dockets (for example invoices showing that H1.2 timber was ordered, delivery dockets showing it went to the site and photographs showing it was installed).

It is essentially required to demonstrate traceability for product compliance and workmanship for restricted work throughout the manufacturing and assembly process.

3.5 QUALITY ASSURANCE SUPPORT

Off-site manufactured components differ from traditional site-based building work mainly in following ways:

- They can be built away from the area where the building consent is granted and away from the local BCA authority. However, compliance with the relevant building code needs to be ensured.
- They are manufactured in a factory or a similar controlled environment.
- This manufacturing tends to follow a documented, process-driven approach.
- There are usually strong production controls and quality assurance (QA) systems in place.

Factory applied QA documentation for production control can be utilised, extended or adjusted to support the consent and compliance evaluation process.

When identifying and selecting suitable modular solutions, designers and contractors are encouraged to look for prefabricators with robust QA systems and product assurance in place.

Quality Assurance systems can demonstrate compliance of modular components via:

- Factory processes.
- Manufacturing controls.
- Details of any installation or assembly requirements.
- Details of any transportation requirements or pre-installation protocols (to minimise the risk of damage in transit or of substandard components being accepted at the building site).
- Any independent or self-certification of the factory .[33]

Quality assurance systems generally have the following attributes which are then integrated into a document called a quality management manual:

- A quality policy setting out the general quality-based objectives of the organisation, the broad allocation of quality related responsibilities and the target level of quality.
- The specific organisation structure and responsibilities.
- Key processes including controls over purchasing and task allocation.
- Regular reviews or audits to make sure quality policies are being followed (these can be done by internal and/or external parties).
- Mechanisms to record quality problems and to analyse these and change processes, tasks or materials as appropriate.

3.5.1 TRACEABILITY

Consistent tracing of product information and workmanship during the production process of components is inevitable. For the contractor it is recommended to agree with the prefabricator the standard of and the submission of traceability documentation prior to delivery.

Traceability covers the documentation for compliance and contractual purposes:

- Registered design professionals.
- Registered trades (i.e. electricians and plumbers).
- Registered 3rd party inspectors (i.e. fire alarm and sprinkler systems).
- Licenced Building Practitioners (LBP).
- Material manufacturers and subcontractors: Test reports, conformance documentation.
- No variations from the consented design and specifications.
- Any variations or alternative design solutions must be approved by the designer and recorded.
- Where traceability of products or workmanship is required, this may need to be recorded in As-Builts or other traceable methods.

- Usually key components require their product markings, with exposed timber structures markings are removed and traceability or product performance must be recorded with an alternative method.
- Traceability of on-site work can be realised with QA documentation.

Figure 5: Traceability of products – labelling of every component from the manufacturer. (Photo: Contract Construction)

3.6 AUCKLAND CITY COUNCIL COMPLIANCE PROCESS

The Auckland Council has published guidelines for manufactured modular components (Manufactured Modular Component Guidance, 02/2020)[31] and recommends a proactive involvement of the BCA for modular builds before Building Consent is lodged. The process allows the BCA to determine and document requirements and expectations with the building owner. Four types of modular components and corresponding processes are proposed (refer to Table 4). The types are distinguished by their production location, the desired compliance process for the individual proposed components and the final build location. It should be noted that a building can be assembled by several components from different factories across NZ or offshore. Consequently, a combination of types can apply to one building consent process. It is recommended to work with the BCA in the location of the final build well before building consent is applied.

TYPE DEFINITION	TYPE 1	TYPE 2	TYPE 3	TYPE 4
Modular Component Fabrication	In the BCA area	NZ, outside BCA	NZ, outside BCA	Offshore
Consent Authority	BCA	Home BCA	BCA	BCA
PROCESS				
Pre-Application Meeting	•	•	•	•
Consent & CCC issued by other BCA (component only)		•		
Memorandum of Understanding	•		•	•
QA plan for factory fabrication	•		•	•
Inspection of QA by BCA or agreed 3rd party			•	•
Product Technical Statement	As agreed	As agreed	As agreed	•
Logistics plan	•	•	•	•
BCA issues consent & CCC for entire project	•		•	•
BCA issues consent & CCC for site specific work only		•		

Table 4: Modular component types and consent process overview – Interpretation of Auckland Council Guide.

In the pre-application meeting the consent approach and strategy are discussed and then documented in a Memorandum of Understanding. During this process, the council will determine which modular components are classed as building work and which are not and how their compliance is achieved. The evaluation of the final assembly and construction method will further determine the process for final compliance.

At consent application the council requires the submission of:

- Project Overview.
- Designer's statements.
- Compliance path.
- Plans, specifications etc.
- Clear demarcation on drawings on what is done in the factory and what is done on site. *"Leave nothing to assumption!"*[31]
- CodeMark or Multiproof if applicable.
- Manufacturers technical literature, test results etc.
- Detail of the construction methodology and maintenance requirements.
- Traceability – how module components will be identifiable through manufacturing, shipping, delivery and assembly process.
- Reference to the Memorandum of Understanding.[31]

The Auckland council is clear about refraining from the traditional design and consenting approach and about clearly telling the story literally and graphically on how the building is assembled to avoid queries, resubmissions and delays. The council also requests a proposal on an inspection regime for notifiable work.

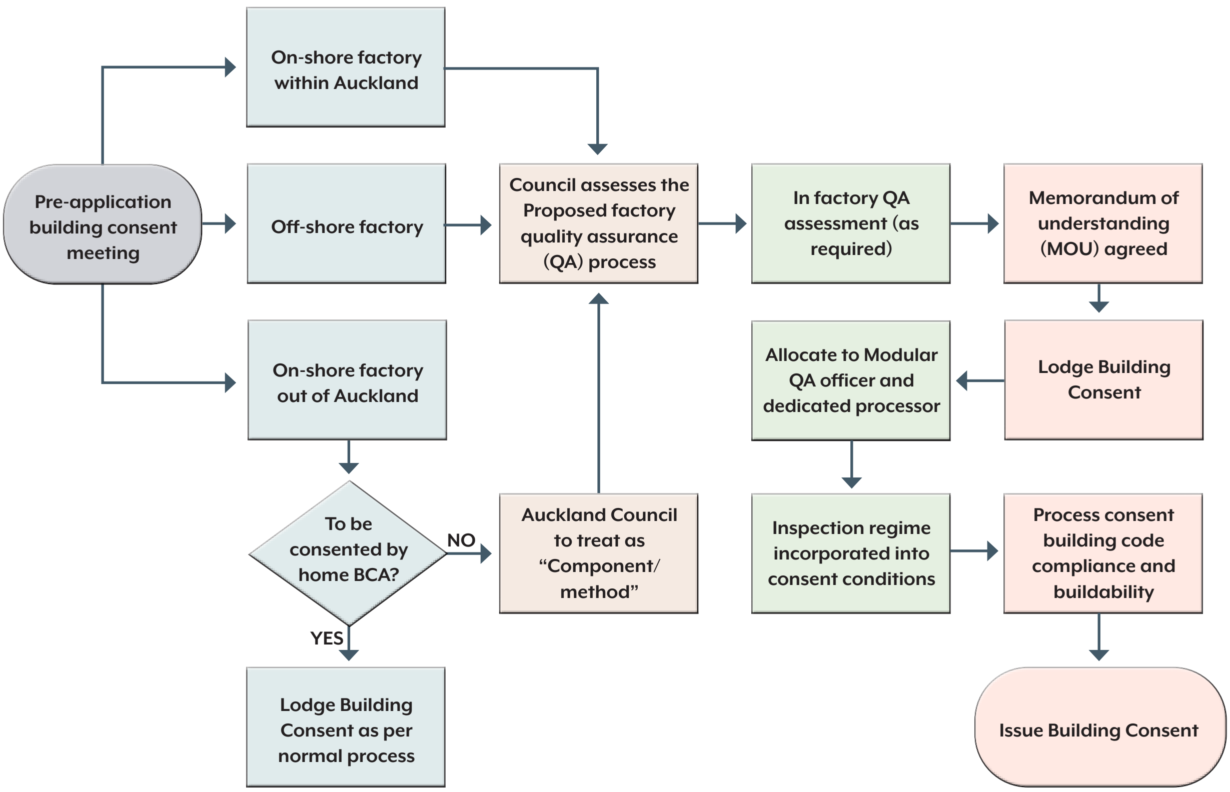


Figure 6: Auckland Council Building Consent Process for Modular Components.

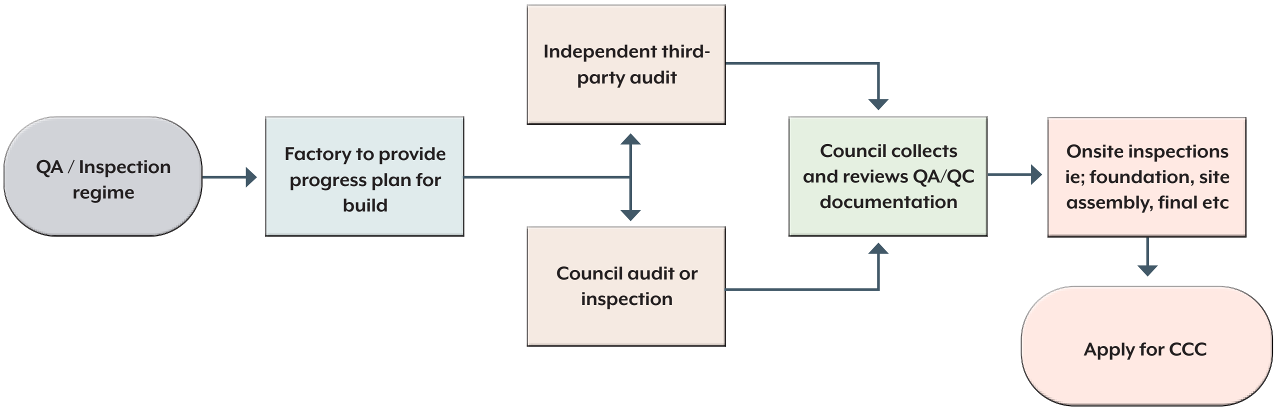


Figure 7: Auckland Council – Inspection Regime for Modular Construction and Component.

3.7 CONCLUSION

Designers must plan the overall compliance process at design stage. Design should consider the final selection of components, where the components are made, by whom and how they are assembled. The consent application needs to demonstrate to the BCA how compliance is achieved.

Prefabricators, builders and contractors need to be aware that compliance requirements must be met for restricted building work at the time of manufacturing and assembly. Understanding and implementing the project specific compliance process from early on is vital. Comprehensive quality assurance systems need to be in place. If possible, it is advisable to actively support the design team in the compliance proposal process.

4. DFMA

4.1 PLANNING. PLANNING. PLANNING

Failing to plan is planning to fail: *If you are not simple, you can't be fast, and if you can't be fast, you can't win.*[34]

Speed of construction on site is key for economic success of most construction projects. Build time and costs can only be reduced with a Lean approach to production and assembly. Construction planning at design stage impacts on the way in which the project is actually delivered.

Building with prefabricated systems requires a rethink of the relationship between design and construction.

4.2 DEFINITION FOR CONSTRUCTION

Developed since the 1970s, Design for Manufacture and Assembly (DfMA) is the design of discrete components and modules of a building for ease of manufacture (production) and ease of assembly (construction).

- DfMA is a structured design process.
- DfMA is the simplification and standardisation of details and processes.
- DfMA can apply to bespoke buildings as well as mass production.
- DfMA enables mass production.

4.3 OBJECTIVES

The objectives of DfMA are a Lean manufacture and assembly (build) phase:

- Improved quality.
- Less time.
- Less cost.
- Improved maintenance.
- Improved safety.
- Less site trades.
- Less impact on customer operations and public.

DfMA is <u>NOT</u> value engineering:

- Reducing scope.
- Squeezing the supply chain.

4.4 METHOD

DfMA develops a build process that is based on manufacture and installation rather than construction:

- Analyse an entire building, determine the optimal way of breaking it into components or modules including a method on how to assemble them.
- The entire design team must engage with the assembly methodology.

4.5 TOOLS

DfMA addresses wastes (refer to 5.1) and applies standardisation through strict simplification:

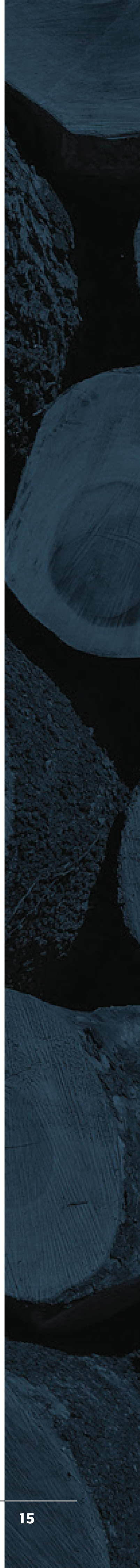
- Commercial ➔ keep it simple, contracts to support collaboration and information flow.
- Design for productivity ➔ production and assembly flow.
- Design for logistics ➔ reduce double handling, introduce ease of handling.
- Design for modularity ➔ produce off-site if feasible.
- Design for efficient jointing methods ➔ assembly flow and reduced errors.
- Simulation and correlation (BIM) ➔ assembly flow optimisation, constructability.
- Process capabilities ➔ uninterrupted flow of information and materials.
- Reduce the number of parts ➔ increase repeat work / automation.
- Use standard parts ➔ reduce design and production effort.
- Repeat use of parts ➔ design and production effort reduced.
- Reduce assembly risks ➔ increase flow and reduce errors.
- Reduce interfaces ➔ reduce trade coordination, work on site, errors.
- Ease of part fabrication ➔ avoid unnecessary features and simplify geometry.
- Tolerance within capability ➔ design tolerances to the production capability.
- Clear and unambiguous assembly ➔ assembly only one way and error free.
- Shape for easy transport ➔ design for easy and efficient logistics.

4.6 PROCESS & IMPLEMENTATION

DfMA is enabled by BIM. BIM is more efficient when coupled with DfMA. BIM produces a model with components which contain information (metadata). Building the components and their correlation to one another based on DfMA guidelines, assists in the development of a model that is built around the modular delivery of a project.

DfMA enabled BIM relies on a collaborative design team, with direct input from DfMA engineers, contractor, prefabricator and key subcontractors as early as the concept design. Although each project (or product development) is different, it is generally recommended to implement a robust DfMA process during design development (for an example refer to Table 5). From *'The Handbook for design of modular structures'*[6] (Monash University):

- Throughout the design phase, the designers should consider the full lifecycle process, including the manufacturing and assembly processes.
- Stakeholders should conduct collaborative DfMA and Lean Manufacturing workshops throughout the design phase to maximise production efficiency, reduce programme risk and minimise cost.
- Involved parties should seek to quantify the 'value add' in the off-site manufacturing process by creating preassembled elements; for example, facades, finished internal walls, and service cores.
- A continuous improvement process should be embedded in the development process to ensure issues are reported, recorded, and resolved.



DESIGN STAGE	BIM LOD	DfMA PROCESS
Concept Design	LOD100	• BIM execution plan, platform, file exchange and ifc type standards • Modular component concept / reduce number of components • Sequence and speed concept (takt time or rhythm) / service integration concept • Identify opportunities for off-site production • Integration concept for off-site elements • Prefabricator → capability reviews • Decision: prefab yes or no
Preliminary Design	LOD200	• DfMA guide – concept and development, modular concept, interface definitions • Compliance process – concept • Sequence refinement
Developed Design	LOD300	• BIM coordination and clash detection • DfMA guide – developed and detail development • Compliance process – detailed • Sequence refinement (4D), constructability and producibility review, construction logistics
Detailed Design	LOD350	• BIM coordination and clash detection • DfMA guide – complete • Compliance process – complete • Sequence refinement (4D), constructability and producibility review
Consent Documentation	2D	• Compliance process submitted
For Construction Documentation	LOD350 (updated)	• BIM coordination and clash detection • DfMA guide – update and continuous improvement • Sequence refinement (4D), constructability and producibility review
3D Fabrication Model = as Built	LOD400	• Final coordination and clash detection, RFI's • Designer's review and sign off • DfMA guide update and continuous improvement (for mass production) • Production documentation • Machine files (export to CNC machines)
2D Factory / Assembly Documentation = as Built	2D	• Production and assembly drawings • Designer's review and sign off • DfMA guide update and continuous improvement (for mass production) • Potential QA documentation

Table 5: Example DfMA process during design development.

This front-loading of the design process with manufacturing and assembly input is in direct contrast to the linear and traditional procurement process of design-bid-build that usually does not consider production and assembly until design is complete, reducing the opportunities to save costs (refer to Figure 8).

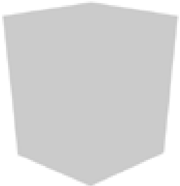
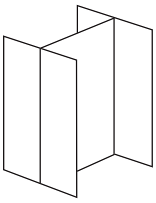
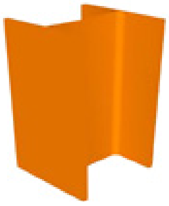
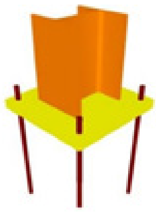
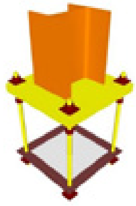
LOD 100	LOD 200	LOD 300	LOD 350	LOD 400
				
Only the volume, conceptual, potentially no geometry	Generic placeholder, enough detail to recognise the component	Quantity, size, shape, location, orientation can be measured	Connections and interfaces with other building systems represented	Components modelled at detail and accuracy for fabrication / installation

Table 6: LOD levels explained (Graphics from Level Of Development (LOD) Specification Part 1 and Commentary[30]).

The project team needs to develop a DfMA guide to document project specific constraints or opportunities. Good and detailed DfMA analysis enables efficient design, considering:

- Customer brief: functionality, form, shape, spec, scale, repeatability.
- Compliance: RMA, building regulations and New Zealand standards, BCA requirements for modular construction.
- Design: accountability, coordination, BIM.
- Production model: shop drawings for production and assembly, review process.
- Site constraints: access, terrain, ground conditions, topography, space, crane limitations, overhead lines, maneuverability for vehicles.
- Transport limitations: within NZTA standards, module sizes and weights, transport options.
- Manufacturing: capabilities, competencies, capacities, strategy, material selections, producibility, robustness and transportability, sizes, shape complexities.
- Assembly: sequencing, constructability, erection techniques, lifting plan, equipment, temporary propping and supports, pre-assembly complexities and constructability (on or off site).
- Just in Time delivery, manufacture and assembly Takt times (refer to 5.4).
- Accuracy: production and assembly tolerances.
- Fixings and connections: specialist fixings, tools and equipment.
- Finishes: timber treatment, final finishes, exposure and temporary protection.
- Contractual specialties with manufacturers and prefabricators.

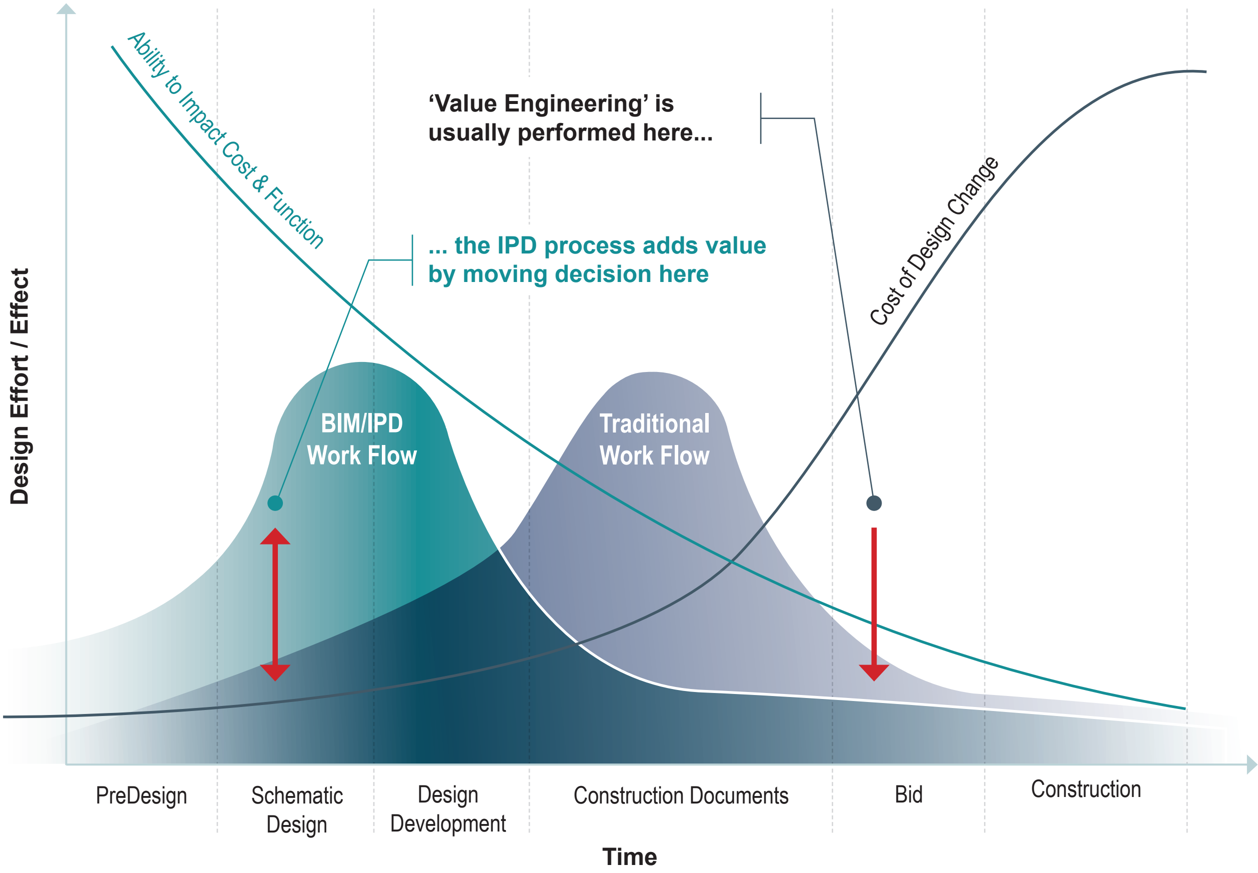


Figure 8: The MacLeamy Curve, "front end loading" required for successful DfMA and Integrated Project Delivery.

4.7 COORDINATION

The extend of BIM modelling depends on the project. For detached houses, modelling may be sufficient in a fabrication model (see 4.8). Large and/or complex buildings may require extensive models, providing a multidiscipline single point of reference in a digital, federated model. BIM coordination methods are covered by numerous other sources and will not receive further explanation in this document.

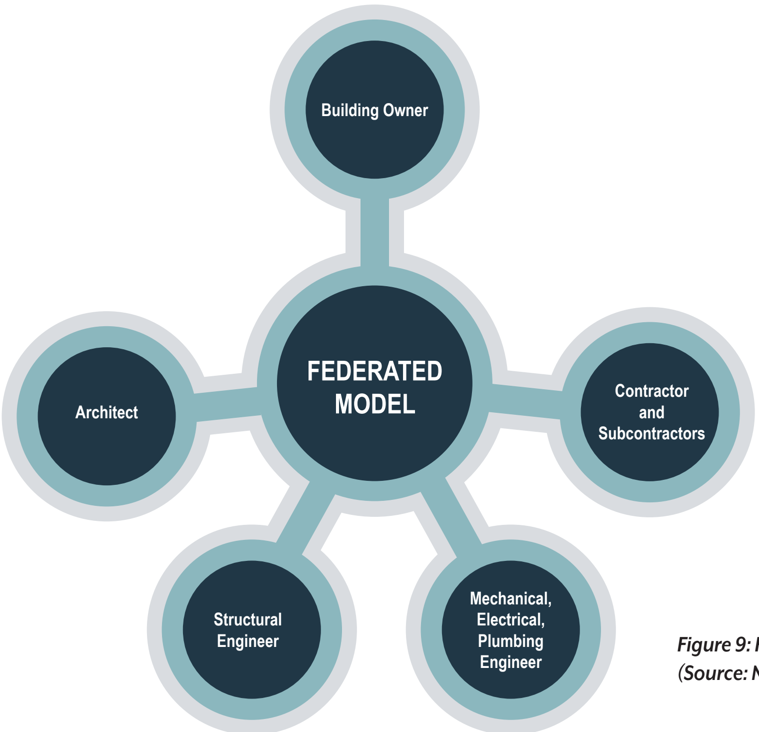


Figure 9: Federated BIM Model - One source of truth.
(Source: NZ BIM Handbook 2016 Edition)

4.8 AUTOMATION

For automation in timber prefabrication, coordinated engineering BIM models must be translated into machine files. Designer's BIM software does often not provide this capability. The translation is enabled by the preparation of one or several separate 3D fabrication models in a specialist software that enables the export into CNC machine readable files. This translation is done by specialist teams, understanding CNC machines, production and assembly processes. These specialists are the 'off-site site managers' in prefabrication, resolving the smallest detail on the fabrication model. The early involvement of the specialists at the time of BIM coordination enables DfMA with real-time feedback and proactive design optimisation. Depending on the project, this could also enable the concurrent development of the fabrication model for an earlier production start.

Fabrication models integrate with BIM platforms. The data exchange standards between BIM and fabrication software packages are constantly developing and at various stages for individual software packages. The BIM execution plan should establish the data exchange standard with the fabrication models.

For good BIM level guidance refer to *Level Of Development (LOD) Specification Part 1 and Commentary* [30]. BIM LOD depends on the level of information required for the fabrication process. The BIM execution plan should allow for appropriate BIM levels (BIM LOD) to cover coordination and meticulous development of standard details for DfMA:

- Secondary structural and seismic fixings.
- Detailed service planning.
- Penetrations incl. passive fire, acoustic, seismic clearances etc.
- Openings: doors, windows, access hatches etc.
- Features: rebates and recesses.
- Interior fit out: locations and fixings for kitchens, furniture, features, curtains, lights etc.
- Module interfaces: construction or element joints, services and scope demarcations etc.
- Façade: flashings, balconies, louvres, water- and air tightness, fire, thermal, acoustic.
- Assembly: structural purpose for sequencing, lifting points and equipment, module joints etc.
- Transport: robustness during transport (vibration / shocks), fixings, support, water ingress.

4.9 PROCUREMENT & DELIVERY MODELS

4.9.1 Traditional vs Integrated Procurement

Procurement here refers to the phase from engagement of a delivery team to the delivery of a project to site, including client handover.

The traditional procurement process intends to create price competition by separating the design and construction of a project, separately awarding the design and construct-only contract to (usually) the lowest bidders. This way, the traditional procurement model and respective contracts introduce a significant gap between the parties involved.

A separation of design from construction is a major barrier for integrated project delivery with DfMA. The knowledge transfer from manufacture and construction to design is disrupted.

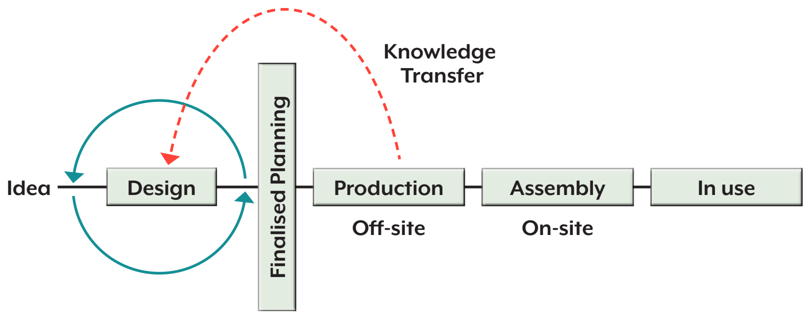
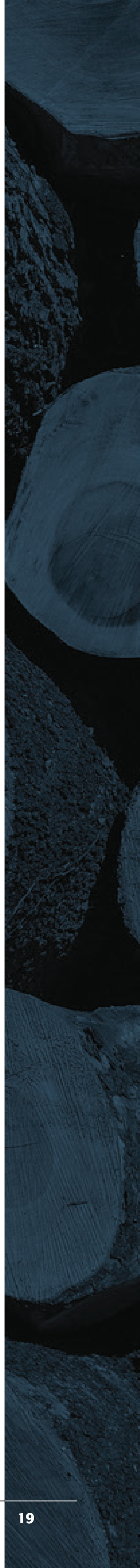


Figure 10: Traditional project stages are missing knowledge transfer.

Opportunities for innovation and efficiencies in traditional procurement are severely limited through the contractual and timely separation of design and construction.



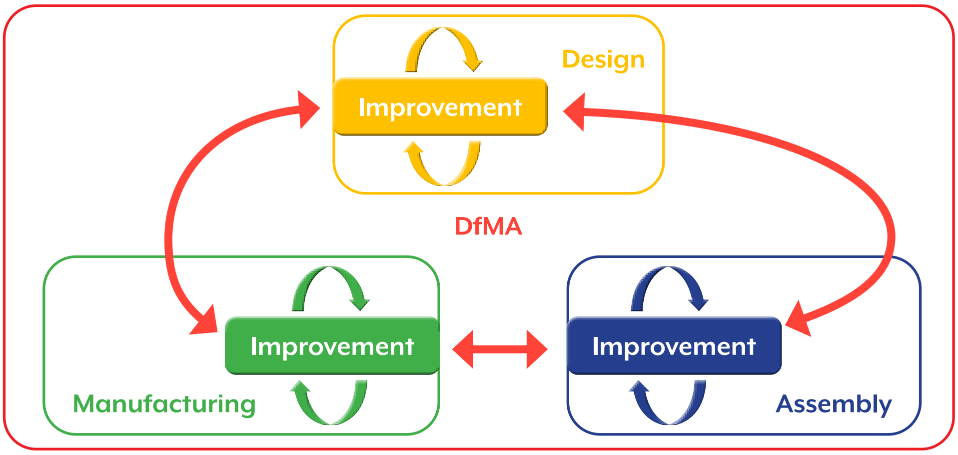


Figure 11: Integrated Design – Cycle of Continuous Improvement with DfMA.

4.9.2 Integrated and collaborative Procurement

As the name implies, an integrated approach between design and construction demands a collaborative approach to procurement. Integrated project delivery models with contractors and prefabricators are displayed in Figure 12. Integrated procurement enables DfMA by breaking down barriers and demanding a clear definition and allocation of project risk. Problems are solved by the team via the continuous cycle of improvement during the design phase (Figure 11), as opposed to siloed design disciplines. Front-loading the design process requires additional time for pre-construction activities. Construction periods can be reduced by frontloading the design phase.
Alliancing is the most suited framework for integrated design and procurement on complex projects.

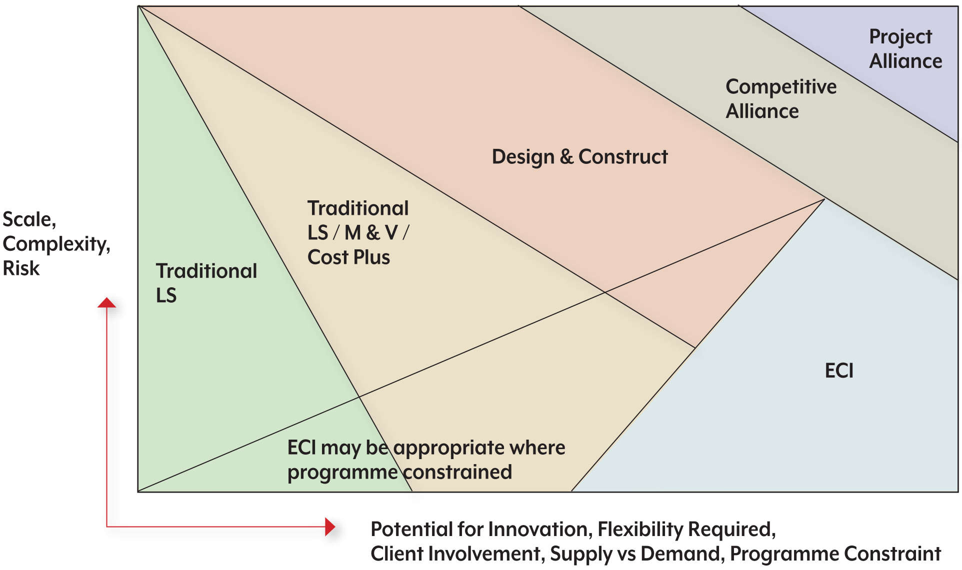


Figure 12: New Zealand Transport Agency (NZTA) Delivery model selection diagram.

4.9.3 Early Contractor Involvement (ECI)

Early Contractor Involvement (ECI) may be considered during the design phase where contractor input is desired, however the actual contractor has not been appointed yet. ECI is a means of involving a preferred contractor early to help inform a design, with potential compensation for the contractor in return.

4.9.4 Project Alliance or Design and Construct

The customer establishes a contract with a single party (ideally a designer/contractor consortium) which assumes the full responsibility for both design and construction. Through early contractor involvement the client grants the freedom to the contractor (or consortium) to propose and realise an innovative design, including the use of new materials, production and assembly techniques. The main requirement is that the design meets the client's functional requirements.[6]

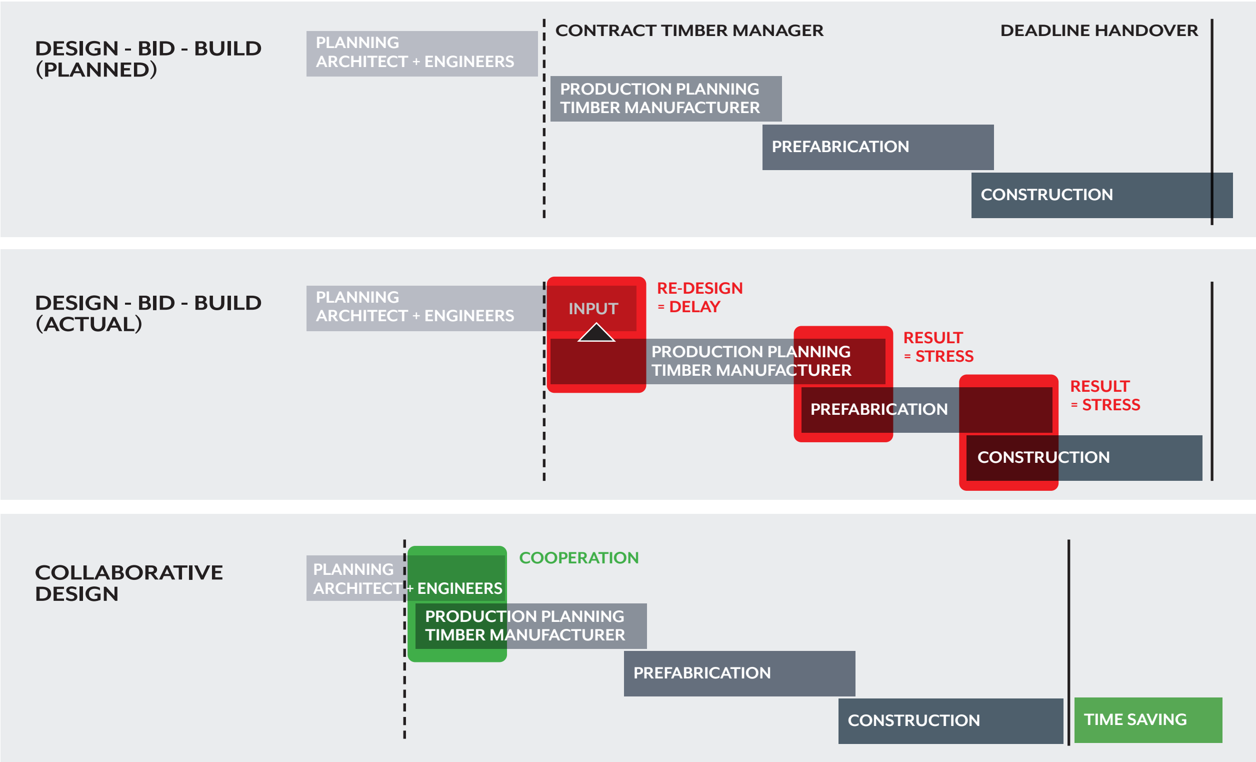


Figure 13: Design-Bid-Build vs Integrated and Collaborative Design. [leanWood – Technical University Munich, Germany]

4.10 CONCLUSION

DfMA is about how a building (product) can be designed, to be manufactured and assembled with as little waste as possible. Prefabrication affects design choices and decisions throughout the project. The decision for off-site production should not be added after the design is finalised.

DfMA focuses on the standardisation and simplification of materials and details, creating a meaningful default library for designers that should not be deviated from. DfMA becomes the cookbook for the design team, aligning design with manufacture and assembly processes.

In case DfMA is compromised by design too much, the project may not be suitable for a particular prefabricator or prefabrication at all.

> **Adam Locke, Laing O'Rourke, UK:**
> ***"It (DfMA) can provide enormous benefits in terms of productivity, safety, environmental improvement and higher quality. We're getting four times as much productivity than you would otherwise, certainly in terms of output per man hour.***
>
> ***… 70% of any given project is constructed using DfMA, leading to a 60% reduction of onsite labour and a 30% reduction in programme – all in comparison to a traditionally constructed alternative. It is also aiming for zero accidents and towards-zero carbon emissions."*** [47]

DfMA enables Modern Methods of Construction (MMC) and removes the uncertainties of traditional construction approaches. DfMA enables efficient construction solutions, the key to high productivity.

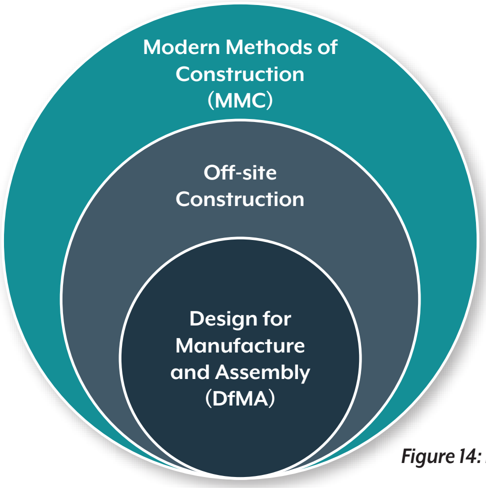


Figure 14: Modern Methods of Construction (MMC).

The virtual representation of a building allows a contractor to better assess any construction risks. Visualizing the building before it is build and identifying any risks by assessing build methodologies, enables design adjustments and risk reductions.

A contractor can influence the building process by informing the design process through DfMA. DfMA informed BIM models provide a level of detail that enable safety, sequence and logistics analysis for the site. 4D BIM is the intelligent linking of time or sequence related information to a 3D model. Sophisticated models for large projects may include crane movements and trace the route of individual modules to their final destination. A 4D time-analysis of the assembly process has the potential to pre-empt logistical issues, optimise the process and dramatically increase the efficiencies on site.

Beyond 3D geometry, fabrication models can contain meta-data and production information e.g.

- carbon emissions.
- ethical sourcing.
- materials.
- manufacturer.
- volumes.
- sub-systems.
- products.
- quantities.
- links to ERP systems.

DfMA enables increased automated data processing for project administration like costing, purchasing, tracking, tracing, progress tracking through 4D and production automation to name a few.

TRADITIONAL DESIGN APPROACH	DfMA APPROACH
Disconnected project teams: • design disciplines work in isolation. • teams manage risk at company interfaces, not collectively. • risks are pushed into the tender/build phase. • opportunities to remove constraints are not realised.	Collaboration between trades and disciplines to: • apply innovative off-site methods effectively. • reduce modules/components, eliminate clashes, manage interfaces. • understand and visualise assembly instructions. • integrate compliance processes. • consider operational use and maintenance. • BOM – material take offs (BIM or production models). • BOM can be linked with ERP systems. • 4D planning, constructability and programme optimisation. • Off-site production – automation. • Tracking of materials and products. • Facility Management.

Table 7: Traditional Design vs DfMA from a contractor perspective.

5. LEAN CONSTRUCTION

Lean focuses on a customer-centric project culture, creating value to the customer by reducing waste. Lean construction forms the basis of high-quality construction in the shortest possible timeframe at the lowest possible cost. This guide is not intended as comprehensive source on Lean Construction, but merely a brief overview of the Lean Philosophy, Lean Principles and Lean Tools.

Lean strategies are not just manufacturing related, they are applied across many other industries: Health, Governments, Software development and so on.

> ***"All we are doing is looking at the timeline from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that timeline by removing the non-value-added wastes".***
>
> **(1988, Taiichi Ohno, Lean/TPS inventor and Chief Engineer Toyota)**

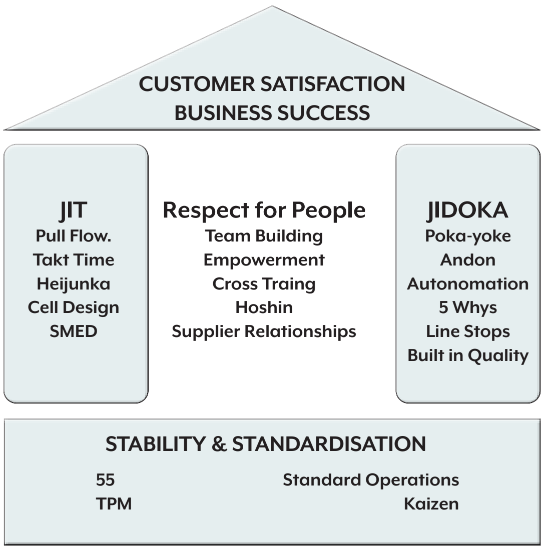


Figure 15: Lean Basics – Lean Manufacturing Tools. [leanmanufacturingtools.org]

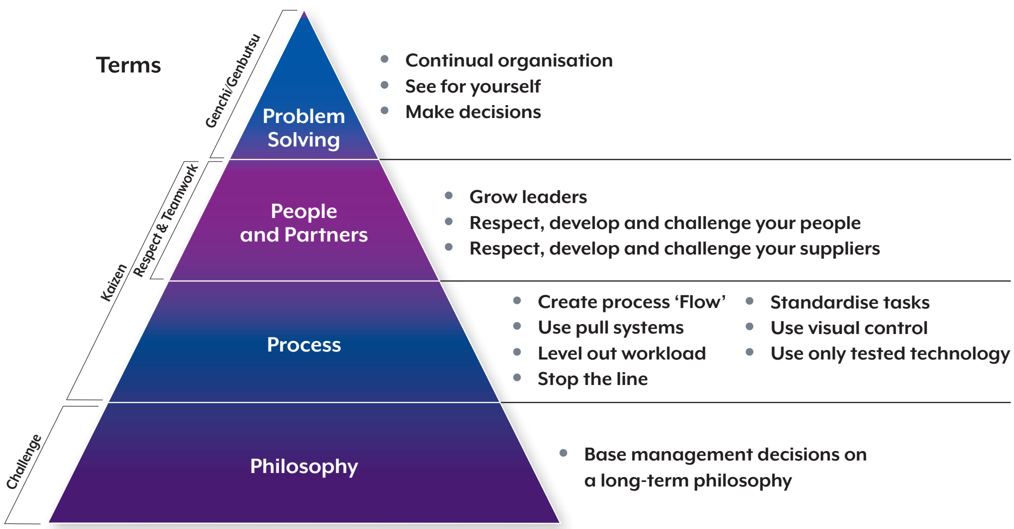


Figure 16: Lean Philosophy – Toyota Production System. [partnersinexcellenceblog.com]

5.1 WASTE REDUCTION

The Lean philosophy was developed from Toyota's thought process in car manufacturing (TPS – Toyota Production System[27]). Lean attempts to focus on what adds value, by reducing everything that is not adding value. Non value-adding aspects are called waste. Waste creates cost in the project delivery. Reducing waste reduces costs. Lean differentiates eight different types of waste with the commonly known acronym TIMWOODS:

T I M

Transportation – wasted time, resources and costs when unnecessarily moving products and materials

Inventory – wastes resulting from excess products and materials that are not processed

Motion – wasted time and effort related to unnecessary movements by people / material / equipment

W O O D S

Waiting – waste from time spent waiting for the next process step to occur

Overproduction – waste form making more product than customers demand

Over Processing – waste related to more work or higher quality than is required

Defects – waste from a product or service failure to meet customer expectations

Skills – wastes due to underutilisation of people's talents, skills and knowledge

5.2 FLOW

The timeline of prefabricated projects (including resulting implications on procurement) are best understood working backwards in time from the assembly of prefabricated modules on site, which is comparable to the final assembly line of a car manufacturer. The critical path of a project emerges by carefully matching design, production and supply of resources to the assembly speed and processes on the final assembly site.

Make it flow. Uninterrupted and efficient flow of construction work is the end goal for a contractor. Identifying interruptions and addressing their root causes improves flow. Good design and planning can create flow.

As an example, a Lean construction tool for flow is the Last Planner® System.

Figure 17: Speed with flow – pre-assembled frames and space planning for continuous lifting, Trimble Building.

Figure 18: Example for Last Planner®. (Photo: Naylor Love)

5.3 JUST IN TIME (JIT)

Flow is enabled by JIT, the process of managing the timely delivery of materials, subcontractors and services required: what, when, where, how and the quantity, to ensure the on-time completion of a construction project.

In traditional construction, JIT delivery of a project is the expertise of the Main Contractor. For off-site construction projects, JIT planning must be considered during the DfMA design phases and must be informed by prefabricators and contractors.

5.4 ON-SITE CYCLE AND TAKT TIME

On-site cycle time is the overall time to install one component on site, from the time it is delivered to site until the final step in the installation process on site.

As an example, cycle time is the time during which a precast concrete panel arrives on site, is attached to the crane, lifted, landed, propped, grouted, weld plates welded and propping removed. Cycle time can be several hours or days.

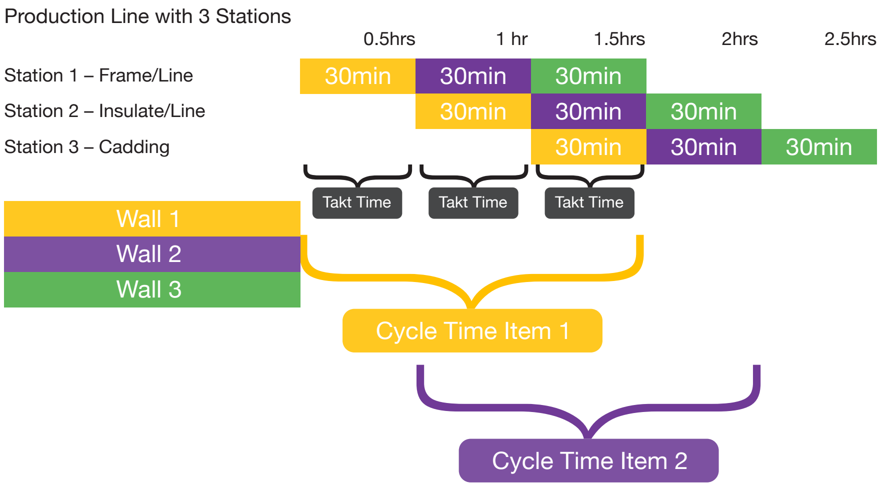


Figure 19: Multi Station Factory – Manufacturing Cycle and Takt Time.

On-site takt time is the heartbeat or rhythm of the construction site, the frequency in which install crews move from one area on site to the next and install components to form the finished building. Takt time is the time it takes from the start of installation of one component to the start of the next component.

Takt time is a borrowing of the Japanese word takutotaimu (タクトタイム), which in turn was borrowed from the German word Taktzeit, meaning clock interval. The word was likely introduced to Japan by German engineers in the 1930s.[Wikipedia]

Figure 20: Metronome – Music aid providing 'Takt' time to musicians.

For example, on-site takt time is the time it takes from attaching one component to the crane hook to the next (crane hook time) as per Figure 21.

As an example, from a Toyota car factory, a car comes off the production line every 87 seconds[48] (Takt Time) with each car having a total build time of approximately 13 hours[48] (Cycle Time).

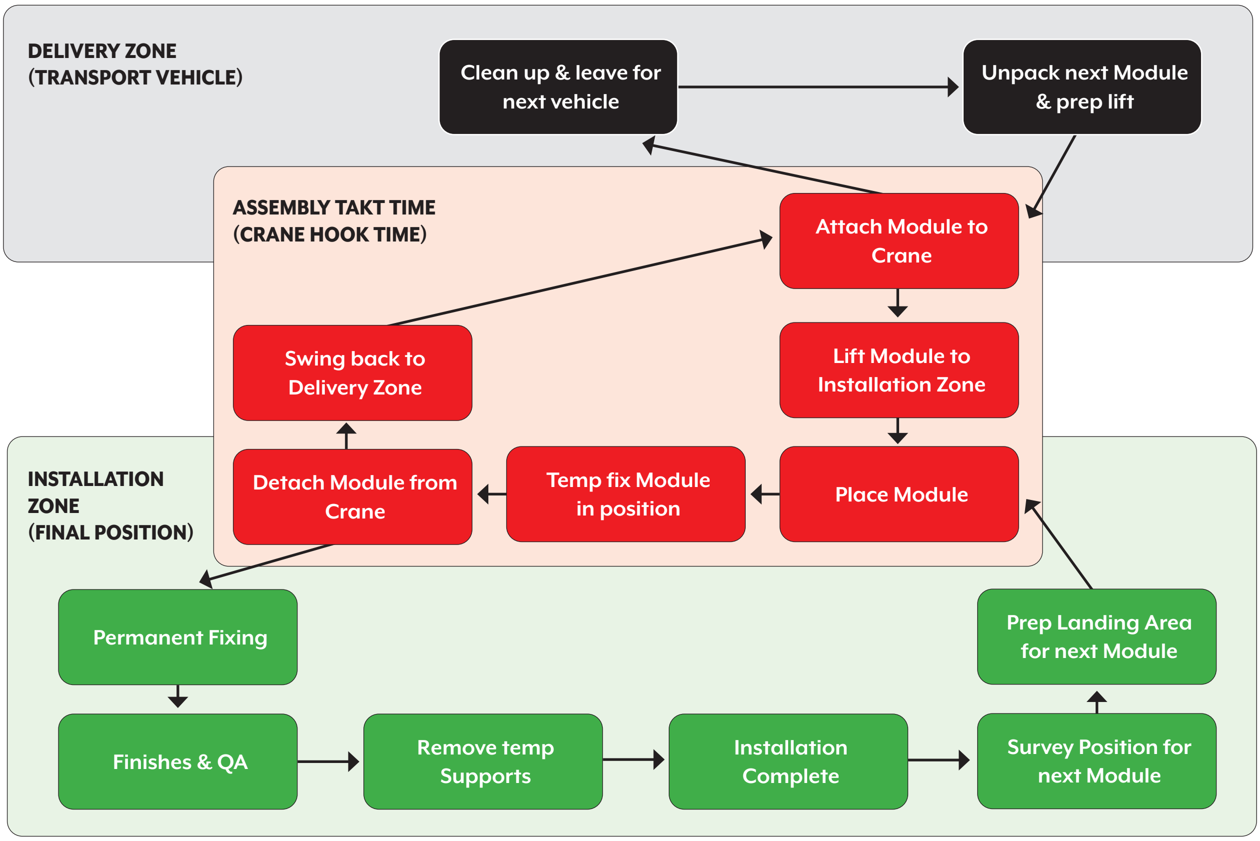


Figure 21: Example Assembly Takt Time – Installation of an item with a crane.

5.5 PUSH AND PULL

Cycle and takt times also apply for the off-site production lines for modules and components. Takt times for manufacturing and assembly are interdependent. Manufacturing must keep up with the on-site speed and vice versa. Components are 'pulled' 'just in time' onto the assembly site from various prefabricators. 'Pull' means 'make to order' in which the production sequence, pace and speed are based on actual demand.

'Push' would allow for manufacturing to provide components to assembly no matter the sequence, quantity and speed.

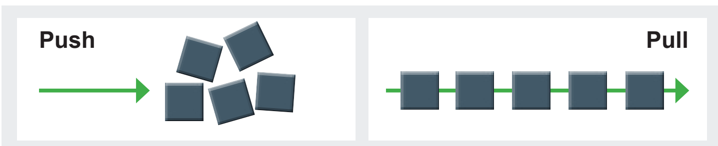


Figure 22: Push vs. Pull.

5.6 LABOUR PRODUCTIVITY & PRODUCTION LEVELLING

Labour productivity is the efficient utilisation of the labour force, reducing time waste by ensuring that staff are executing the right task (effectiveness), the right way (efficiency) (refer to Figure 23).

Efficiency	X	Effectiveness	=	Productivity
Doing things right		Doing the right things		Employees carry out the correct tasks (effective) in the right way (efficient)
Is the employee working on the task in the best way possible?		Is the action the employee taking achieving the intended outcome?		
e.g. Is the carpenter using the most efficient tool to cut timber?		e.g. Is the carpenter working within or outside his skillset?		

Figure 23: Labour Productivity equation.

Traditional construction is constantly exposed to short notice and unexpected changes, resulting in downtime, uneven resourcing and productivity losses. This can be caused by various reasons: weather, site -, supply -, quality -, design delays etc. Workers stop and need to be re-allocated by management: de- and re-establish, travel, idle, re-organise etc.

The goal is an evenly distributed workload: production levelling. Transferring much of the workload into controlled factory environments eliminates a vast range of on-site related productivity losses. Workforce forecasting and planning are critical to create stability and predictability for any contractor. Short on-site takt time and efficient cycle time enable high on-site productivity using small teams.

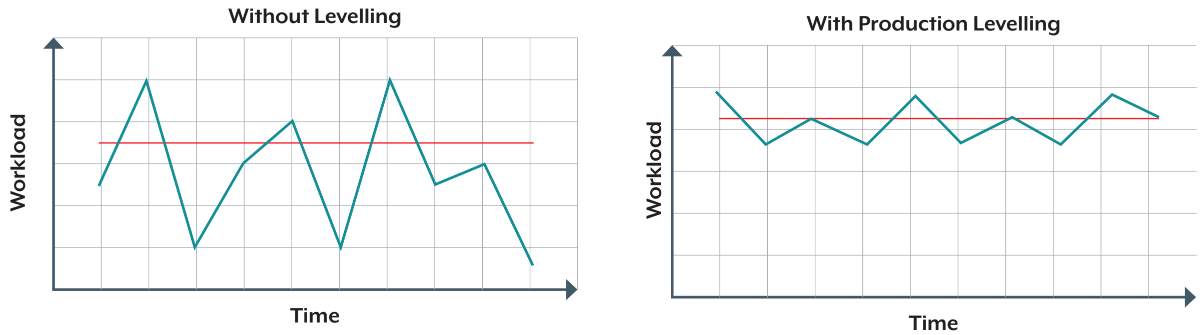
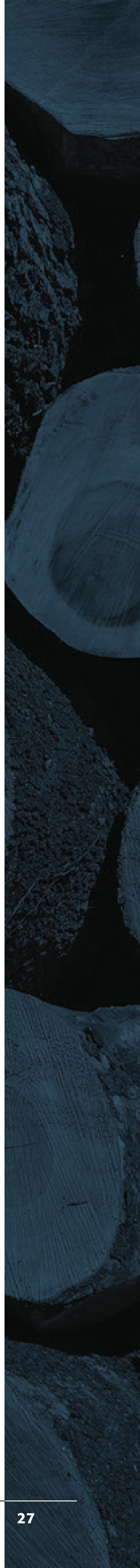


Figure 24: Production Levelling.

5.7 VALUE STREAM MAPPING

Value stream mapping is the analysis of project information and production flow to identify expectations, responsibilities, workflow, value adding steps and most importantly: types and amount of wastes. Robust processes for continuous improvement enable the systematic reduction of any wastes and an increase of productivity for design, administration, on-site and off-site activities.



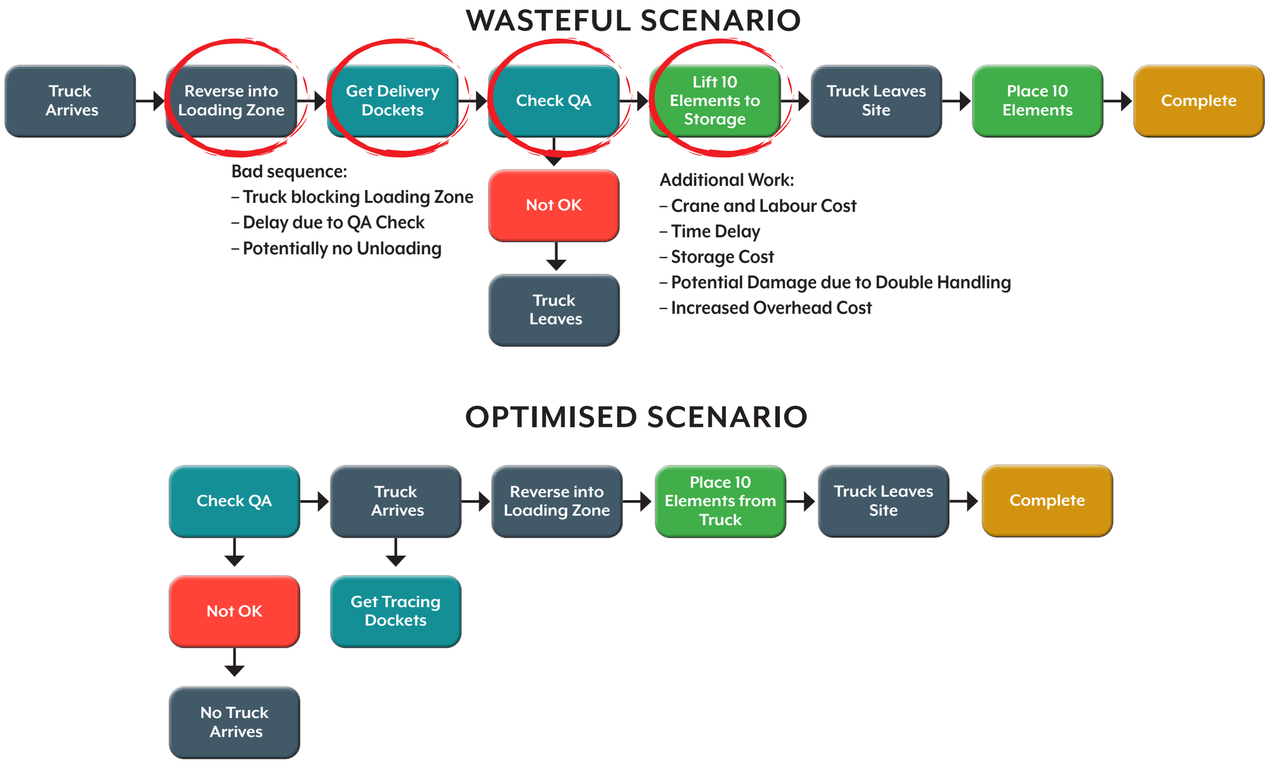


Figure 25: Value Stream example for the identification of on-site waste.

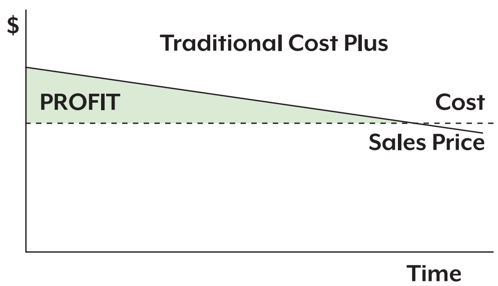
5.8 CONTINUOUS IMPROVEMENT

> *"Since it is not perfect, improve it!"*

Continuous improvement is the constant review of the current processes and operations with the aim of waste reduction. Improvements are based on small changes rather than radical changes. Changes come from suggestions of the employees themselves which makes it easier to implement improvements. An engaged workforce and a management structure proactively driving change, are the key to waste reduction and productivity increase.

5.9 COST

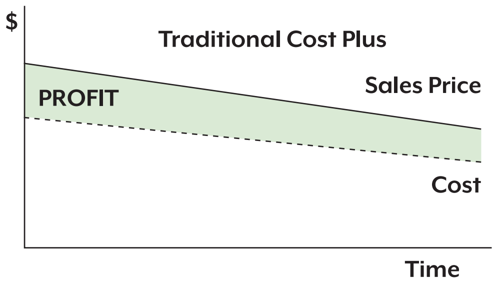
Traditionally the contractor is forced by prevailing customer procurement strategies and prescriptive designs to a conventionally driven price competitiveness on a Cost-Plus model.



Cost + Desired Profit = Selling Price

The Lean Thinking Model has the emphasis on:

- Costs are controllable and can be reduced by the application of Lean manufacture and construction principles.
- The sales price is determined by what the customer is willing to pay, not by EBITDA goals.



Selling Price - Cost = Desired Profit

Arithmetically, both approaches are identical, the difference in the beliefs and their importance have a significant impact on industry or company behaviour, market dynamics and performance.

5.10 CONCLUSION

Lean Construction is waste reduction, achieves high productivity, better quality, shorter time frames and as a by-product: controlled and sustainable cost reductions. Off-site production enables a leaner construction process. DfMA integrates the Lean construction expertise of contractors and prefabricators into the design.

In short: Integrated design enables productivity increases and better buildings. Continuous improvement ultimately leads to fully optimised design, manufacture and assembly processes.

Lean innovations do not necessarily have to be about automation, they can be about smarter processing and efficient workflows in administration, production or on the building site.

Figure 26: Productivity increase as result of Long Term Thinking, DfMA, Prefab, Lean Construction.

6. CONSTRUCTION PLANNING

Large commercial and small residential projects differ in their selection of prefabricated systems, contractual arrangements, teams, budgets, design complexities and delivery approaches. This chapter covers general elements in the construction planning when working with prefabricated timber systems.

6.1 FABRICATION MODEL

In addition to chapter 4:

RISK	CAUSE	PROTECTIVE MEASURE
Poor Coordination	No fabrication model	• Plan in 3D where applicable. • Machine produced components must be modelled in 3D.
	Poor clarification of interfaces	• Clear execution plan for fabrication model. • Appoint a responsible party / person for coordination. • Interfaces and deliverables between trades to be precisely defined.
	Trade coordination missing or not happening at the same time	• Coordinate model involving key trades from the beginning. • Allow time for fabrication model development on construction programme.
	Poor Design Coordination	• Clarify client deliverables to enable fabrication model progression. • Coordinate with fabrication models of key trades. • Check design for producibility and constructability. • Check design and extent of fabrication model development.
	Lack of producibility	• DfMA - Work with prefabricator to obtain knowledge about the CNC or manual machining capacities and capabilities.
	Poor production model coordination	• Contractors to upskill construction teams to review and manage 3D models. • Contractors to educate construction teams on working with various timber solutions and prefabrication. • Allow sufficient time to review models
	Lack of constructability	• DfMA – Work with contractor and subcontractors to harness their knowledge of site logistics.
	Lack of traceability	• Agree on a labelling and component naming conventions across the models to avoid confusion. • Naming conventions in the model should be applied throughout the production process – agree with the prefabricator on their naming conventions to avoid confusion. • Components need to be able to be traced back to their production batches. • Each component is to be labelled by each prefabricator for traceability. • Quality assurance systems are required to record component ID's.

Figure 27: No federated fabrication model: lift door and CLT lift shaft door opening do not line up.

Figure 28: No federated model: afterthought – Passive fire protection on an exposed CLT panel.

6.2 CONSTRUCTION PROGRAMME

Lead times for off-site activities cover all events enabling the timely delivery of components to the gate of the construction site.

Understanding critical off-site activities are crucial when setting realistic project timelines. Lead times in timber prefabrication are often underestimated or not understood. Off-site activities need to be planned, coordinated and executed. Production capacities in New Zealand are limited, and production slots with manufacturers and prefabricators must be pre-booked.

Information flow supporting the production of fabrication models often define a project's progress. Complex critical paths now occur in off-site coordination activities and need to be represented on a construction programme. Contractors should therefore work closely with prefabricators. Close attention must be paid to events and design sequences that enable fabricators to progress with fabrication models, shop drawings, production starts, CNC processing, production slots and points of no return, e.g. for design changes. Display periods and their dependencies on the construction programme for communication with the project team. Ensure that fabrication models for other trades advance simultaneously to enable fabrication model coordination:

- Engage competent people to manage operations over the whole of the building lifecycle, from design through to installation.[6]
- Procurement - plan off-site activities, use lean tools and processes, identify the critical path:
  - Understand start dates for fabrication model planning, e.g. manufacturers may only start with building consent and/or 'issued for construction' documentation.
  - Milestones for design development, fabrication model, coordination, reviews and sign off.
  - Off-site production capacities, takt times, material lead times.
  - Highlight agreed production slots with prefabricators.
  - When utilising new (uncertified and/or untested) products, display periods for product developments, testing, verifications, witnessing and certifications.
- Construction - non-traditional on-site activities:
  - Plan installation by components, plan assembly sequence, determine takt times.
  - Optional with fabrication or BIM model: 4D sequence optimisation for rapid assembly.
  - Plan for non-traditional speed and resourcing requirements for services and finishing trades.
  - Allow for drying times for timber after enclosure.

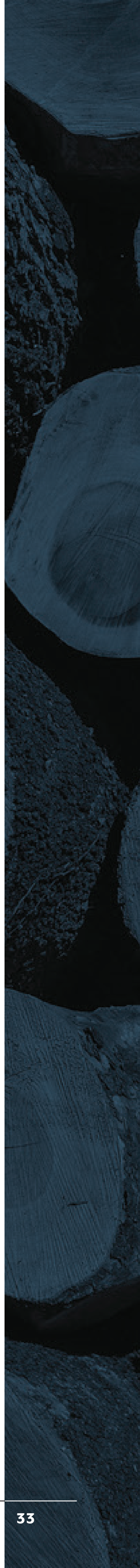
For commercial projects care should be taken with customer provided programmes and expectations. Procurement periods need to be checked for their existence and scrutinised regarding duration and start dates.

The following default process should be explored, adjusted and documented with the prefabricator, and communicated to the customer on the construction programme.

- Stage 0 - Enabling customer deliverables
  - Goal: Provide all design documentation without delays to produce fabrication model.
  - Fully consented, developed, coordinated, adequately dimensioned, producible, and constructible design documentation (issued 'for construction').
  - Design freeze(s). Agree milestone to progressively lock down an evolving production design.
  - Signed head contract.
- Stage 1 – Product Sourcing Approval
  - Goal: Enable prefabricator to source and/or produce blanks or billets from the manufacturer.
  - Prerequisite: Design freeze on grids, levels, dimensions, material grade, treatment and other properties which enable the production of blanks or billets.
  - Components are usually made from custom-made material for each project.
  - Produce fabrication model (e.g. LOD300) and shop drawings
  - Fabrication model / shop drawing sign off by the customer (designer).
  - Result: material order.

- Stage 2 – Processing Approval:
  - Goal: Enable prefabricator to machine blanks or billets (CNC or manual machining).
  - Prerequisite: Design freeze all details and design coordination.
  - Produce fabrication model coordination including node connectors (metalwork) and other trades.
  - Fabrication model / shop drawing sign off by the customer (designer).
  - Machine export or shop drawings for postproduction processing, CNC or manual processing.
  - Result: CNC processing and/or production of subassemblies.
- Stage 3 – Pre-Assembly off-site (if required):
  - Goal: Enable prefabricator to pre-assemble components in the factory to an agreed scope and quality.
  - Prerequisite: Design freeze factory preassembly scope, QA, documentation etc.
  - Produce shop drawings for off-site (factory) pre-assembly.
  - Shop drawing sign off by the customer (designer) (if required).
  - Result: Pre-assembly off-site and shipping.
- Stage 4 –Pre-assembly on-site (if required):
  - Goal: Enable contractor to pre-assemble to an agreed scope and quality.
  - Prerequisite: Design Freeze on-site pre-assembly scope, QA, documentation etc.
  - Shop drawings for pre-assembly scope on-site.
  - Obtain customer (designer) sign off for pre-assembly (if required).
  - Result: Pre-assembly on-site.
- Stage 5 – On-site assembly (if required):
  - Goal: Confirm assembly sequence, scope and quality to assembler.
  - Prerequisite: Design Freeze on-site assembly, QA, documentation, sequence.
  - Produce final assembly drawings and QC documentation for QA and traceability.
  - Obtain customer (designer) sign off for pre-assembly (if required).
  - Result: Final Assembly.

RISK	CAUSE	PROTECTIVE MEASURE
Poor Coordination	Poor design / lack of DfMA	• Rigorous DfMA process from the beginning. • Customer to understand and provide their deliverables.
	Late customer deliverables e.g. late design documentation / no consent	• Customer to provide deliverables on time and in full. • Show deliverables on construction programme. • Clarify and agree customer deliverables at tender / DfMA process.
	Poor programming / planning	• Understand and reflect the off-site procurement processes on programme: - customer deliverables. - contractor/prefabricator deliverables. - critical path on off-site information flow and prefabrication processes. • Monitor progress, communicate and document to customer via regular progress reports.
	Poor contracting Late procurement of timber prefabricator	• Off-site procurement periods likely longer than construction work, engage very early with prefabricators and negotiate contract. • Prefabricator contracts and/or T&C's may not be in line with head contract conditions, allow time for negotiations. • Prefabricators may require significant deposits and offsite claims allow time to negotiate with customer and prefabricators.
	Timber treatment lead times	• Some treatments (H3.x) are not applied off the material production line and additional time may need to be allowed. Additional treatment may also be required post CNC fabrication and prior to pre-assembly. This process can take several weeks. Check with prefabricator that this allowed for in their production periods.
	Poor quality	• Implement robust QA processes and checks during production stages, inspections and assembly checks.
	Poor communication	• Stay in touch with production progress, visit manufacturers and prefabricators.
	Late supply of fixings with limited availability in New Zealand	• Special consideration to lead times from overseas and order on time. • Airfreighting is always available but expensive.
	Poor planning for connectors	• Understand and consider long lead times for connectors. • Allow for sampling and production time buffers. • For further information refer to Chapter 7.1.4.



6.3 TOLERANCES

CNC technology allows the production of consistent tolerances, down to millimetres. Structural requirements may demand very tight tolerances. Care should be taken when reviewing the design documentation for installation tolerances for producibility and constructability. Designers should consult prefabricators and contractors to agree on dimensional design tolerances to:

- Communicate typical and possible production tolerances (prefabricator).
- Understand the practicality of the final assembly (contractor).
- Clarify design expectations (designer).

Good designs feature tolerances, carefully considering and accommodating (some examples):

- Structural and seismic requirements.
- Shrinkage and expansion of timber.
- Weathertightness and systems.
- Thermal expansion and contraction.
- Material creep or creep avoidance.
- Fire protection and acoustic separations.
- Architectural features.
- Material tolerance.
- Module / prefabrication production tolerance.
- Installation / assembly requirements or other purposes.

Critical tolerances need to be identified early and must be shown on design, production and assembly drawings. Onsite installers need to understand installation tolerances, their purpose and ensure that they are maintained during assembly.

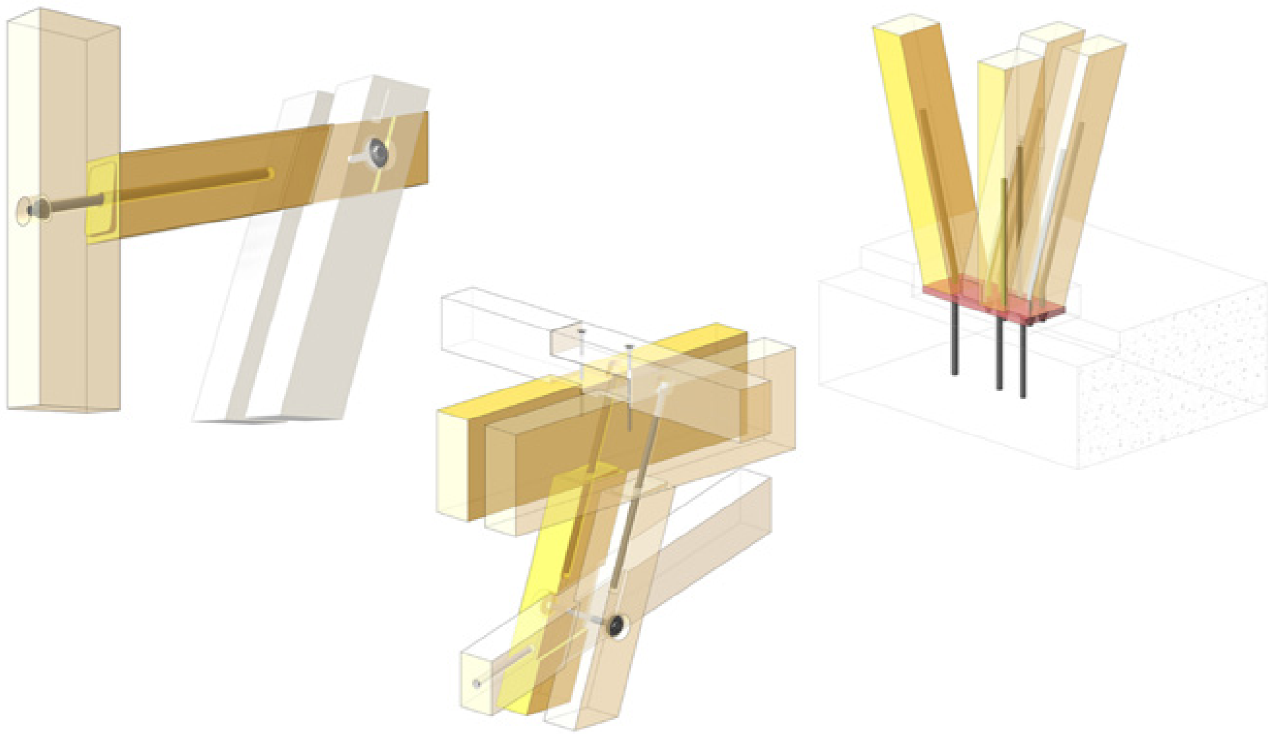


Figure 29: Collaborative DfMA with designers, manufacturer and contractor: optimised junctions to meet manufacture and assembly tolerances – Cathedral Grammar. (Photo: Andrew Barrie Lab and Ruamoko Solutions)

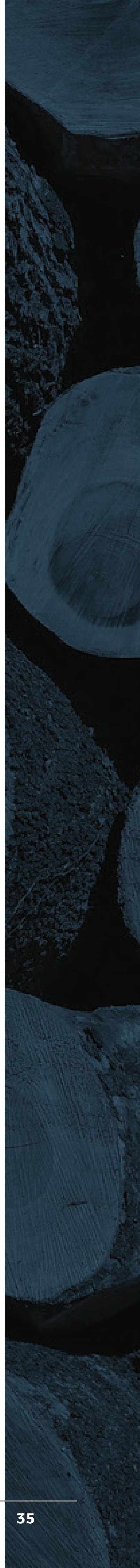
Some reasons to consider tolerances from an assembly point of view:

- Interface with existing structures, e.g. out of plumb, not level.
- Interface with other materials and their specific tolerances, e.g. steel, concrete, brick.
- Interface with other prefab components in Hybrid projects, e.g. wall/wall, wall/floor, pod/walls, connectors, fixings etc.
- Proximity – allow room for installation to avoid rework and delays:
  - Lifting equipment like strops/chains/cables and safety belts.
  - Rotating and movement of elements into final position.
  - Workspace to fix and/or finishing work (connections, access for tools and equipment).
  - Tapes and sealants.
  - Temporary support clearance.
  - Temporary or permanent water- and/or surface protection measures.

RISK	CAUSE	PROTECTIVE MEASURE
Existing structure and off-site timber components do not fit	Poor coordination or lack of tolerance considerations	• 3D scan existing structure or accurate as Built and implement into BIM + fabrication model. • Allow adequate tolerances between interfaces. • Correct installation set out to fabrication model.
Hybrid components or services and timber components do not fit	Poor design, lack of DfMA	• Coordinate all design disciplines. • Design for realistic tolerances of other trades. • Confirm tolerances early in the process. • Introduce tolerance buffers, e.g. Drossbach tubes, grouting, shimming etc.
	Poor production coordination	• Coordinate trades with one federated fabrication model, i.e. one source of truth.
	Poor set out	• DfMA recommended detailing and systems that accommodate certain tolerances at interfaces. • On -site works and set-outs should be done from fabrication model and shop drawings, e.g. set out of cast in elements from fabrication model in form of a slab set out plan. • Accurate surveying and installation of e.g. cast in plates, bolts. • QA and triple check, ensure nothing shifts / is damaged during pour • Consider use of templates.
Timber and connectors do not fit	Refer to 7.1.4	• Refer to 7.1.4
Timber structure cannot be machined	Poor Design, lack of DfMA	• Machining maybe limited to tool sizes and workable cuts etc. • Work with prefabricator, they know their CNC or manual operation best for design advise.

Figure 30: Rework delay due to insufficient tolerances.

Figure 31: CLT – On-site panel cutting to access fixings below panel.



6.4 TEMPORARY TIMBER PROTECTION STRATEGIES

Engineered Timber Products (ETPs) respond to moisture just like natural wood and respond to moisture changes in their environment with shrinkage and expansion. From factory to site prefabricated timber solutions should ideally be kept at the same climatic conditions. ETPs needs to be protected as best as reasonably possible to maintain structural integrity and visual appearance. Temporary Timber Protection Strategies (TTPS) must be planned and specified at design stage.

Generally, the best strategy is designing for constructive wood preservation and designing for Lean construction: enclose the building as soon as possible with all its timber components.

6.4.1 Considerations for Timber

Timber is a natural product and the following characteristics must be considered:

- Timber absorbs water faster than it releases when it dries.
- Timber absorbs water much faster via the end grain than the side grain.
- Timber dries in the right conditions: low air humidity, air circulation, heat and protection from rain / moisture, undercover air circulation provides the best means to dry timber.
- Moisture related movement in timber can cause major quality problems.
- Mould grows under certain conditions: high humidity levels, warm temperature, nutrients, pH, UV light, spores.
- Mould grows on the surface of timber; however, most often does not affect its strength.
- Dirt on wood increases risk of mould growth, since it can contain spores and may retain moisture.
- Mould growth can be a precursor for other, more serious attacks.
- Rot develops at constant high moisture levels and will break down the strength of wood.
- Painted surfaces may slow moisture uptake and extend the drying out process.

Timber deteriorates when it is exposed to moisture for long periods of time. Fungi may develop and breaks down the strength of the wood.

Timber expands when exposed to moisture and contracts when drying. Shrinkage and expansion occur in tangential, radial and longitudinal directions. Due to their build up and production processes, ETP products react and behave differently during expansion and shrinkage. The manufacturers can provide advice on their specific products.

Shrinkage and expansion can have significant effects on the ability to assemble timber structures and must be considered during design and at assembly planning stages.

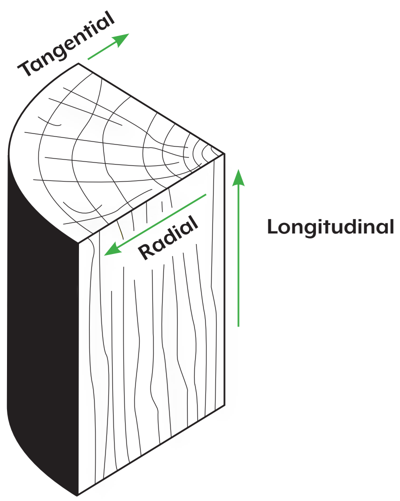


Figure 32: Timber expansion and shrinkage

6.4.2 Timber Treatment

Permanent timber protection or Durability is covered in the New Zealand Building Code in section B2 – Durability and section E2 – External moisture and the New Zealand Standards NZS3604 and NZS3602 specify the level of treatment and their application.

6.4.3 Protection Stages

Timber treatment alone does not protect ETP and prefabricated structures during manufacture, transport and installation until the building is fully enclosed and watertight.

Temporary timber protection can be split into three stages:

- Temporary protection during manufacture and storage.
- Temporary protection during transport.
- Temporary protection during and post installation (until a building is enclosed).

Timber protection during manufacture, storage and transport including their transitions is usually covered by the prefabricator and should be agreed prior to delivery. This guide focuses on temporary protection during and post installation.

6.4.4 Factors

Several factors significantly impact any TTPS:

- Type of construction (Heavy Post and Beam, Mass Timber Panel, etc).
- Shape and form of the building (complex exposed or practically shaped).
- Time of Exposure (speed of construction and permanent enclosure).
- Location (subtropical Auckland vs. temperate, relatively dry Christchurch).
- Time of the year (dry periods vs wet periods).
- Product selection (type of timber and treatment, if any).
- Structural Performance (high or low performance).
- Architectural Finishes (exposed or concealed).
- Degree of prefabrication (services or other materials vulnerable to moisture and sun).
- Other.

6.4.5 Strategy

Temporary timber protection strategies should be implemented at design. If at all, temporary timber protection is usually only poorly described in specifications or contradicts other contract documentation. Specified TTPS may not be practical or not fulfil the intended purpose. The contractor may consider careful examination of design documentation and be aware of possible TTPS.

Timber protection should not contradict and be clearly specified in one place. This allows a contractor to plan and allow for appropriate TTPS. However, effective timber protection is developed as collaborative teamwork considering all aspects of the project delivery. Weather-related matters that could affect finishes and performance need to be accepted by the entire team.

The customer (designer), contractor and prefabricator should develop and agree an adequate protection strategy that:

- Describes a reasonable and practical protection method.
- Which meets design requirements and expectations.
- Generates a realistic customer budget.

6.4.6 Method

The timber protection method should cover:

- What needs protection.
- With what solution.
- When.
- For how long.
- Optional Inspection Plan (refer to Chapter 6.4.8).

6.4.7 Protection Solution

Customers (designers) and contractors need to be aware of possible timber protection solutions, their advantages and disadvantages, and agree on the best mix of solutions for the project. ETPs may sustain some wetting during construction without losing their structural performance. Conditions need to be established with the designer, manufacturer and prefabricator with a project specific TTPS.

- Option 1 – Design for timber protection in service by design:
  - Eliminate or reduce exposures of timber to sun and rain, water ponding.
  - Enclose or cover timber by permanent structures: eaves, overhangs.
  - Cover from water / effective water drainage: drip edges, flashings, protect end grain with end caps etc.
  - Elevate from water ponding surfaces, e.g. column bases off concrete surfaces.
  - Good envelope detailing: two lines of defence, thermal performance, air- and watertightness, (WUFI modelling – movement of heat, air and moisture within building components).
  - For durability of exposed timber structures, a maintenance regime must be provided by design and communicated to the customer.
- Option 2 – Design for Lean construction:
  - Fast construction by design with minimum timber exposure during assembly.
  - Degree of prefabrication, module sizes etc.
  - Construction methodology, e.g. sequence, JIT delivery, fast assembly.
  - Smart roof and façade design that allows a quick enclosure.
- Option 3 – Construction with sealers, painted surface protection, e.g. hydrophobic agents slowing moisture uptake:
  - Timber structure remains exposed during the construction period, can get wet and dry out.
  - Temporary sealers provide temporary protection for up to 12 weeks, are optional and applied by prefabricators.
  - Structures may require significant enclosure within the sealer's validity period.
  - Temporary sealers may not be able to be re-applied.
  - Temporary sealers can be penetrating or film-based. Obtain advice from the prefabricator on recommended products.
  - Temporary sealers must be checked for their compatibility with subsequent coating systems.
  - Permanent sealers to concealed surfaces and end grain, are optional and applied by prefabricators, use flexible coating systems to allow for movement in the substrate through moisture and temperature variations.
  - Designers need to understand this protection method, design and allow for moisture management and movement of joints.
  - This solution is low maintenance, practical and cost effective.
- Option 4 – Construction with mechanical protection e.g. moisture resistant wrapping:
  - Care should be taken when suggesting this protection method. The use and/or incorrect application can cause damage to timber, the use is limited and expensive.

- Mechanical protection needs to be consistently maintained which can be difficult or dangerous, e.g. complexity in structure, at heights, wind zones, quantity, near airports etc.
- Mechanical protection can obstruct assembly, particularly at joints
- Mechanical protection can result in unnoticed damage:
  - permanent physical and stain damage by its fixings.
  - UV staining between exposed and non-exposed areas.
  - sweating and mould growth staining due to condensation / humidity.
  - localised water ingress and subsequent damage.
- This method is best for localised application.
- If this solution is required:
  - select permeable products to reduce the potential of mould growth.
  - non damaging fixing methods.
  - provide cavity between cover and timber surface for ventilation.
  - remove as soon as possible.
  - agree method and the likely impacts on timber finishes with customer (designers).

- Option 5 – Construction with full permanent or temporary cover of the entire or part of the construction area:
  - Temporary roof or façade during construction.
  - Partial enclosure with tarpaulin, scaffold and plastic wrap etc.
  - Full enclosure:
    - tent, fixed or wheel temporary roofing.
    - climbing weather protection.
    - expensive and may require purpose design.
  - Best timber protection and most expensive solution.

Figure 33: Permanent, factory applied sealer at junctions for timber protection. (Photo: Nelson Pine)

Figure 34: Mechanical timber protection. (Photo: Nelson Pine)

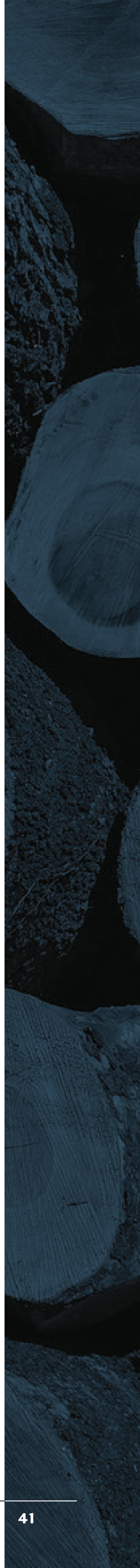
6.4.8 Inspection Plan

An optional inspection plan may be developed to scrutinise the protection strategy and may cover:

- Which components need to be checked in which location (e.g. beam ends, underside etc).
- For which criteria.
- When.
- At what intervals.
- For how long.
- What moisture measuring method is applied.
- What moisture content (moisture in wood) levels are considered as acceptable by designers for how long (for enclosure, structural performance, architectural finish) with the associated notification process when criteria are not met.
- What additional temporary supports are required (moisture creep).

RISK	CAUSE	PROTECTIVE MEASURE
Rejection of timber finishes by customer (designers)	Unrealistic expectations by customer or designers Timber is a natural, non-homogeneous product made from a soft material	• Educate customers and designers. • Select product to match expectations. • Clearly point out imperfections before project start: - glue lines, finger jointing. - inconsistent colours and grains and impact of treatment. - healthy knots, dead knots, filled knots. - pith. - blue stain discolouration. - joint width (CLT, Glulam, PLT). - glue penetration. - patching of imperfections. - plugging of holes (transport / lifting / rainwater management). - traces of planing. - checking and cracking (Glulam). - delamination. - fixings. - brackets. - cupping of surface boards (CLT). • Remove product marking of ETP were required in the factory – maintain product traceability. • Designer to understand specified product grading and visual appearances, consider design inflicted handling and protection methods with realistic expectations for the end product.
	Insufficient inspections and quality checks	• Develop timber inspection plan with customer (designer) and prefabricator. • Implement QA checks for acceptance of finishes (project dependant), e.g. customer (designer) inspections during various inspection stages of completion: - Production of blanks and billets / planning / sanding. - During / after pre-assembly. - At time of delivery. - Before application of finishes.
	Damage during transport	• Ensure prefabricator packs for damage free transport (e.g. edge protection for strapped packs). • Agree timber protection during transport and storage with prefabricator. Depending on the project it may be appropriate to pack each component, entire packs or none at all. • Check at delivery; check components are intact, match delivery docket with material, identify and record any damage, moisture checks, check for dirt.

RISK	CAUSE	PROTECTIVE MEASURE
Metal-stained surface	Moisture and contact of temporary fixings/ props	• Insert separators between timber surface and metal fixings. • Remove props as soon as possible.
	Corrosive materials	• Do not use untreated / corrosive material near timber. • Avoid contact or run offs from untreated metal surfaces.
	Corrosion by metal bracketry or fixings	• Application of primers / final coating in factory prior to installation. • Avoid corrosive fixings.
	Swarf from steel connections or other work	• Eliminate with robust design. • Change of materials or connections (i.e. to aluminium). • Avoid on-site drilling. • Predrill off site where possible. • Mechanical protection. • Remove swarf immediately after drilling. • Avoid grinding or welding in the proximity of timber.
	Temporary wrapping and covers	• Avoid or use non-corrosive materials and methods for protection methods.
Staining by wet trades	Concrete pours, lack of protection	• protect timber surfaces from wet trade installations. • seal all potential gaps to avoid concrete run-off / leakage.
Damage during transport or handling	Incorrect or poor handling causing scratches, scuffmarks, disfigurement	• Reduce handling requirements. • Care during transport to and on site. • Educate install team and handling rules. • Protectors on equipment: - Choose correct handling equipment. - Use protectors to avoid direct contact with prongs. - Use edge protectors with suitable slings. • Other additional protection of material. • Do not walk on timber during pre-assembly. • Do not overstress timber components during handling. • Use clean hand or gloves. • Have strategy in place when to remove factory applied protection, this can be as early as possible or as late as possible on site, depending on the timber protection strategy. • Do not leave tools, materials, lunches or other on the timber. • Remove bad stains (grease, dirt, boot marks etc.) as soon as possible. • Do not drag and drop timber.
Damage post installation	Poor care and protection from trades/environment	• Educate operators and subcontractors at induction and weekly safety briefings. • Protect surfaces where required. Check and clean when required. • Close off finished parts of the building to any non-essential access.
Poor finishes	Incorrect preparation or treatment	• DfMA: Sampling and sign off with customer and design team. • Treatment and its processes may interfere with final coatings or the adhesive used with coverings, check that specified products are compatible. • Staining in dark colours may not be advisable as it may attract heat which can impact resin bleed, distortion or cracking.
	Cloudy and/or milky results with fire/smoke treatment	• DfMA: poor design may specify inadequate product and installation timing (i.e. prolonged exposure to moisture). • Some products can turn cloudy over time with exposure to moisture. Interrogate systems and best time for application. • Ensure timing of installation and method is appropriate for the project. • Investigate alternative products.



RISK	CAUSE	PROTECTIVE MEASURE
Differential ageing of wood surface	UV Effect Natural wooden surfaces naturally darken/change colour after exposure to daylight/UV.	• Robust Design to avoid physical protection (construction speed and sequencing). • Remove physical protection and covers on site. • Use factory applied temporary sealer, cover visual surfaces until the building is closed in as last resort. • Close in building as quick as possible. • Choose UV-resistant final finishes where there will be high incident natural light. • Finishing trade to allow for sand and treatment before applying the final coating.
Water stains, roughened surface, mould, swelling.	Wet timber surfaces/ standing water / capillary action	• Design junctions to keep timber (especially end grain) away from ponding water, like ponding surfaces on concrete. • Factory or site-applied temporary sealing to exposed surfaces. • Factory or site-applied permanent sealers to concealed surfaces and end grains. • On site sealing of critical junctions where capillary action can occur. • Sweep off ponding water.
	Poor temporary drainage	• Robust Design – rainwater considerations. • Rainwater management strategy during construction.
	Excess water over prolonged periods of time Sweating/humid timber under plastic wrap	• Design for short build time and quick enclosure. • Build only as much as can be permanently covered in time. • Constantly check for water ingress, especially during rain. • Keep wood products dry, plan for rainwater management strategies during construction (covers, temporary downpipes). • Maintain cavity between timber and covers. • Use breathable water-resistant wraps when required.
	Connector failure due to swelling	• Potential swelling needs to be considered, and connections exposed to swelling need to be discussed with designer regarding construction monitoring. • Swelling can cause for tight connections not to fit, design and contractors to be able to review shop drawings for adequate tolerances.
Moisture / Rot	Incorrect ventilation during construction	• Ensure protected timber is always adequately ventilated. • If product is covered, remove cover when environmental conditions allow and allow timber to dry.
	Incorrect ventilation post construction	• Ensure that for high temperature areas (e.g. roof spaces), timber is well ventilated and is designed for. • Ensure timber is enclosed below recommended EMC (usually 18%).
Post Hand Over Failures	Poor Maintenance	• Assemble and provide the client with a detailed maintenance schedule. • For exposed timber projects the maintenance regime may need to be understood at planning stages.

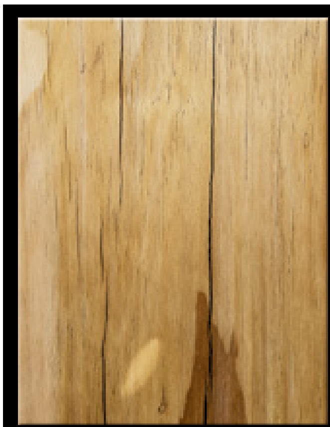


Figure 35: Glulam cracking.

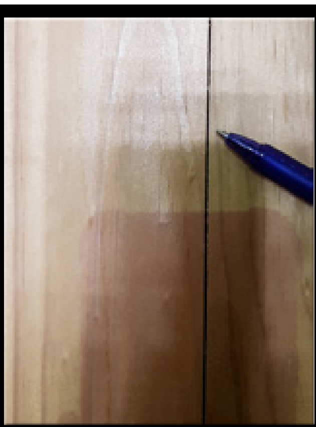


Figure 36: CLT panel, surface board joint.

Figure 37: CLT panel, panel Joint.

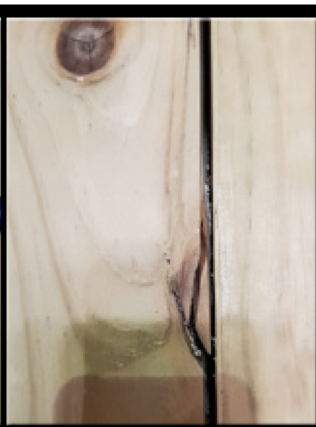


Figure 38: CLT panel, knot at panel joint.

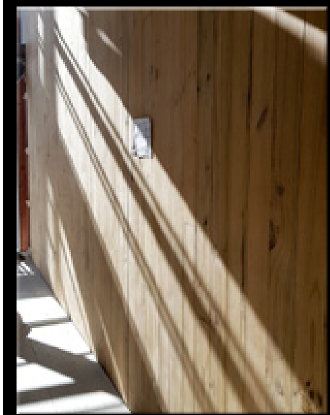


Figure 39: CLT – surface board cupping in critical light.

Figure 40: Grind marks.

Figure 41: Grind marks.

Figure 42: UV staining between exposed and protected area – consequence of mechanical protection.

6.5 TEMPORARY WORKS AND SUPPORT

Temporary work and support cover propping and other temporary structural supports or structures that enable the assembly of a building. Temporary works are defined in the British Standard BS5975 as: “parts of the works that allow or enable construction of, protect, support or provide access to, the permanent works and which might or might not remain in place at the completion of the works”.[16]

The Structural Engineering Society of New Zealand have established a special chapter with The Temporary Works forum (TWf). TWf have published the good practice guideline *Temporary Works Procedural Control*[16] to provide guidance on how to control temporary works risks as far as reasonably practicable.

Depending on the choice of modularisation and construction method, temporary supports with adequate designs implemented through robust procedures may be required and should follow the beforementioned guideline.

High moisture content in ETPs during construction may result in creep deflection. The TWE should consider possible deflection during construction and temporary supports as and where required (NZS3603).

Figure 43: Galvanised proprietary propping. (Photo: Rothoblaas)

Figure 44: Heavy column propping. (Photo: Contract Construction)

6.6 TEMPORARY STORAGE

Avoid temporary storage where possible. Incorrect storage can cause damage to the material: swelling, distortion, discoloration, and potentially structural failure.

RISK	CAUSE	PROTECTIVE MEASURE
Damages to material	Double handling into and in storage	• DfMA installation sequence, optimise flow. • Get materials delivered as late as possible. • Plan to avoid double handling. Lift components directly from delivery truck into final position if possible. • Plan on-site preassembly, double handling, and storage processes.
	Incorrect storage	• Cover and protect timber, follow prefabricator's recommendation. • Store dry, level and on suitable supports. • Store out of direct sunlight. • Provide sufficient ground clearance. • Align dunnage for even load transfers between packs. • Ensure ventilation. • If members are wrapped, split the underside of the wrapping to release moisture collection. • Check materials and effective protection regularly. • Damaged wrapping – replace or repair wrap, ensure material has not sustained any damage. • Cover wrapped packs with tarpaulin and provide ventilation.
	Long term storage	• Liaise with and follow prefabricator's recommendation.

Figure 45: Panels Damaged by prolonged exposure to moisture in storage.

Figure 46: Good practice – dry on-site storage of CLT panels. (Photo: Contract Construction)

6.7 ERECTION PLAN, LIFTING AND DELIVERY

6.7.1 Erection Plan

An erection plan covers the location of cranes, delivery trucks, personnel, installation sequence, temporary support installation and removal, Health and Safety aspects, traffic management, accountabilities and responsibilities. It is good practice to:

- Engage a competent person design and control erection, lifting and delivery.
- Start with the on-site installation sequence and work back to the production line.
- Agree delivery sequences with prefabricators.
- Reduce double handling and storage.
- Develop a comprehensive lifting history:
  - From on-site delivery to installation.
    e.g. lifting from truck to storage and from storage into final position.
  - If required design for lifting processes prior to delivery (usually completed by prefabricator).
- Consider all associated risks with erection, transport and deliveries.

6.7.2 Lifting

Depending on the type of timber system, a variety of lifting systems are available. Temporary stresses may be acting on prefabricated modules. Standard lifting details and a method statement for the lifting and positioning process may need to be developed. Prefabricators may be able to contribute pre-engineered and proven lifting procedures and lifting details.

In the absence of any lifting solution provided by the prefabricator, Temporary Works Engineers (TWE) may be called upon to design a suitable lifting system and conduct checks on modules resulting from temporary stresses during the lifting process.

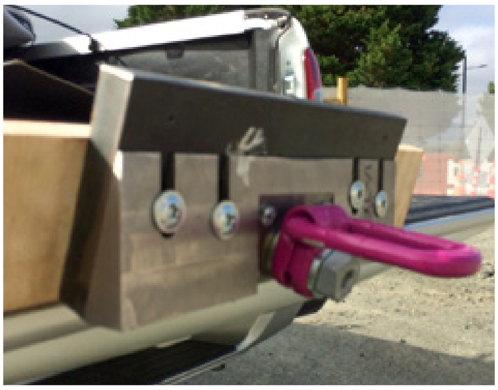


Figure 47: TWE designed bracket for lifting, allowing rotation of the element. (Photo: Naylor Love)

Figure 48: TWE designed lifting, allowing rotation of the element on two axis. (Photo: Naylor Love)

Considerations need to be made with clear instructions as part of a lifting method statement if necessary:

- Define clear responsibilities for lifting design and lifts.
- For complex lift designs engage a competent structural TWE.
- Define clear lifting design limitations: crane location, pick up and drop-down requirements, distances, heights, weights, rigging, obstacles, wind etc.
- Robustness of the prefabricated components:
  – Form stability of the component during the lift, compression forces with slings, deflection under self-weight etc.
- Consider proposed lifting configuration:
  – Centre of gravity, lifting equipment (i.e. spreader bars), slings or lifting anchors, component stacking etc.
  – Rotation of components during the lift and associated forces.
  – Distortion and load equalizer (chain blocks).
- Lifting paths to avoid clashes with other obstacles:
  – Temporary bracing locations and connections.
  – Crane, rig, module, structures, overhead lines tec.
- On-site lifting must be done by competent riggers and certified equipment.
- Consider all current Health and Safety regulations, e.g. working at heights etc.

Figure 51: Lifting LVL frame with corner protection. (Photo: Contract Construction)

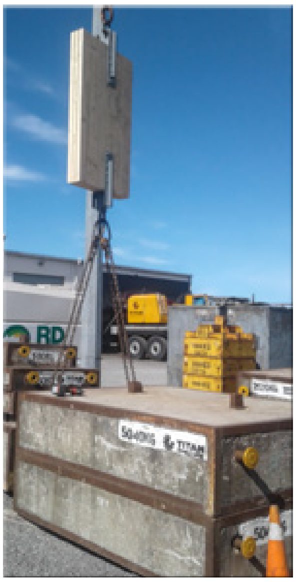


Figure 49: Lifting Bracket test. (Photo: Contract Construction)

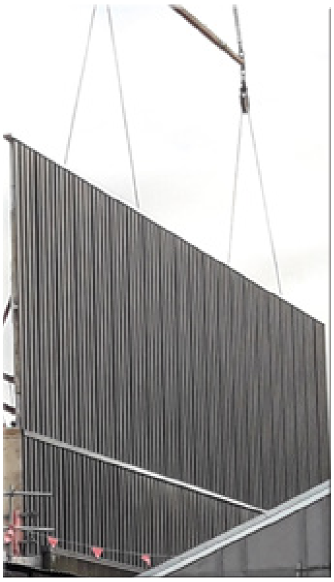


Figure 50: Lifting of prefabricated CLT panel with cladding for boundary wall with spreader beam. (Photo: Contract Construction)

The complexity of the project usually determines the complexity of the erection and lifting plan. The following should be covered as a minimum:

- Crane location and capacity:
  - Consider scenarios for the largest and heaviest and most complex component.
  - Distance between delivery location and crane to furthest install location.
  - Height between delivery vehicle and crane to furthest install location.
  - Lifting equipment that may impact on the crane height (spreader beams or other).
  - Maximum crane capacity on load and reach (check regionally available crane capacities).
  - Travel path of the component and any obstructions.
  - Ground conditions.
- Unloading Situation:
  - Directly from the delivery vehicle:
    - Best option to reduce double handling and all associated disadvantages.
  - From temporary storage location:
    - Consider unloading capacity when components are delivered in packs, define maximum pack sizes or weights with the prefabricator to meet on-site lifting capacity.
  - From container - consider method to unload on site and determine container type for transport with prefabricator:
    - Size: 10/20/40ft containers, Standard or High Cube.
    - Type: Standard (open ends only), Open Side, Flat Rack, Open Top.

Figure 52: Container size options – standard cube vs high cube.

Figure 53: Other container options for better access.

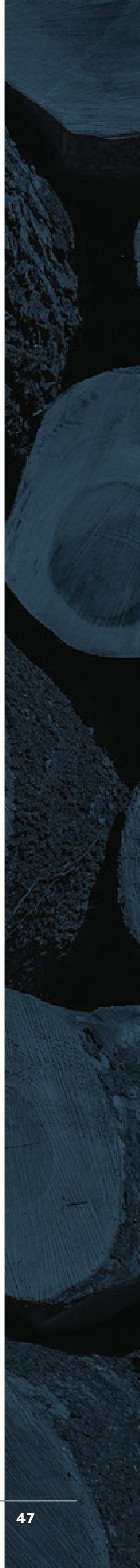
6.7.3 Delivery

It is best practice to engage the prefabricator to deliver materials to site. Deliveries from the prefabricator shall match the installation sequence and agreed delivery conditions:

- Sequence of delivery vehicles.
- Sequence of materials on the delivery vehicles (first component is on top, last at the bottom).
- Documentation provided upfront (refer to 6.10).

Any delivery shall be checked upon arrival:

- Delivery dockets match the delivered components.
- Component sequence is maintained.
- Quality check (damages, protection, quantities, etc).



6.7.4 Risks

RISK	CAUSE	PROTECTIVE MEASURE
Damages to material	Wrong lifting gear	• Implement lifting design and equipment at planning stage. • Only use certified lifting gear and equipment. • Use clean, dry and soft webbing slings and strops. • Do not use chains for slinging timber. • Use spreader beams. • Use corner protection where required.
	Complex lifts / top lifts	• Get TWE to design lifting equipment (e.g. top lifts). • Implement lifting design during fabrication model design stage if required. • Use safety belts where required.
	H&S	• Not considered in this guide.
Difficult to install	Wrong lifting gear	• Consider chain blocks hoists for adjustment of the component when required.

Figure 54: Reusable flat webb slings. (Photo: NZ Safety Blackwoods)

Figure 55: Lifting of a floor panel. (Source: Concision)

6.8 ON-SITE MODIFICATIONS

- No on-site alterations should take place unless agreed in advance with customer (designers) and prefabricator.
- Where site modifications involve cutting or machining treated timber, any site-cut surfaces may need to be site-treated to the required hazard class with a compatible treatment system.

6.9 CLEANING OF TIMBER

In case wood products suffer from stains, marks or mould, some cleaning methods maybe applicable depending on the situation and extend:

- Clean timber as soon as possible.
- Let dirt marks dry and then sweep and brush off. If applicable wash down with water.
- More persistent stains and mould can be cleaned with Oxalic acid available from common merchants. Note that the acid is a dangerous good and all associated Health and Safety requirements apply.
- For more persistent stains and the use of other cleaning products (e.g. Intergrain Reviva, Dulux) contact the manufacturer.
- Do not waterblast.

6.10 TRACEABILITY

This guide does not cover traceability of project documentation (RFI's, change orders etc.) and merely focuses on material and workmanship tracing from supply through to final assembly on site. Contractors should check prefabricators' tracing capabilities and capacities before engagement, especially in cases of alternative compliance processes (refer to Chapter 3.3).

Traceability covers all practicable aspects of inspection and verification, recording the accountability for:

- Design.
- Material supply.
- Workmanship.

Traceability in prefabrication deviates from the traditional approach. Designers and prefabricators significantly impact the methods of site assembly. Prefabricators take a larger portion of work and responsibility for compliance of materials and workmanship.

The documentation prefabricators need to provide needs to be contractually agreed, ideally documented at design stages for compliance:

- Compliance documentation (i.e. Electrical Certificates, Plumbing Certificates, Producer Statements for relevant Building Code Clauses).
- Traceability of Restricted Work (LBP, certified plumbers and electricians etc).
- Quality Assurance Documentation (i.e. ITPs, QC sheets, test results, photos).
- Instructions for on-site handling, storage, installation and commissioning.
- Guarantee and warranty information for all products and the modules.
- As Built documentation and assembly of final product datasheets.
- Manuals and maintenance documentation.

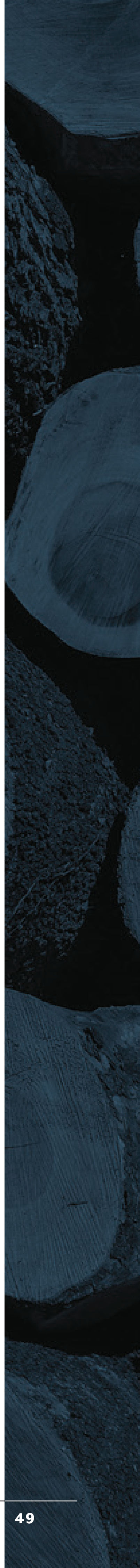
Other contractually required information:

- Quality control is important for traceability; identifies potential for future failures, better to identify, track and fix failures.
- Primary responsibility for verification of conformity lies with the prefabricator and manufacturer of materials.

Consistent traceability also enables preventative maintenance and defect identification. As an example, the installation of a faulty product or installation process can be traced back to a certain product batch, which then can be traced forward to certain modular components. Proactive corrective measures can be implemented early and at low costs. Customers need to understand the complexity, accountability and transparency on their verification process of a contractor's price. The costs of a contractor need to illustrate that compliance and traceability of all material has been allowed for.

6.11 COMPLIANCE

- Overall compliance usually covered by the structural inspection by the project structural engineer (PS1 – Design , PS2 – Design Review, PS4 – Construction Review).
- Collect and provide all documentation specified by the designer: PS3 (Construction), weld certs and tests, steel source certificates.
- Please note that some prefabricators or the compliance process may require an LBP for the installation of prefabricated elements.



7 INSTALLATION

This chapter provides examples and selected information on a variety of prefabricated timber systems. These are pointers only and may not be applicable to every project. Contractors are required to understand the project specific documentation and prefabricator's documentation and recommendations.

Types of timber construction covered in this guide:

Heavy Post and Beam
(Chapter 7.1)

Mass Timber Panel
(Chapter 7.2)

Light Timber Framing (LTF)
(Chapter 7.3)

Volumetric Elements
(Chapter 7.4)

7.1 HEAVY POST AND BEAM

Note that this chapter is an extension to Chapter 6.

7.1.1 Introduction and Examples

Materials	• LVL (Laminated Veneer Lumber), GLT (Glue Laminated Timber) - Glulam. • CNC or manually machined. • Partially preassembled in the factory. • Kitset approach possible: timber, brackets, fixings provided by one supplier.
Applications	• Post and beam structures: open plan buildings (offices, schools), portal frame industrial buildings (barns, production), residential timber featuring homes (traditional mortise and tenon frames).
Advantages	• Efficient use of material and flexible use of space (large spans, open plan, multi-storey). • Simple assembly strategies, efficient construction methods, assembly by builders (potentially LBPs). • Products locally made, low carbon footprint, support local industry and add value to logs. • Passive fire protection can be addressed by: a) oversizing members allowing for charring of the cross section. b) encapsulating members with other materials.

Figure 56: – Hybrid: Heavy Timber and prefabricated LTF roof panels – Nelson Airport. (Photo: Daron Graham)

Figure 57: Shear Wall – Trimble Building.

Figure 58: Industrial Construction – Tumu ITM Manufacturing Facility Hastings. (Photo: Nelson Pine)

Figure 59: Hybrid: Heavy Timber and Floor Panels – NMIT Building Nelson. (Photo: Nelson Pine)

7.1.2 Fabrication Model

Figure 60: Federated 3D model – Nelson Airport. (Photo: Nelson Pine and Offsite Design)

Figure 61: Reality – Nelson Airport. (Photo: Daron Graham)

7.1.3 Installation Tolerances

Figure 62: Tolerance discrepancy in the width of a beam.

Figure 63: Combination of misalignment of metal plate (tolerance), non-standard flat dowel cause damage to LVL veneer.

7.1.4 Connectors, Tools and Fixings

One of the biggest risks for a heavy timber post and beam structures are custom-made metal connectors. Designs significantly impact on producibility and constructability and must be very carefully examined regarding sequencing and tolerances.

Clearly communicate any concerns to customer and designers. Modifications to enable production and assembly are not uncommon and can significantly impact time and cost.

There are no general rules or guidelines, the evaluation depends on the contractors' experience, capabilities, and capacities.

RISK	CAUSE	PROTECTIVE MEASURE
Time and cost explosion in design for custom-made connectors	Design creep during design and construction stages	• Constantly review and critique bracket design. • Aim for simplicity and repetition. • Use standard profiles and materials where possible. • Work with prefabricator and assembler to ensure producibility and constructability to tolerances.
	High labour cost due to complexity of connections	• Pricing based on weight not realistic. • Price on a piece by piece basis, scheduled. • Use experienced metalwork contractors who understand tolerances. • Contemplate risk sharing with customer.
Lack of constructability (assembly)	Lack of DfMA	• Implement DfMA • Interrogate installation sequence for H&S, quality and constructability. • Understand production and assembly tolerances. • Highlight and tag lack of constructability. • Sampling and dry fit assemblies (jigs or samples).
Lack of producibility (prefabrication)	Lack of DfMA	• Interrogate steel production tolerances with prefabricator, ensure they understand the required tolerances for timber structures. • Understand impact of heat related processing on production tolerances, like welding or galvanising. • Use machined timber jigs to test brackets.
Timber and connectors do not fit	Poor Design, no DfMA	• Designers and contractors to understand tolerance and material behaviour, e.g. anisotropic nature of ETP and its behaviour of shrinkage and expansion. • Introduce and specify tolerance requirements. • Designers to consider and coordinate with metalwork to meet ETP tolerances, include timber prefabricator and assembler. • Avoid welding and galvanizing for high precision components.
	Poor sequencing	• Simulate assembly sequence during design and at fabrication model planning at the latest.
	Poor coordination	• Design in one federated fabrication model. • Preassembly QA and triple check, shape, dimensions etc. • Dry fitting. • Check timber is bevelled at brackets welds to allow a smooth fit.
	Poor Quality Assurance	• Size of timber can vary during raw material production and storage. Ensure dimensions are checked and recorded for each component.
	Poor workmanship	• Sampling and dry fitting. Set expectations before mass production starts. • QA and check pre-assembly off-site and on-site.
Fixings cannot be installed in sequence or location	Lack of DfMA	• Detailed assembly sequence simulation. Understand method and check available working space and access requirements. • Ensure tools are available and fit. • Ensure tolerances are understood and/or trialled. • Ensure pilot drilling is done in the factory.
Specified fixings do not exist	Lack of DfMA	• Check fixings for their existence.
Tool is not available in New Zealand	Lack of planning	• Plan assembly method and sequence, order specialist tools when required. • Ensure compliance with H&S requirements and power conversions. • Operators may need to be trained and thorough QA implemented.

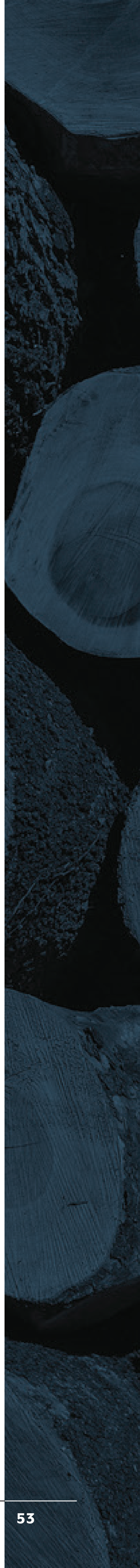


Figure 64: Dry fitting: Specified welded bracket does not fit, intense welding process deformed materials beyond tolerance requirements – Nelson Airport. (Photo: Naylor Love)

Figure 65: Dry fitting: DfMA developed non-welded bracket fits, no distortions from any welding – Nelson Airport. (Photo: Naylor Love)

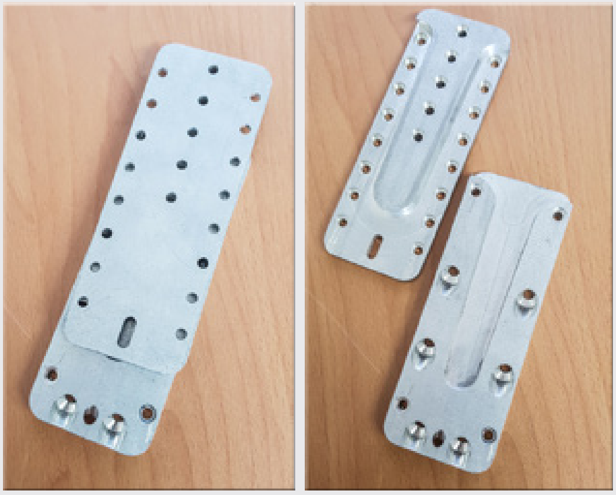


Figure 66: Standard fixing. (Photo: Offsite Design)

Figure 67: Post tensioned timber frames during tensioning. (Photo: Contract Construction)

7.1.5 Service installations

RISK	CAUSE	PROTECTIVE MEASURE
Clashes between services and/or structure	Poor design, lack of DfMA Sizeable on-site drilling is near impossible and not recommended.	• Implement DfMA and coordinated, federated BIM model. • Check for clashes with services, consider design and build trades. • Contemplate seismic and passive fire requirements. • All penetrations to be installed in the factory.
	Poor coordination	• Federated fabrication model. • Services in concealed rebates to be coordinated in model for CNC production.

7.1.6 Temporary Protection and Visual Surfaces

Heavy timber structures are usually exposed for longer periods of time until progress on roof and envelope provide protection from weather. Conditions need to be established with the designer, manufacturer and prefabricator with a project specific TTPS.

In addition to Chapter 6.4.9:

RISK	CAUSE	PROTECTIVE MEASURE
Rejection of timber finishes by customer (designers)	Damage to edges	• Design to consider bevelled or rounded edges to reduce potential of damages, and for continuous timber protection at edges. • Utilise edge protection and plan for reduced and careful handling. Consider edge protection during construction.
	Lifting and handling requirements Holes or screw fixings	• Drill holes in components for lifting/handling purposes need to be communicated to and signed off by the customer. • Allow for plugging holes where required.
	Damage during transport	• Ensure prefabricator packs for damage free transport (e.g. edge protection for strapped packs). • Agree timber protection during transport and storage with prefabricator. Depending on the project it may be appropriate to pack each component, entire packs or none at all. • Check at delivery; check components are intact, match delivery docket with material, identify and record any damage, moisture checks, check for dirt
	LVL – splitting on surface veneer	• Possible during shorter periods of exposure of moisture and heat. • Unlikely impacting structural performance. • Work with manufacturer and prefabricator on client expectation.
	Glulam – checking	• Appears across growth rings due to stresses by changes in moisture content. • Is a natural appearance of timber and reduced with Glulam. • Can be minimised by reducing prolonged exposure of timber components during construction.
	Glulam – delamination	• Work with the prefabricator, some glue line delamination may be expected, ensure expectations are clear and appropriately addressed with all parties.
	Excessive sanding / shiny surfaces	• Where satin and matt surfaces are required do not over sand. • Work with coating applicators on samples prior to final application.
Failed moisture test (e.g. LVL)	Incorrect testing equipment or method Manufacturing process, treatment type, wrong equipment, method or lack of conversion may result in incorrect moisture readings	• Always have an appropriate moisture reader available on site. • Merchants provide guidelines on how to measure moisture content on locally made LVL products. • Timber products require special reading equipment and conversion to obtain realistic results. Refer to the manufacturer's guidelines: - Moisture Meter Correction Figures For Nelson Pine LVL Framing.[39] - Moisture Meter Correction Figures For J-Frame LVL Framing.[43] - Carter Holt Harvey products on merchant websites. - Redstag products on company website. - Other – refer to the manufacturer.

Figure 68: Factory applied permanent treatment to protect flat surface from water, here top surface of shear walls.

Figure 69: Mechanical protection of column base connection.

Figure 70: Temporary Protection during transport, edge protection and timber protected from straps.

Figure 71: Protect timber from wet trades and expansion gap. (Photo: Contract Construction)

Figure 72: Temporary Protection to end grain during assembly. (Photo: Nelson Pine)

Figure 73: Permanent timber protection on floor cassettes. (Photo: Contract Construction)

7.2 MASS TIMBER PANEL

Note that this chapter is an extension to Chapters 6 and 7.1.

7.2.1 Introduction and Examples

Materials	• CLT (Cross Laminated Timber). • PLT (Parallel Laminated Timber). • Partially preassembled in the factory. • Kitset approach possible: timber, brackets, fixings provided by one supplier.
Advantages	• Speed of construction due to large panel format and simple structural connections on site. • Easily combined with e.g. prefabricated wall panels from other systems. • Speed due to faster pace of follow on trades. • High precision, even for complex panel geometry and carpentry. • Sustainable due to large amounts of stored carbon. • Higher thermal mass than lightweight systems. • Has inherent high shear resistance. • Manufacturers typically offer a range of structural and appearance grade panels. • High strength in relation to the self-weight of the material. • Good structural, seismic, fire, thermal performance. • Small construction tolerances with good dimensional stability. • Restriction in panel sizes are usually largely limited by transport. • Durability in corrosive environments (i.e. swimming pools or coastal locations).
Typical applications:	• Can be utilised for floors or walls or roofs, in combination or with other prefabricated timber systems. • Honeycomb structures (apartments, multi-unit housing, aged care facilities, etc.) where internal and permanent walls act as primary supports for short to medium spans. • Prefabricated solid timber stairs, e.g. cut from CLT.

Figure 74: PLT floor panels. (Photo: Woodspan / Taranaki Pine)

Figure 75: Honeycomb structures with CLT panel. (Photo: Miles Construction)

Figure 76: CLT Wall Panels. (Photo: XLam NZ Ltd)

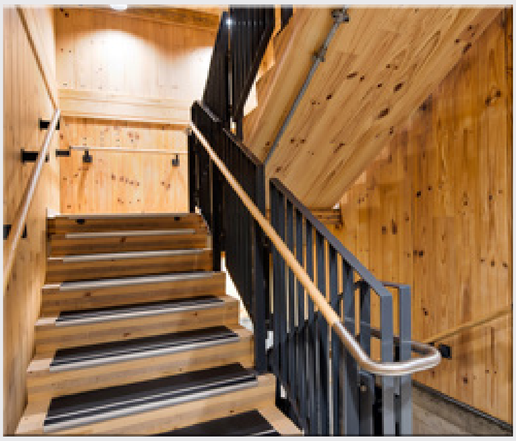


Figure 77: CLT Stairs – Xlam AirStair – Arvida Parklane. (Photo: Engco Ltd)

7.2.2 Fabrication Model

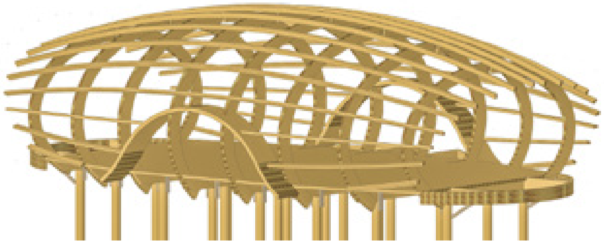


Figure 78: Green School New Zealand – Federated model - PLT floor panels. (Photo: Woodspan / BOON team architects)

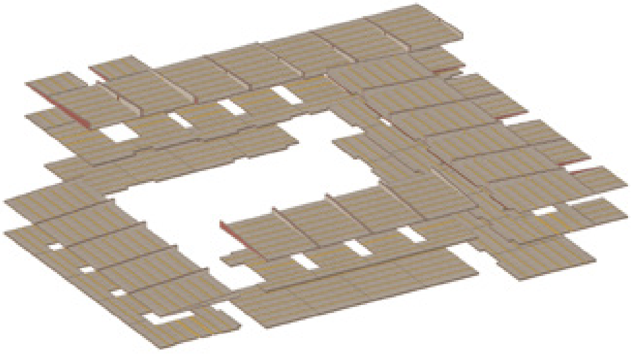


Figure 79: Apartment PLT floor slabs. (Photo: Woodspan)

7.2.3 Construction Programme and Off-site Activities

The critical path of superstructure construction can be significantly reduced, when mass timber panels are utilised for wall, floor, roof panels or in combination with other timber systems. The structures have extremely short construction periods. Access for following trades to large areas is exceptionally quick. Fixing materials to solid timber surfaces is fast, efficient and quiet. Critical paths for following trades may change as they do not need to wait for curing, removal of temporary support structures, scaffold, service penetrations or other obstructive preconditions. Subcontractors need to be educated and resource the projects accordingly.

CLT products offer the choice of balloon and platform construction. Site constraints (e.g. access, propping strategy etc.) must be considered when designing for a construction solution.

Stairs made from mass timber panel products provide permanent, quick and safe access to multiple levels for relevant trades.

RISK	CAUSE	PROTECTIVE MEASURE
Procurement Delays	CLT fabrication modelling, production and shipping	• Allow additional lead time for shipping, customs clearance, devanning etc. • Redstag in Rotorua is commissioning a CLT plant as new local supplier.

Figure 80: CLT Panels – Balloon Construction. (Photo: Miles Construction)

Figure 81: CLT Panels – Platform Construction. (Photo: Miles Construction)

7.2.4 Installation Tolerances

Mass timber panel construction is relatively new in New Zealand. Designs, connection details and installation techniques are in the process of continuous development. A knowledge transfer from large concrete panel product tolerances and techniques can be applied to a certain degree. Panel tolerances should be designed to match large components. Panels should easily be dropped into position.

Timber panels are made to relatively small tolerances and are dimensionally relatively stable. There are expectations on tight installation tolerances for final finishes, structural performance and other performance requirements (e.g. passive fire). The right balance between practicality and expectation is challenging and needs managing. Tolerances are project specific and need to be carefully reviewed on a project by project basis.

Tolerances at panel junctions should further consider other design requirements that affect on-site installation, e.g:

- Visual covers or connections (timber infills, structural connections).
- Air tightness (tapes, seals, membranes).
- Thermal performance (tapes, seals).
- Acoustic separation (seals, tapes, elastomeric packers or strips).
- Smoke and fire separation (seals, strip materials).

Installation tolerances should be identified on assembly shop drawings. Install teams need to be aware and maintain tolerances.

Figure 82: Preparation – Connector Installation to slab.

Figure 83: Clashes with reinforcement in slab.

7.2.5 Connectors, Tools and Fixings

Projects utilise unique and project specific connections and fixings. Typical fixing methods are:

- Anchor nails.
- Screws (wood construction or universal).
- Dowels (tight fitting and/or self-drilling).
- Steel angles brackets (heavy duty) and other wood connectors.
- Bolts (incl. fixing bolt anchors).
- Specialist fixing equipment.

Possibly some specialist equipment is required, most are familiar to the skilled carpenter:

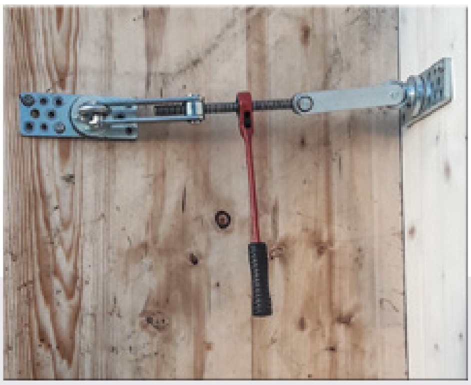


Figure 84: Carpenter beam ratchet / clamp with screw plate (with hooks as separate tool). (Photo: Contract Construction)

Figure 85: Large Mafell beam saw – cutting up to 185mm deep (here on-site processing). (Photo: Contract Construction)

Figure 86: Mortising machine (On-site rebating for services). (Photo: mafell.de)

Figure 87: Custom made and designed hold down Connection.

Figure 88: Recessed hold down fixing. (Photo: Miles Construction)

Figure 89: Hold down Fixings. (Photo: Miles Construction)

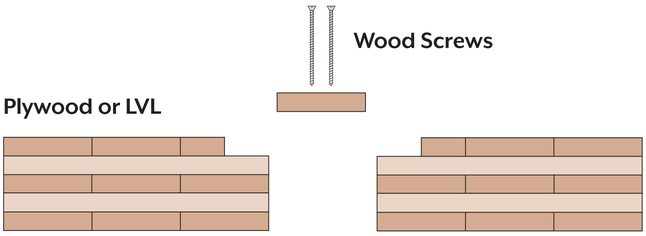


Figure 90: Typical floor connection .

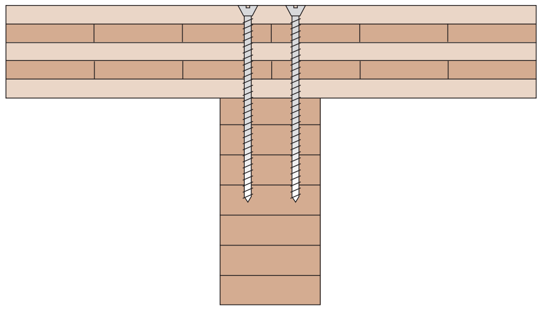


Figure 91: Typical floor to timber beam connection .

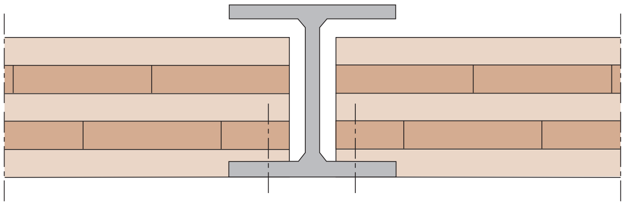


Figure 92: Typical floor to steel beam connection.

7.2.6 Service Installations

The approach with service installations is project specific. Service distribution along ceilings and floors can be achieved via suspended ceilings, bulkheads or raised floors. On walls services can be run inside rebates, behind linings, or surface mounted.

Rebates and penetrations

- Limit the structural integrity of a panel, may be restricted by the prefabricator in size and location.
- Penetrations may need to be adequately treated for sound, fire, smoke, air- and water tightness and should be coordinated at design stage.
- Rebates in exterior walls may require additional treatment to achieve air tightness, weather tightness and durability requirements, depending on the remaining wall thickness and wall build ups. Air leakage through penetrations can cause long term damage to timber. Airtight casings, installations or sealing maybe required. Follow the designer’s and prefabricator’s recommendations.
- Refer to 7.2.12 for on-site modifications.

For cables in rebates

- Rebating and cut outs for casings are recommended to be done in the factory.
- Care needs to be taken on visually exposed timber components.
- Designs must be clear on the location and sizes of plugs / switches / lights.
- Cabling recommended in conduits as protection against mechanical injury and for fire protection.

Water supply, wastewater, heating systems etc.

- Preferably run in separate cavities and not rebated into CLT.
- Consider acoustic treatment and fixings.
- Additional treatment of floors in wet areas may need consideration for permanent timber protection.
- Running pipes on floors may require consideration for waterproofing for potential leakage and water damage.
- When fixing to CLT floors, protect services during construction and against damage by other trades.

Large size service runs

- Rebating is not recommended
- Services may require alternative solutions to rebating, e.g. wall lining on cavity, service risers.

Figure 93: Typical rebate for service installation into CLT wall panel. (Photo: KLH manual)

Figure 94: Typical service installation on exposed wall. (Photo: KLH manual)

Figure 95: Surface mounted service runs on CLT panel.

7.2.7 Temporary Protection and Visual Surfaces

Mass timber panels have larger surfaces and are naturally more exposed to heat and moisture during construction than a post and beam structure. Although a full shelter is the best strategy, it is usually not possible or cost prohibitive. The most suitable TTPS should be agreed with the customer and implemented.

Mass timber panels can sustain a certain degree on moisture, depending on the factors called up for in Chapter 6.4.4. Unmanaged high moisture content of mass timber panels can:

- Result in structural failure.
- Damage the visual appearance:
  - Mass timber panels are not waterproof, under circumstances water can penetrate and stain the underside of panels.
- Deform panels (warping and cupping).

Practical and reasonable mass timber panel protection methods may incorporate some or all of the options below:

- Treat surfaces and end grain in the factory if possible.
- Stand walls and install floors as quick as possible to form a room which is easier to protect.
- Install only as much as can be protected in time from bad weather.
- Protect surfaces overnight and in wet periods:
  - Cover with tarpaulins or by other means.
  - Manage the water run offs, away from the timber structures below.
- Plan for drying out of panels, remove protective layers in dry periods.
- Brush water of wet (floor) panels after rain.
- Allow for drying out panels after enclosure, e.g. floor panels before applying floor finishes.
- Understand added Health and Safety risks with protective layers:
  - They can be slippery or icy in cold periods.
  - Fall protection, penetrations through floors need to be securely covered etc.
- Protect end grain:
  - Top of walls.
  - Underside of walls.
  - Openings.
  - Panel ends and sides / edges.
  - Plan for the installation of protective layers in the factory (paint or membrane).

Figure 96: Metal props fixed away from finished surface. (Photo: Xlam NZ Ltd)

Figure 97: Good practice - CLT panels with permanent sealer for end grain protection. (Photo: Contract Construction)

Figure 98 - Footprints on CLT panel.

Figure 99: Marked surface due to forklift prongs.

7.2.8 Lifting Equipment

Prefabricators usually develop and propose their own lifting and handling methods and provide designs and processes.

Floor and Roof Panels

- Are usually designed with four or more lifting points.
- Lifting points are top mounted with lifting plates, bolts or wood screws, potentially CNC'd into the panel.
- Visually exposed floors may require alternative lifting strategies.
- Lifting anchor points may need to be removed and holes filled (fire, smoke, acoustic, air tightness).
- For narrow panels, and where edge protection is not required, wide lifting ties can be used – check with the prefabricator.

Wall Panels

- Can be top mounted as floor panels.
- Can have removable slings threaded through holes predrilled through the panel.
- Holes may require filling after.

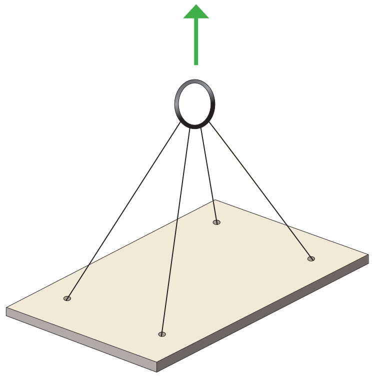


Figure 100: Typical floor lifting method.

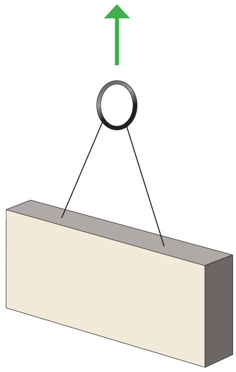


Figure 101: Typical wall lifting method.

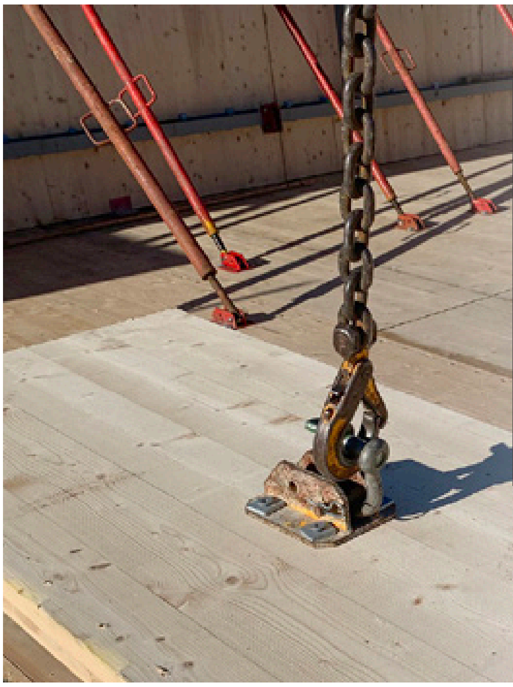
Lifting

- Use only approved and certified gear: anchors, slings, ties, ropes, chains.
- Due to large sizes, consider wind and possible impacts during a lift.
- Consider at lifting design and choice of lifting gear that self-weight can cause deflection.
- For the first install, have a prefabricator's representative on site for advice.
- Temporary bracing design must be in place before lift begins.
- Have appropriate propping gear on-site.
- Consider edge protection, for finished and visible product.
- Slinging: ties with round cross-section (e.g. chains, rope, synthetics) should not be used.

Shop and assembly drawings should identify:

- Overall panel dimensions.
- Weight of the module.
- Centre of gravity.
- Lifting points and lifting system to be employed.
- Lifting and installation method statement.

CLT prefabricators should design and prescribe lifting methods. A good range of possible lifting options and considerations are described in The CLT Handbook Volume 2 Chapter 12[45] from the Canadian publisher FPInnovations.



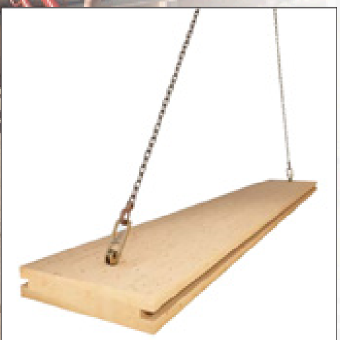


Figure 102: Lifting Hook. (Photo Rothoblaas)

Figure 103: Transportation Anchor. (Photo: Wuerth)

Figure 104: Custom made lifting bracket. (Photo: Contract Construction)

7.2.9 CLT – Specifics

Mass timber panel construction is light construction. Light construction demands specific solutions for fire and smoke rating, acoustics and façade construction. The contractor should be aware of the detailing and experienced to deliver good quality buildings, e.g:

- Fire cells, protection of structural connections, treatment of penetrations through panels.
- Smoke spread, surface treatment.
- Acoustics, flanking, impact noise, suspended ceilings, floating floors, acoustic battens.

RISK	CAUSE	PROTECTIVE MEASURE
Damages to material	Surface Layer board cupping and shrinkage	• Avoid exposure to moisture (weather, poor storage, prolonged exposure). • Check with prefabricator and designer for structural consequences. • Sanding of floors, additional layer to top of CLT floors for specific floor finishes (e.g. tiles or vinyl).
	Panel cupping (planar variations)	• More layers may reduce cupping of the panel. • Crucial components should have multilayer panels (e.g. min 5 layers for lift shafts). • Avoid exposure to moisture (weather, poor storage, prolonged exposure) and heat. • Avoid uneven exposure to moisture and sun, close in as soon as possible. • Cupping may be addressed with additional propping.

Figure 105: Acoustic Battening.
(Photo: Miles Construction)

Figure 106: CLT Stairs for quick access.
(Photo: Miles Construction)

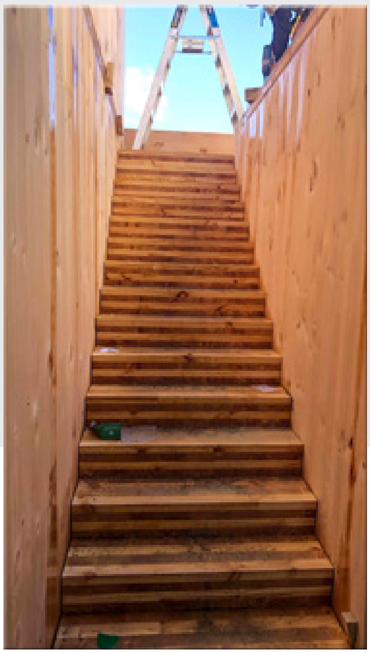


Figure 107: CLT Stairs istalled.
(Photo: Miles Construction)

7.2.10 PLT Specifics

PLT panels are commonly utilised as structural floor and roof panels. Top and undersides can remain exposed as an internal finish. PLT panels are available as New Zealand made product for short procurement periods. New Zealand made PLT panels are CNC cut for high accuracy. Panels are currently available as 890mm wide panels.
Joints between panels are usually done as spine or lap joints for ease of construction.

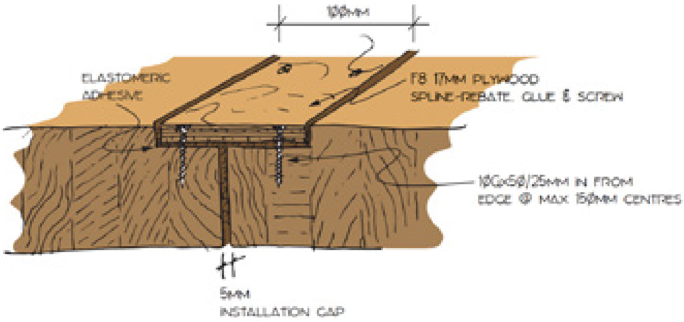


Figure 108: Top Spline Joint. (Image: Woodspan)

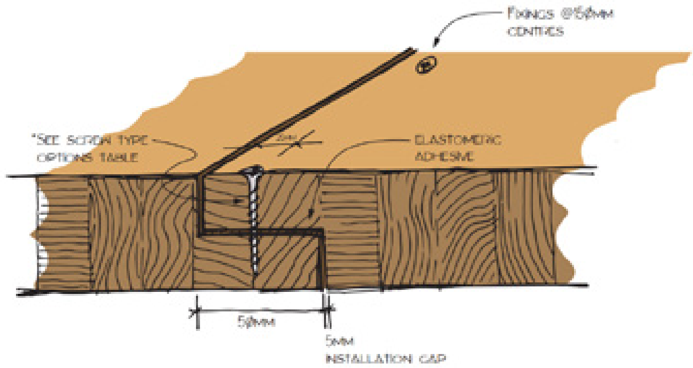


Figure 109: Lap Joint. (Image: Woodspan)

Panels are supplied with a factory applied temporary sealer (with up to 5 weeks exposure) to top face and all sides and can be dispatched fully wrapped. Steel brackets to assist with the lifting can be provided on loan. Alternatively, PLT can be lifted into place with slings or strops.

Figure 110: Lifting Bracket for PLT panels. (Image: Woodspan)

PLT panels have good load capacity parallel to the grain and are generally fixed to the structure with timber screws. Penetrations may be drilled on site under strict guidelines by the prefabricator in conjunction with design approval. Notching is not acceptable.

RISK	CAUSE	PROTECTIVE MEASURE
Damages to material	Surface shrinkage	• Avoid exposure to moisture (weather, poor storage, prolonged exposure). • Check with prefabricator and designer for structural consequences. • Sanding of floors, additional layer to top of PLT floors for specific floor finishes (e.g. tiles or vinyl).
	Panel cupping (planar variations)	• Avoid uneven exposure to moisture and sun, close in as soon as possible. • Fasten panels as soon as possible to the substrate. • Install to meet installation tolerances and allow for shrinkage.

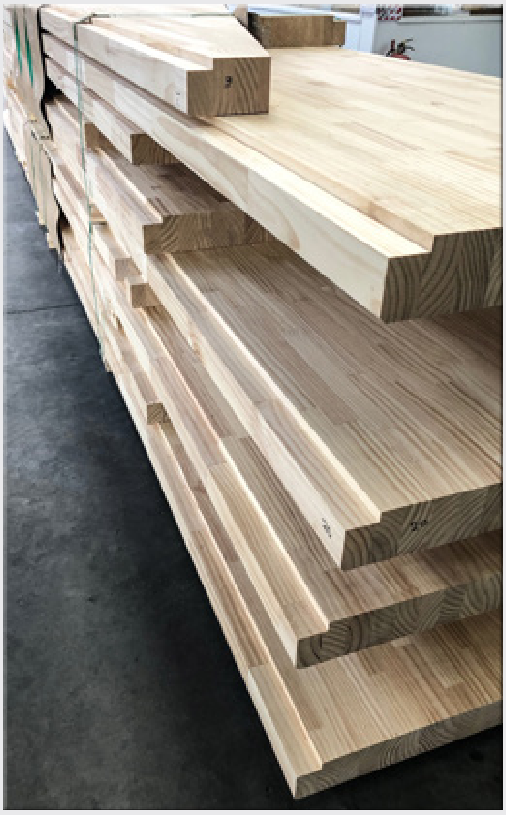


Figure 111: CNC machined PLT Panels. (Image: Woodspan)

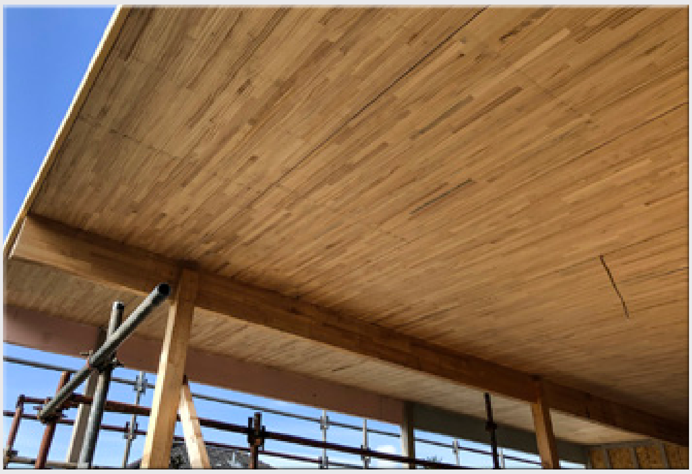


Figure 112: PLT panels as exposed ceiling. (Image: Woodspan)

Figure 113: PLT panels as floor slab. (Image: Woodspan)

7.2.11 Compliance

Please note that some prefabricators or the compliance process may require an LBP for the installation of prefabricated elements. Follow the consent requirements or the proposed compliance strategy (refer to Chapter 3.3).

7.2.12 On-Site Modifications

In addition to Chapter 6.8:

- Typical on-site modifications regarding timber systems include:
  - Rebates or penetrations for services (e.g. late changes).
  - Additional loads (e.g. design changes).

7.3 LIGHT TIMBER FRAMING (LTF)

Note that this chapter is an extension to Chapters 6, 7.1 and 7.2.

7.3.1 Introduction and Examples

Materials	• Timber framing: LVL, I-Beams, MSG, usually Engineered Timber Products for dimensional stability. • Panel products (strand board (OSB), ply, rigid air barrier etc). • Optional: insulation, window joinery, exterior cladding, interior lining, insulation, services etc. • Kitset approach possible: panels, brackets, fixings provided by one supplier.
Advantages	• Various degrees of prefabrication available (open/closed, with/without window joinery, with/without cladding, with/without services etc). • Can be made to meet NZS3604. • LTF is commonly utilised in traditional construction and well understood by most New Zealand builders, a builder can become a prefabricator. • High flexibility regarding shapes and finishes. • Easily combined with other prefabricated timber systems. • Speed of construction due to large panel format and simple structural connections on site. • Speed due to faster pace of follow on trades. • High precision, even for complex panel geometry and carpentry. • Light weight, can be insulated, services can be installed off-site. • Panel sizes are usually only limited by production capabilities in the factory, panel handling and transport.
Typical applications:	• Can be utilised for floors, walls, or roofs, in combination or with other prefabricated timber systems. • Light weight housing construction. • Honeycomb structures (apartments, multi-unit housing, aged care facilities, etc). • Commercial construction – framed walls for schools, offices, industrial etc.

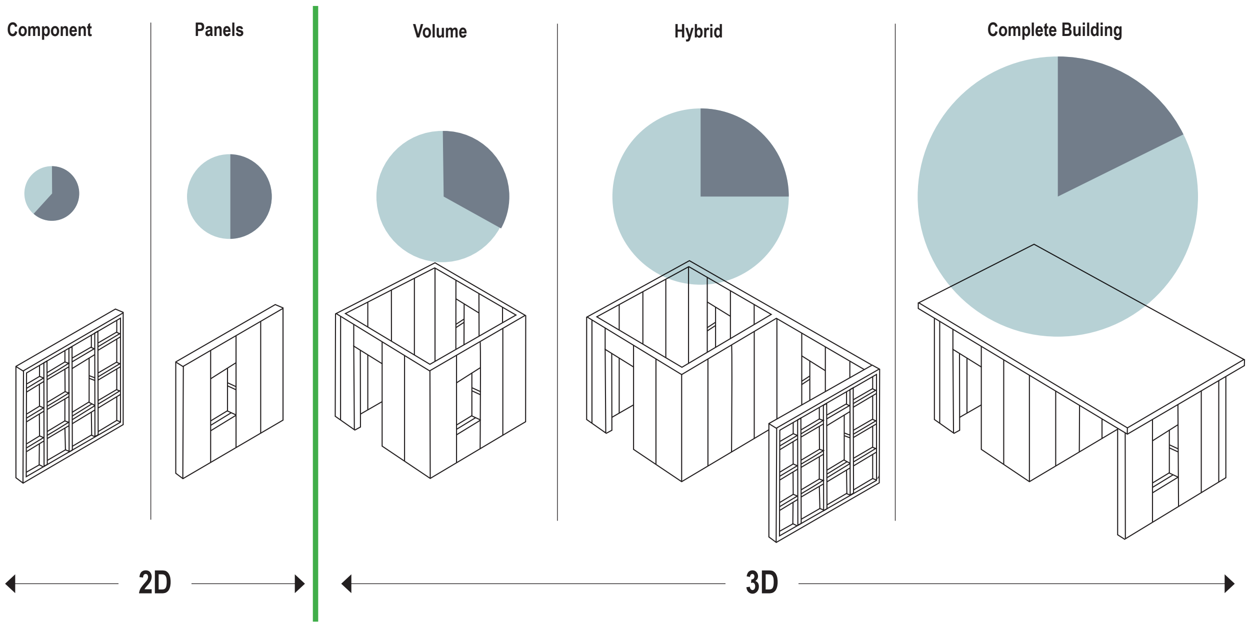


Figure 114: Modules – Spectrum of prefabricated Timber Systems.

Figure 115: LTF wall panel containing services. (Photo: Concision)

Figure 116: Closed LTF wall panels during installation. (Photo: Concision)

Figure 117: LTF roof cassette during installation. (Photo: Potius Building Systems)

Figure 118: Wall panel, window joinery preinstalled Clever-Core Factory. (Photo: oneroof.co.nz)

7.3.2 DfMA

Rigorous DfMA is essential for the success of LTF prefabricated panelised projects. The flexibility of prefabricated LTF is vast and can be its demise: too many design options may reduce a factories' capabilities and capacities. Contractors need to know that prefabricators may apply and enforce DfMA for their projects:

- Shape of the building (e.g. roof, layout).
- Standard library of details (e.g. structural details, façade details, services locations etc).
- Limited customisation (e.g. selection of finishes that do not impact production capabilities and capacities).
- Standard list of materials (e.g. framing, cladding, window joinery, lining, insulation etc).
- Building performance (e.g. Building Code, Homestar, Green Star, Passive House etc).
- Type of foundations (e.g. piles, slab types, mass timber panel floors).

It is recommended to work with the prefabricator's recommendations and experiences from the early design stages.

7.3.3 Fabrication Model and Shop Drawings

RISK	CAUSE	PROTECTIVE MEASURE
Building geometry too complex	Complex junctions and details	• Simplify the geometry and floor plans of the building. • Simplify and standardise details. • Agree standard details with the prefabricator. • Avoid non-value adding details and features. • Design for claddings – set out points, blocking for flashings, construction joints etc.
	Alignment issues between components Tolerances between components cannot be matched	• Pods should be self-supporting and not form part of exterior walls (compliance, tolerances etc).
Water ingress	Lack of TTPS	• Design and Plan for water protection strategy during construction.
	Protect structure during construction phases	• Only build as much as can be protected in time. • Cover every night and at rainy periods. • Uncover in dry periods.
Late design changes	Design Freezes not implemented	• Allow for design freezes. • Allow sufficient time for design reviews.
Budget overrun on scope definition	Lack of scope definition between prefabricator and on-site installations	• Clear and descriptive design and documentation (refer to consent process in 3.6). • Clear documentation of contract scope in supply and subcontract agreements.
Passive fire installation not considered	Performance specification rather than descriptive passive fire design	• DfMA fire details (penetrations, lining etc.) in the model. • Specify passive fire products. • Install required blocking etc. in the factory.

Figure 119: Prefabricated LTF Home – 3D model. (Photo: Offsite Design)

Figure 120: Prefabricated LTF Home – Reality. (Photo: Offsite Design)

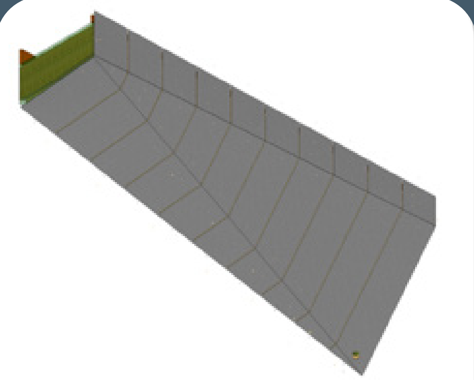


Figure 121: Complex LTF Chevron feature – 3D model – Nelson Airport. (Photo: Offsite Design)

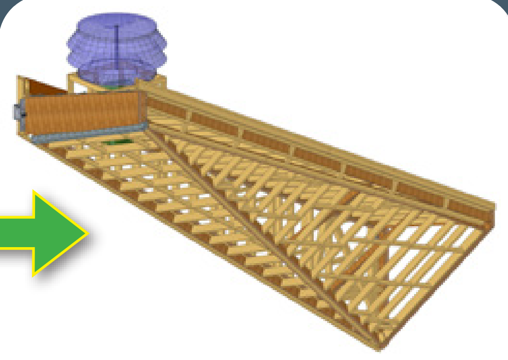


Figure 122: Fabrication Model – Frame only. (Photo: Offsite Design)

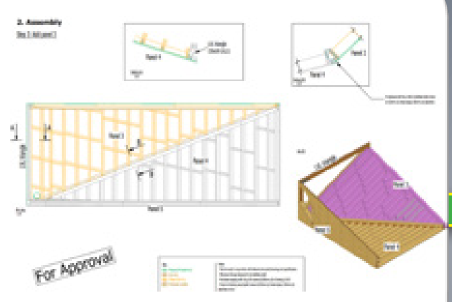


Figure 123: Shop Drawing - Framing. (Photo: Offsite Design)

Figure 124: Pre-assembly Factory 1 – Framing. (Photo: Naylor Love)

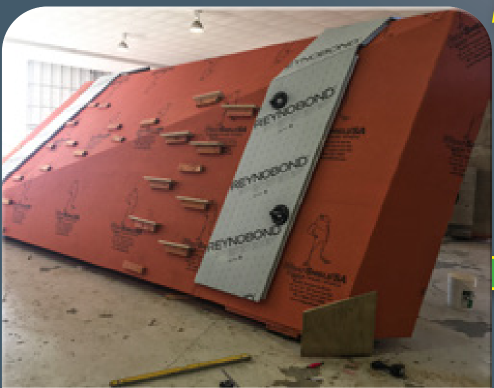


Figure 125: Pre-assembly Factory 2 – Cladding. (Photo: Naylor Love)

Figure 126: Chevron Installation. (Photo: Naylor Love)

7.3.4 Construction Programme and Off-site activities

Off-site activities heavily depend on the project and the prefabricator's offerings:

- Type of prefabrication solution.
- Fabrication modelling, shop drawings.
- Production capacities and capabilities.
- Storage and logistics.
- Production environments: highly automated or very manual, etc.

It is recommended to follow the guidelines offered in 6.2.

Figure 127: Roof cassettes with roofing material for quick enclosure – Lean Construction.
(Photo: Potius Building Systems)

Figure 128: Prefabricated LTF roof panels. (Photo: Concision)

Figure 129: Panel assembly in the factory, high degree of prefabrication – exterior cladding installed. (Photo: Concision)

7.3.5 Installation Tolerances

Off-site modules are typically dimensionally accurate (millimetres) with tight tolerances compared to insitu construction (centimetres). The junctions between panels are usually well designed and documented by the prefabricator, allowing for the required installation tolerances. When mixing prefabricated timber systems, it is advisable to coordinate the tolerances between components in one fabrication model.

Time consuming tolerance issues can arise between prefabricated components and insitu installations, e.g. slabs substructures and services. Junctions require careful planning and execution:

RISK	CAUSE	PROTECTIVE MEASURE
Components do not fit	Lack of DfMA	• Confirm install tolerances early in the process. • Consider how to fix panels, easiest way of fixing (up/down, inside/out). • Minimise fixings inside panels. • Obtain training from prefabricator.
Substructure and off-site timber components do not fit	Concrete slab tolerances Slab has +-20mm tolerance vs Prefab with +-5mm tolerance	• Slabs to be level to agreed tolerances. • Specify and install slabs to tighter tolerances. • Survey flatness of floor slab. • Allow tolerance packers/strips between concrete and components. • Design 'sole plate' to be installed laser levelled, packed prior to component delivery and installation.
	Clashes with reinforcement	• Get prefabricator to provide slab layout with bolt/anchor locations. • Install reinforcement to avoid clashes.
Services not in the correct location	Incorrect set out of the slab	• Get prefabricator to provide slab layout with service locations. • Correct installation set out to fabrication model. • Use jigs / templates.
Slow installation	Difficult integration of several components Lack of DfMA	• The fewer parts on site, the better. • Avoid separate members like steel posts and beams. • Design and specify posts, beams, etc made from engineered wood product instead. • Install beams and posts in the factory if possible. • Consider manually installing smaller panels to reduce crane time. • Coordinate lifting sequence with prefabricator. • Define optimum level of prefabrication (open/closed, cladding or not).

Figure 130: Packing under bottom plate beyond acceptable tolerance.

Figure 131: Steel beam and roof cassette not lining up.

7.3.6 Service Installations

Service installations fall into the category of restricted building work. When considering service installations in the factory it is recommended to carefully plan for a compliance process (refer to Chapter 3) and to thoroughly DfMA details, service runs, junctions, off- and on-site interfaces, demarcation points, responsibilities, compliance and project documentation.

It is recommended to consult and partner with services coordinators and subcontractors.

RISK	CAUSE	PROTECTIVE MEASURE
Clashes of services with framing and blocking Slow On-site assembly / post installation work	Lack of services coordination	• Work with subcontractors which are willing to be involved and are pro-active in the design/detailing phase. • Confirm location of all installations, cable runs etc. • Install 'builders work' (blocking) in the factory. • Model on site installed service runs. • Skills: engage a service coordinator. • Coordinate service runs in the slab to avoid clashes with the prefab interface.
	Lack of concentrated service runs	• Consider service risers. • Consider modular service risers.
Damage to concealed services	Damage in factory	• QA processes for commissioning of services. • QA documentation provided to contractor at or prior to delivery.
	Damage on site	• Potential damage on site because of on-site installations. • Keep services away from potential penetrations (away from fixing routes, away from surfaces). • Identify service runs on surfaces. • Design isolation of services on site at the components (e.g. for pods isolation valves for water supply at the pod interfaces).

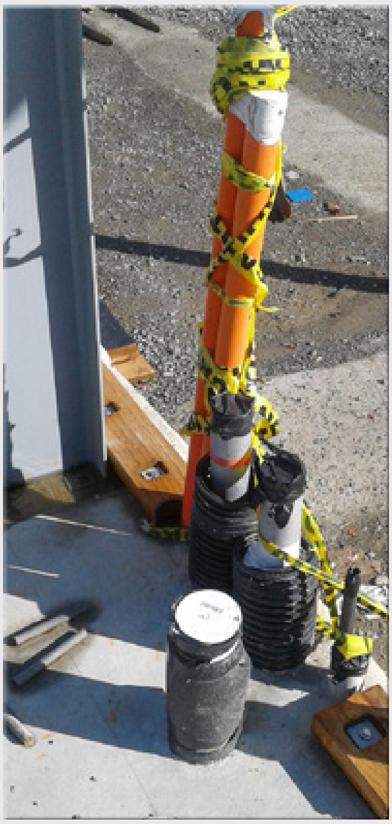


Figure 132: Poor service coordination, sleeves too big for panel.

Figure 133: Poor Service coordination, sleeve clashing with stud.

7.3.7 Temporary Protection and Visual Surfaces

The climate encountered by prefabricated LTF modules after leaving the factory should be as close to the climatic conditions the modules will be exposed to once in service. It is important not only to protect timber products, but also other materials forming part of the prefabricated system, e.g. plasterboard, insulation, services and finishes.

Prefabricators usually provide protection strategies for their components. For hybrid prefabricated solutions from multiples prefabricators, a TTPS should be implemented. Solutions entirely depend on the project. Temporary protection can be designed into the production and assembly process of modules, ensuring a seamless transition between all stages until full enclosure is achieved. For Example: application of overlay finishing layers on site, reduces the level of protection required of (otherwise finished) surfaces until after installation.

For small projects (e.g. family home) weather protection can be addressed with increased prefabrication to minimise the time during which a project is left exposed. Advanced prefabricated systems can be lockable and weathertight in a few days for a typical family home.

Figure 134: Roof element in factory, permanent membrane overlays edges to provide temporary water protection – Nelson Airport. (Photo: Naylor Love)

Figure 135: Bathroom pods wrapped in plastic. (Photo: Concision)

7.3.8 Lifting Equipment

The design of LTF components must consider robustness and dimensional stability during lifts and transport. Due to their nature, timber frames are lighter and more vulnerable to deformation during lifts. It may be required to integrate lifting beams into the components at design stage and/or design for load spreading devices that allow for seamless and damage free logistics and installation.
Large scale and light weight elements are prone to windy conditions, even at low wind speeds it may be unsafe to lift LTF panels.

Large panel lifting and transport are as described Chapter 7.2.8.

Figure 136: Lifting wall component with truck loader crane. (Photo: Concision)

Figure 137: Light timber frame – roof panel installation with truck loader crane. (Photo: Concision)

7.4 VOLUMETRIC ELEMENTS

Note that this chapter is an extension to Chapters 6 and 7.3.

7.4.1 Introduction and Examples

Materials	• Timber framing: LVL, I-Beams, MSG, usually ETP for dimensional stability, steel studs. • Any building products that allow the formation of volumetric components.
Advantages	• Very high degree of prefabrication and finish can be achieved (e.g. finished internal surfaces including carpets laid and curtains hung), harnessing many benefits prefabrication has to offer. • Standardised size modules may be mass-customised and produced in a continuous process akin to an automobile assembly line. • Entire buildings can be made to meet NZS3604. • LTF is commonly utilised in traditional construction and well understood by most builders, a builder can become a prefabricator. • Easily combined with other prefabricated timber systems. • Speed of construction due to reduction of trades on site. • Restriction in sizes are usually largely limited by transport.
Typical applications:	• Rooms or parts of a building with a high concentration of services, e.g. bathroom pods and mechanical plant rooms, etc. where factory prefabrication can dramatically simplify un otherwise complicated site-based construction process. • 3D volumetric modules for buildings made up with repetitive modules, e.g. multi-storey hotels, apartment buildings, student accommodation.

Figure 138: Bathroom pods during manufacture and installation.

Figure 139: Bathroom pod production. (Photo: Concision)

7.4.2 DfMA

Pods and volumetric elements are thought to be installed as a plug ‘play scenario: Components are landed, structurally fixed in place, services plugged in and minor cosmetic finishing work done at intersections with other components. The design should consider the sequence in which components are placed and that all connections are easily accessible during assembly.

It is recommended that prefabricator DfMA is applied and followed during design. This can cover the choice of linings, frames, floors, the location of services etc.

7.4.3 Tolerances and Service Installations

The full or partial integration of services should be thoroughly considered at early design stages. Should service installations result in crossovers between off-site and on-site installation, it is recommended to take advice from site experienced service coordinators or subcontractors. For various reasons it may or may not be advisable to crossover in certain situations or for specific trades (i.e. fire sprinkler).

- Interfaces between off-site and on-site work should be defined in the design documentation, consider compliance (refer to 3.4) and contractual requirements, e.g. QA, testing, commissioning, warranties and guarantees, As Build documentation and manuals etc.
- Determine tolerances at interfaces, e.g. pipework, ducting, etc.
- Provide access (e.g. hatches) to interfaces for installations and future maintenance.
- Allow working space for installation and commissioning if necessary.
- Ensure supplied off-site systems are compliant with available on-site systems.
- Provide space for passive fire / seismic / acoustic solutions for penetrations and interfaces.
- Avoid accidental penetrations of concealed services by on-site installations: where reasonable, design should centralise installation paths and manufactures should identify paths on exterior walls.
- Coordinated slab set out drawing should be provided by designers or prefabricators.
- Example: Cast in pipes in concrete slab to connect to prefab modules can be in the wrong place:
  - Design solution: Carefully coordinate slab penetration set out and diameter among designers and prefabricators using one central BIM model. Designers are to provide a slab penetration set out plan to the contractor.
  - Practical Solution: In addition to the above prepare identical set out templates which the sites and prefabricators are working to.

7.4.4 Erection Plan, Lifting and Delivery

Modules arrive with a high degree of finishes. Logistics can cause damages at various stages.

RISK	CAUSE	PROTECTIVE MEASURE
Broken tiles and/or failed tanking	Transport Vibration / Incorrect lifting/ transport	• Design for robustness during transport. • Reduce vibration. • Ensure adequate form of transport. • Eliminate deformation during lifts and handling.
	Lack of care by following trades	• Design to exclude / minimise access for following trades. • Lock units post installation for any trades. • Install floor protection.
Broken Finishes	Transport Vibration / Incorrect lifting/ transport	• Tape finishes (tape close shower doors, mirrors, WC etc). • Protect from impact. • Reduce handling.
	Vandalism and theft	• Vandalism strategy. • Safe storage, Security on site. • Lockable units.
Water ingress and damage	Lack of or correct wrapping	• Adequate and robust wrapping. • Remove wrapping when area is watertight (design). • Bathroom pods should not represent external walls.
	Mould and Condensation	• Avoid prolonged storage. • Allow to ventilate. • Have access to interior for inspections (zip in plastic covers).
Damages to Pipes and installations post installation	Design coordination	• Design installations away from post install work areas.
	Lack of communication	• Identify and clearly mark wall areas with services behind.
Failed Testing and Compliance	Lack of planning / QA	• Contractual agreement with supplier for QA, testing etc. • Ensure traceability is accounted for. • Ensure prefabricator undertakes restricted work with qualified staff. • Regular QA inspection by contractor / third party.

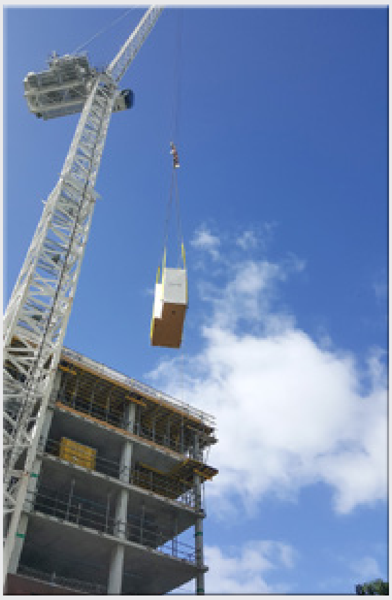


Figure 140: Bathroom pods during installation. (Photo: Concision)

Figure 141: Bathroom pod temporary protection with access door. (Photo: Concision)

8 CONCLUSION

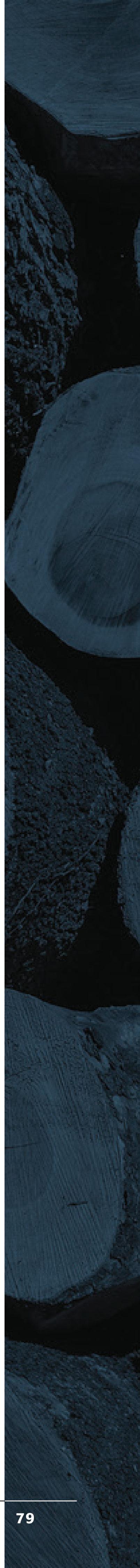
Successful prefabrication and especially prefabrication with timber products require a methodical and organized approach from early design stages. The decision to prefabricate will significantly influence the design. Prefabricated timber products and systems require efficient protection from the environment until full enclosure is ensured. Consequently, the leanest production, logistics and assembly approach will not just ensure best timber protection but also the most efficient production and installation process, resulting in high productivity.

Keep it Simple. Be Smart. No shortcuts.

As a summary, the following table may serve as an overall collaboration guide for successful prefabricated timber projects.

Top 10 Tips	Design (All design disciplines)	Off-site manufacture (Manufacturers and Prefabricators)	On-Site Assembly (Contractors and Subcontractors)	Completion / Handover / Maintenance (All)
1	Collaboration and Teamwork | Ownership| Support culture			
2	Design for Manufacture and Assembly (DfMA) | Confirm build methodology: producibility and constructability			Collaborative problem solving until the end
3	General understanding of Lean Manufacture and Construction	Apply Lean manufacturing principles	Apply Lean construction principles	Continuous improvement: close feedback loop to entire team
4	Think modular and in components Think in assembly sequence	Site assembly documentation and logistics to be produced / resolved early	Assembly sequence to be determined at concept stage	Regular inspections by designers and TAs
5	Simplify and Standardise where possible, design to optimise assembly speed	Supply speed to match assembly speed	Agree site assembly speed	Create tangible project KPIs: e.g. production and install speed
6	Design for timber protection during install and in-service	Contribute timber / prefab protection expertise	Implement timber protection	Realistic expectations on timber finishes
7	Consider the alternative compliance process	In-factory QA (may form part of alternative compliance process)	Skills On-site: Assembly skills and QA (may form part of alternative compliance process)	Compliance Documentation, Traceability, Maintenance and Manuals in full
8	Implement and stick to Design Freeze at agreed milestones	Production slots are agreed for programme certainty (Limited resources in NZ)	Early Procurement: Understand critical path for off-site activities	Collaborate with Building Consent Authority during design, build and completion phases
9	Share, coordinate and federate BIM model with prefabricator and constructor enabling 4D/5D with adequate LOD	Fabrication model and production documentation produced in time to a high standard	Skills Off-site: 3D coordination, 4D planning, 5D costing	BIM and fabrication models evolve into As-Builts
10	Model review in 3D in addition to 2D shop drawings	Supply materials on time (e.g. oversea fixings/ fasteners)	Consider supply risks (e.g. overseas suppliers)	Be happy and celebrate success
AND	Always ask, share and resolve together: What can go wrong?			

Table 8: Collaboration Matrix for prefabricated timber structures.



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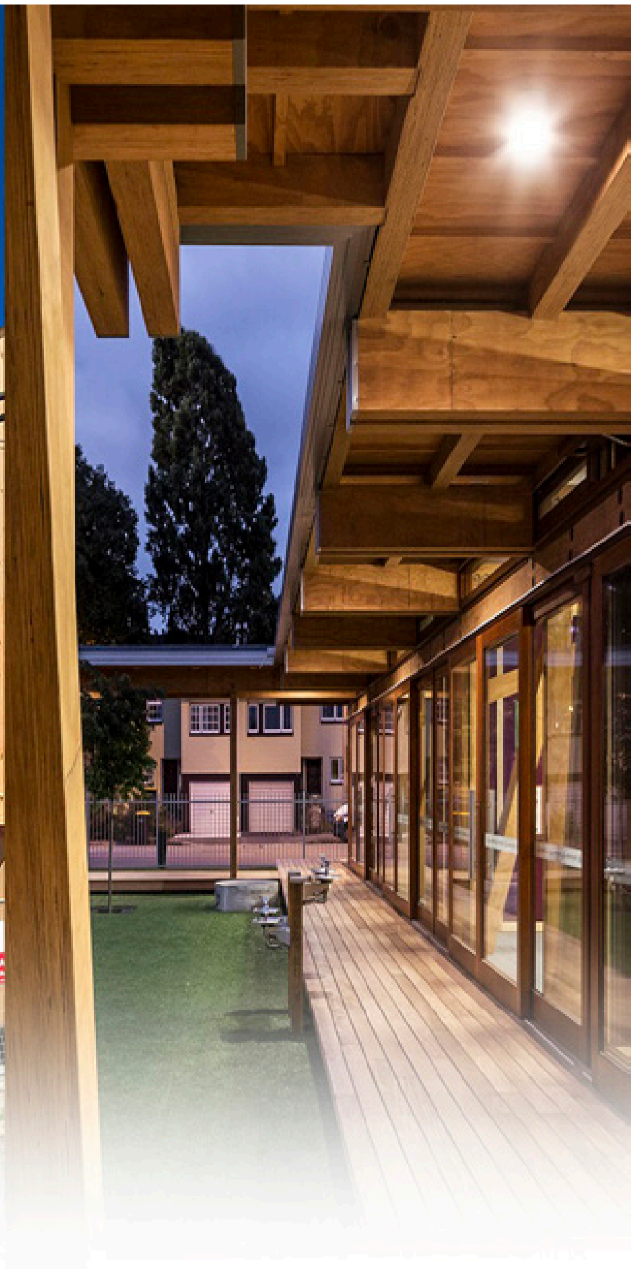

ABOUT THE AUTHOR

Thomas Kästner is passionate about construction with wood. The touch, the smell, and the warmth of wood enhances the spirit and comfort of human beings. Wood in our buildings connects us with nature.

A construction manager, qualified carpenter and German-trained engineer, Thomas has led iconic and award-winning commercial and prefabricated timber projects across the South Island. Before immigrating to New Zealand from Germany, he gained valuable experience in timber prefabrication, in the factory and onsite, as well as working on large infrastructure projects in and around Berlin.

Since 2006 Thomas has worked in construction management in New Zealand. Construction with wood, preconstruction, construction work planning, off-site coordination and production, one-off factory planning and implementation are his key strengths. He thinks outside the box and enjoys technical and logistical challenges.

Thomas has experienced the advantages of good prefabrication practices and is passionate about Modern and Lean construction methods. He is experienced and methodical, an exceptional planner and realist with the vision to work with people for a better construction experience with prefabricated wood products.

Thomas works in Christchurch for timber prefabrication specialist Offsite Design Ltd as Construction Management Advisor and DfMA engineer.

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